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Additive technologies

Session Chairs: Prof. Katarina Monkova (Technical University in Kosice, Slovakia) & Dr. Kyriakos Kourousis (University of Limerick, Ireland)

Distortion prediction and design optimisation of aerospace-grade additively manufactured parts

Dr. Sadik Omairey (Brunel Composites Centre, Brunel University London), *Faranak Bahrami; Vasiliki Loukodimou; Olivier Lietaer; Graeme Bond; Sjoerd Van Der Veen; Sofia Sampethai ; Farshad Salamat-Zadeh; Mihalis Kazilas*

Additive manufacturing (AM) has greatly influenced product design, manufacturing, and assembly compared to conventional subtractive manufacturing processes. Hence, AM has rapidly become a strategic technology that will generate revenue throughout the aerospace supply chain because of its several advantages, such as reduced lead times, complex designs manufacturing, easy customisation of part geometry through CAD designs and less material wastage. However, industrial challenges such as lower part quality compared to other manufacturing processes, slow build rates, and iterative trial and error process for final part design optimisation remain a barrier towards wide utilisation. Therefore, this study aims to develop a tool capable of accurately and rapidly predicting and correcting such distortions, offering improved quality of the produced parts and minimising rejection rates, while topology optimisation is utilised to alter the part design for improved distortion and mechanical response. To achieve these aims, a comprehensive mechanical and thermal characterisation campaign is conducted to optimise the print parameters and part geometry. As part of this study, software distortion predictions are assessed and calibrated by means of comparing simulation results with dimensional verification of several 3D printed deterministic and topology optimised aerospace-based demonstrators. This project received funding from the Clean Sky 2 Joint Undertaking under the European Union's Horizon 2020 research and innovation programme under grant agreement number 864819.

The influence of processing conditions in Laser Powder Bed Fusion and powder recycling strategies for an extended titanium powder life-cycle

Mrs. Miriam Löbbecke *(German Aerospace Center), Joachim Gussone, Galina Kasperovich, Guillermo Requena, Jan Haubrich*

Metal-based additive manufacturing (AM) is slowly but steadily about to initiate a paradigm change across multiple industries including the aerospace sector. AM suggests major production benefits for titanium-based components by reducing manufacturing efforts and improving material efficiency compared to conventional machining. Laser Powder Bed Fusion (LPBF) is most widely for near-net shape generation of complex geometries, which are difficult, material-inefficient or expensive to machine subtractively. Moreover, AM also opens new routes for conceiving innovative multimaterial components, e.g. by manufacturing surface features (e.g., pins), which are beneficial for bonding with fibre reinforced plastics. However, the promised advantages often do not materialize due to the difficult processing challenges, the high costs of titanium feedstocks, or the poor material efficiency arising from degradation of the powders during builds and recycling cycles. Particularly, degradation due to pick-up of oxygen, a typical Ti alpha-stabilizer, is detrimental and can lead to ductility loss, while changes of the particle size fraction by successive sieving cycles may influence materials properties. Therefore, LPBF of critical aeronautical or space components ("class 1" parts) requires today virgin powder for every build, which is still a clear technological and commercial limitation. The current work, carried out in the

Horizon 2020 project SUSTAINair, addresses the issues of powder degradation and targets improvements of the LPBF machines' process gas atmosphere and powder recycling procedures. The powder degradation depends strongly on the type of alloy, the processing parameters (particularly build temperature and the build platform occupation) and the machine-specific inert gas system. The number of permissible reuse cycles is studied based on elementary and microstructural analysis and the effects on mechanical performance, both for the original LPBF setup as well as after modification of the system's atmosphere. Mass spectrometric analysis is used for tracking the process gas atmospheres during builds. A comparison of properties of specimens built with virgin powder and those after reuse as well as material properties before and after the machine improvements will be presented.

Bending behaviour of additively manufactured porous structure made of aluminum alloy

Prof. Katarina MONKOVA (Technical University in Kosice, Slovakia), *Milan ZALUDEK, Peter Pavol MONKA, Martin KOROL*

The current development of additive technologies brings not only new possibilities but also new challenges. One of them is the use of common cellular materials in various components and structures in order to fully utilize the potential of porous structures and their advantages related to weight reduction and material savings while maintaining the required safety and operational reliability of devices containing such components. It is therefore very important to know the properties of such materials and their behaviour under different types of loading. The article deals with the investigation of the bending behaviour of a complex porous structure produced by direct laser metal sintering (DLMS) of aluminium alloy AlSi10Mg. Five pieces of Neovious type samples with basic cells of 10 x 10 x 10 mm, total dimensions of 30 x 22 x 250 mm and a volume ratio of 10% were produced and experimentally tested. The tensile test procedure was performed at ambient temperature using a servo-hydraulic testing machine.

Influence of building orientation of additively manufactured samples made of Maraging Steel MS1 on Young's modulus

Prof. Dražan Kozak (Mechanical Engineering Faculty, University of Slavonski Brod), *Janko Morosavljević, Somnath Chattopadhyaya, Alessandro Ruggiero*

Direct Metal Laser Sintering (DMLS) technology produces parts from metal powders, using laser beam energy to promote sintering in an inert and thermally controlled chamber environment. Many factors influence the resulting mechanical properties of individual parts. One of these parameters is the direction of building the component. The paper deals with the behaviour of 3D printed Maraging Steel MS1 in uniaxial tensile tests, during which the effect of sample orientation on Young's modulus as well as other mechanical properties was investigated. The morphology of the fracture surfaces was also evaluated using the scanning electron microscopy technique. Standard samples were prepared by DMLS technology in seven different directions, with ten pieces of samples produced in each direction. After 3D printing, the samples were heat-treated to remove residual stresses and machined to final dimensions after removal from the build platform. The measured values were statistically processed, and the mechanical properties were evaluated. The tests showed that the orientation of the sample during its production has an effect on the mechanical properties. It can also be stated that the comparison of the results with the tensile properties stated by the manufacturer of the steel powder in the data sheet confirmed the values in the declared range. The morphology of fracture surfaces in most samples is characterized by ductile damage with a pitting effect.

In-plane Compression of Material Extrusion and Laser Powder Bed Fusion Steel 316L Honeycombs: An Evaluation of the Load-rate Effect

Mr. Solomon O. Obadimu (School of Engineering, University of Limerick, Limerick, Ireland), *Kyriakos I. Kourousis*

Limited research exists on the load-rate evaluation of additively manufactured metallic honeycomb structures subjected to in-plane compression loading. In the present study material extrusion (ME) and laser powder bed fusion (LPBF) Steel 316L has been used to fabricate different cell size honeycombs. This experimental evaluation has identified the mechanical performance characteristics of these structures, including the modes of deformation experienced during the compressive loading under different load application rates. The load rete sensitivity of the ME and LPBF material has been verified. Moreover, the results have been used to validate a set of empirical models capable to predict the primary mechanical properties, including the plastic collapse stress. A viscoplastic dependency on the cell wall material (Steel 316L) has been established and used in the empirical modelling.

Plastic Anisotropy of Steel 316L Parts Produced via the Material Extrusion Additive Manufacturing Process

Mr. Solomon O. Obadimu (School of Engineering, University of Limerick, Limerick, Ireland), *Anirudh Kasha, Kyriakos I. Kourousis*

The laser powder bed fusion additive manufacturing (AM) process is predominantly employed for metal parts production in the AM industry. However, the recent introduction of metal fabrication via the material extrusion (ME) process offers a cost-effective solution to metal production via AM. In the present study, the ME has been used to produce Steel 316L specimens with varying manufacturing parameters, including raster angle, layer height and print speed. The analysis of variance (ANOVA) statistical tool has been used to gain further insight into the relationship between the manufacturing parameters and subsequent mechanical characteristics. Furthermore, the deformation mechanism/modes of the specimens have been studied with the digital image correlation technique. Experimental analyses confirm a dependence of mechanical properties, including plastic anisotropy, on varying manufacturing parameters. The existence of a non-uniform deformation even at low tensile strain has been confirmed.

Session Chair: Prof. Jerzy Zoltak (ILOT, Poland)

Implementation of CFD as an Educational Practice for Post-Graduate Engineering Programmes with special focus on High-Speed Intake Aerodynamics and Flow Distortion

Mrs. Aristia L Philippou (Cranfield University), *Pavlos K Zachos*

With the continuous growth of the Computational Fluid Dynamics (CFD) industry, CFD numerical simulation in complex engineering systems has become a crucial method in product design covering a wide range of applicability. The Erasmus+ funded APPLY activity, aims to address CFD related challenges in Asian markets and develop a roadmap for the development of highly skilled engineers across a spectrum of industries that benefit from CFD capability. The activity in synergy with a research study focused on high-speed intake aerodynamics, outlines the implementation of CFD as an educational practice for postgraduate engineering programmes. The research study is aimed in understanding complex unsteady flow characteristics in high-speed intakes. Air flow of an unsteady nature arises when an intake operates at off-design conditions, creating an unstable environment in the intake duct, leading to sufficient stability and performance engine losses. The intake-engine matching is further complicated in high-speed propulsion systems, where the intake's operability range is further expanded to cover supersonic to subsonic flow regimes. Better understanding of complex flow phenomena and distortion aerodynamics is vital before the development of new aircraft designs. This paper will address the CFD simulation of an external compression intake and focus on validating the approach of the computation with available experimental data, documented in previous work funded by the ONERA research project PR-OPOSSUM. Aspects related to numerical and modelling uncertainties of the CFD calculations will be included in the paper by completing a grid and domain sensitivity study and investigating different turbulence models. The study will then characterize the distorted flow at the engine face, using time average total pressure measurements.

Helicopter main rotor CFD analysis for different flight conditions using parametric blade model as an application for multidisciplinary optimization

Mr. Jakub Kocjan (Military University of Technology Warsaw), *Stanisław Kachel, Robert Rogólski*

This work is a part of a research program which is intended at finding new approaches and design solutions for helicopter main rotor modelling using multidisciplinary optimization. It is a second stage of work after preliminary parametric modelling of a single rotor blade for CFD analysis and its validation for more sophisticated calculational approach. The paper shows the method of advanced aerodynamic modelling of the whole rotor and exemplary results obtained from complex analyses. The analytical base for different phases of helicopter flight is shown. The analytical calculations are provided to model the blade motion according to its azimuth angle and to validate obtained results. The parametric design method is shown to be applied for different blade planform shapes and various section airfoils. The blade CFD fluid domain is also prepared using parametric method. The parametric graphic script is being developed to create the flow domain for a one-blade simulation or for a complete n-bladed rotor effect. Obtained blade model with enclosure is implemented into CFD environment. In this work two variants of CFD simulation are shown. The method for fluid mesh preparation and the way for defining its properties are given. The one blade steady simulation with parametrization of the inflow properties for different flight conditions and blade motions is presented. The advantages of this variant are provided.

The second simulation is carried out as transient for n-bladed rotor. In this simulation also the various flight conditions were taken into account. Real rotary motion of the blades is simulated with artificially enforced mesh motion. The obtained numerical results were compared then with analytical assumptions. The simulation products which are the inputs for further analysis are shown with graphics representations.
As an output of the research, the new options for main rotor optimization are developed. The usage of combined parametric modelling with aerodynamic analysis for different flight conditions is shown in the work as a new perspective for the main rotor design optimization. Some crucial possibilities of FSI analysis were demonstrated in described simulation cases. Additionally, some possible directions for future researches were proposed, also.

Parametric investigation of the aerodynamic and acoustic performance of a low-boom supersonic airliner

Mr. Chris Bliamis (Aristotle University of Thessaloniki), *Pavlos Papadopoulos, Kyros Yakinthos*

In the present work, a design parametric study in the conceptual design phase of a low-boom supersonic airliner (LBSSA) is presented. The low-boom constrain is of great importance to the near future supersonic airliners, in order to be certified for overland operation, but is also usually associated with a penalty in their aerodynamic performance (e.g. increased drag) and subsequently a higher fuel consumption. A dedicated low-fidelity design tool for the conceptual and early preliminary design of a LBSSA is developed which includes both Class-I and Class-II weight calculations. The design tool is also capable of predicting the aircraft's aerodynamic performance in both the subsonic and supersonic cruise segments of its mission. The aerodynamic behavior of the LBSSA is then compared against the results obtained from high fidelity Computational Fluid Dynamics (CFD) modelling. Regarding the acoustic behaviour of the LBSSA, initially Carlson's simplified method is employed, which is based on the equivalent area distribution of the aircraft, in order to provide representative trends and results early in the design phase. Subsequently, refined estimations are obtained through the PCBoom software, by solving the lossless Burgers equations. Finally, the contribution of the examined design parameters, in the aerodynamic and acoustic performance of the resultant LBSSA is presented and clear trends are indicated.

Designing aerodynamic devices for UAV - lessons learned

Dr. Mieloszyk J. (Warsaw University of Technology), *Tarnowski A., Goetzendorf-Grabowski T.*

Designing new aircrafts, which are state of the art and beyond, always requires developing new technologies. The paper presents lessons learned while designing, building and testing new UAV in the configuration of a flying wing. The UAV contains number of aerodynamic devices, which are not obvious solutions and utilize the latest manufacturing technology achievements, like 3D printing. The paper particularly describes design of the small size pressure port manufactured with the use of the additive technology, design and manufacturing of the leap and inlet duct to the miniature jet engine, flight mechanics design of the rudlets placed at the tips of the winglets, aerodynamic brakes, and divided spoilers on the swept wings. All of the mentioned devices showed interesting challenges to overcome. Solving them brought new experience and lessons learned, which are presented in the paper.

Aerodynamic modeling of a VTOL tilt-wing transition corridor

Mr. Petr Raška (VZLU), *Jan Zakucia*

With the recent rapid evolution of the UAM class concepts in past years, the re-emerged interest in VTOL concepts and their aerodynamics arises. The tilt-wing is one of the possible solutions for such a vehicle. Recent decades of tilt-wing aerodynamic research point to the importance of the understanding transition regime from cruise to hover. Especially the wing stall phenomena which affect descent capabilities and control during the landing phase. Understanding such a regime is crucial for optimal wing design. This paper presents several approaches to the modeling of aerodynamic forces during the critical phase of transition. Computations are aimed particularly to catch the aerodynamic forces in the proximity of the edge of the flying envelope where large portion of separated flow occurs. The low to high fidelity methods are employed and compared with the results of low-speed wind tunnel testing.

Aerodynamic Analysis & Design: Part II

Session Chair: Prof. Jerzy Zoltak (ILOT, Poland)

Multidisciplinary design of aircraft wing for multiregime purposes

Mr. Pavel Hospodar (VZLU), *Armand Drábek*

In this paper is described an optimization process of the geometrical design of the wing. The goal is to minimize the aerodynamic drag for a requested lift in the cruise regime and thus reduce fuel consumption. The second goal is to ensure the requested landing regime of the aircraft. Both cases are solved under wing structural considerations and their weight.

As a fast design computational tool, a lifting line theory is used. It is moreover supplemented by non-linear aerodynamic airfoil characteristics to provide more accurate results of aerodynamic drag of the wing. These airfoil data were calculated with CFD and enables to take significant accuracy between low and high-fidelity method which is verified in previous work.

The list of requirements is set for aircraft for 40 passengers with a range of 2,500 km at a speed of 438 km/h. As the baseline an aircraft L-610 is selected. Optimized wing geometry in calculated in cruise and landing regime/configuration with CFD solver. From the calculation of the weight of the wing and CFD results, the flight performance is calculated for desired flight mission.

Kriging-based framework applied to a multi-point, multi-objective engine air-intake duct aerodynamic optimization problem

Mr. Przemysław Drezek(Łukasiewicz Research Network - Institute of Aviation)

Dynamic development of the global air fleet size forecasted for the upcoming decades obliges aviation R&D entities to endeavor for more efficient design and optimization processes. Moreover, a fast inauguration of disruptive technologies, required to support the goal of net-zero emission air transport, demands the introduction of optimized design workflows.

This study focuses on developing the aerodynamic optimization framework suited for small aircraft engine air-intake ducts and promising improvement in the economic efficiency of the process. The optimization scheme combines the advantages of the Kriging-based Efficient Global Optimization (EGO) with the mesh morphing technique based on the Radial Basis Functions (RBF). Besides the inherent multi-objective character of the intake duct optimization problems, prevention of the performance drop at off-design conditions requires a multi-point optimization. Multiple objectives with specific targets for various flight conditions are combined using the augmented Chebyshev-type Achievement Scalarizing Function (ASF).

The proposed framework is applied to the aerodynamic optimization study of the I-31T aircraft turboprop engine intake system. The workflow aims to reduce the air-duct pressure losses and mitigate the flow distortion at the engine compressor's front face. Multiple flight conditions are considered according to the small aircraft mission profile.

Experimental studies of airliner aerodynamic characteristics at overcritical angles of attack

***Mr. Andrzej Krzysiak (Łukasiewicz Research Network)**, Aleksander Olejnik, Robert Placek, Łukasz Kiszkowiak*

Airplanes are designed to carry people and cargo through the air over longer distances. During their missions, situations in which the aircraft is operating within the range of critical or overcritical angles of attack are rather avoided. However, there may be sometimes such situations when the airplane during its flight enters the area of high angles of attack. This was the case with the Tu-154M aircraft flight that ended with its crash. To determine the flight trajectory of this aircraft in its last moments before impact with the ground the knowledge of the aerodynamic characteristics at the angles of attack higher than the critical angle was necessary.

The paper presents the results of wind tunnel experimental tests of the basic aerodynamic characteristics of the Tu-154M aircraft model in the range of angles of attack α = -900 ÷ 900 and in the range of sideslip angles β = -900 ÷ 900. Two aircraft model configurations were tested, i.e., with no damaged aircraft wing and with the damaged aircraft wing (left wing tip cut off). The wind tunnel tests were carried out in the Łukasiewicz Research Network – Institute of Aviation wind tunnel (with a 5 m diameter test section) using the aircraft model at the 1:20 scale. The tests were performed at the V∞ = 50 m/s, which corresponds to Reynolds number (related to the mean aerodynamic chord) Re = 0.94*106. The balance measurements allowed to determine the impact of wing damage on the basic aerodynamic characteristics of the Tu-154M aircraft model.

Preliminary Design of Next Generation Mach 1.6 Supersonic Business Jets to Investigate Landing & Take-Off (LTO) Noise and Emissions

Mr. Christos Mourouzidis (Cranfield Universoty)

The recent interest towards Civil Supersonic Aviation has stimulated international entities among industry and academia to push the technological boundaries to deliver a new generation civil supersonic aircraft, which could meet the demanding future performance goals while respecting the stringent environmental restrictions proposed by the Committee on Aviation Environmental Protection (CAEP). Among the companies that were directing their efforts towards a new sustainable supersonic civil aviation are Spike Aerospace, HyperMach, Aerion Group, and Boom Supersonic which has recently reached an agreement with United Airlines for the purchase of 15 of Boom's Overture airliners [1], [2], [3]. Furthermore, several research programs on supersonic aviation were launched over the years. Most notably, NASA led the Supersonic Cruise Research (SCR) [4], the N+ programs [5] [6] , and the recent Quiet SuperSonic Technology (QueSST) study [7]. On the other side of the Atlantic, the most notable studies funded by the European Union are the High-Speed Aircraft (HiSAC) [8] project and the recently launched EU Horizon 2020 SENECA (LTO noiSe and EmissionNs of supErsoniC Aircraft) [9] project. The present paper lies within the context of SENECA project. In SENECA, eleven academic and industrial aerospace entities from all over Europe have teamed up to address the challenges raised in the call LC-MG-1-15-2020 "Towards global environmental regulation of supersonic aviation". The project mainly focuses on the investigation of noise and emissions in the vicinity of airports as well as the global climate impact of supersonic civil aircraft. Additionally, it aims to contribute its project results to the ICAO level discussions, in order to scientifically accompany and strengthen the European perspective on the necessary regulations for novel supersonic civil aircraft.

For the aircraft and engine designers of today, the environmental impact is the most important factor since no future vehicle could be considered viable if it is perceived as highly pollutant, regardless of any potential benefits in operating cost or flight duration. Supersonic vehicles present relatively high fuel burn compared to subsonic, while their engines operate at high temperatures across the high-speed mission segments. High temperature operations allow the engine cycle thermal efficiency to increase while reducing the engine core's size and weight. However, this conflicts with the requirement for low gaseous emissions, since increased temperatures give rise to the pollutant NOx emissions. Moreover, there is a trade-off between the engine drag and weight and the propulsive efficiency and noise. Thus, a compromise between all conflicting requirements needs to be identified in order to develop the next generation supersonic civil aircraft.

This paper introduces some of the main research objectives as well as preliminary outcomes of the SENECA project. It focusses on the preliminary design of a Mach 1.6 supersonic business jet, following an integrated aircraft-engine design approach. It illustrates the fundamental design choices behind the design of the Cranfield E-19 Aeolus airframe [10] and the preliminary engine design space exploration. The engine preliminary design was performed accounting for the limitations posed by future environmental restrictions, highlighting the impact of engine design variables on the aircraft performance during the LTO cycle as well as at subsonic cruise for overland operations.

Aerostructures: Part I

Session Chair: Prof. Konstantinos Tserpes (University of Patras, Greece)

From Machine Tool 4.0 to Machine Tool 5.0: Review on Digital and Intelligent Manufacturing in Aeronautics

Prof. Dimitris Mourtzis (University of Patras), *John Angelopoulos, Nikos Panopoulos*

Manufacturing is undergoing several changes regarding the structure, the organization, and operation of systems. Concretely, under the light of Industry 4.0 and the upcoming Industry 5.0 and Society 5.0, a plethora of digital technologies and techniques are being introduced and improved. The integration of computer technologies has led to the upscaling of several design and manufacturing operations, among others product design, simulation, manufacturability of products, management and control of manufacturing systems and networks. Therefore, to realize smart factories, machine tools must be further elaborated towards the integration of intelligence (Machine Tool 5.0), and thus enable seamless and safe collaboration with human operators (Social Factory). Ultimately, the goal is to create a network of fully connected and communicating machines, denoted as Industrial Internet of Things (IIoT), which will facilitate the realization of an improved Intelligent Manufacturing paradigm, the Social Manufacturing 5.0. Therefore, in this research work, the results of a literature review are discussed, aiming towards the recognition of the opportunities emerging as well as the identified challenges from a practical implementation point of view. The contribution of this research work extends to the presentation of a conceptual framework, encapsulating past knowledge and integrating the latest developments in the field.

Optimal design of damping composite lamination

Soheil Bazazzadeh, ***Dr. Marco Morandini (Politecnico di Milano),*** *Gian Luca Ghiringhelli*

The damping loss factor and the transmission loss properties of different, complex composite lamination sequences can be predicted by means of a transfer matrix method. This allows to estimate the above mentioned properties, as a function of frequency, for an infinite plate, possibly with a given radius of curvature, by developing a through-the-thickness model of the plate. The ensuing reduced computational time paves the way for the automatic optimization of the damping treatment, provided the different material elastic and damping properties are known as a function of frequency. The optimization is carried out starting from the lamination sequences defined for the nacelle of an experimental tiltrotor. An obvious issue in setting up an automatic optimization procedure is the definition of the objective function. Simply maximizing the integral of the damping loss factor over the frequency range of interest leads to a design where the maximum allowed thickness of the laminate is fully exploited because, roughly speaking, the more damping material is used the more damping is achieved. The same can be said for the transmission loss. A different objective function, the damping loss factor integral normalized by the increase of mass due to the added damping material, allows to reach a better compromise between the opposite requirements of increasing the damping and reducing the overall non structural mass added to the structure. Optimizations are carried out both for monolithic and honeycomb laminates, showing promising increases in the damping loss factor with relatively reduced increase of the overall lamination thickness. Maximizing the transmission loss requires the introduction of foam barrier materials in addition to the the damping layers, and a more significant increase of the overall lamination thickness. The theory behind the objective function

evaluation is briefly discussed, and the optimized designs, obtained for different lamination sequences, is presented.

Lightweight aircraft structures welded by Refill Friction Stir Spot Welding with integral corrosion protection

Mr. Ilya Ostrovsky (Chemetall GmbH), *Bjoern Sievers, Dr. Jorge F. dos Santos, Dr. Uceu Suhuddin, Dr. Koen Faes, Jens Conderaerts, Dr. Landry Giraud*

The main objective of the DAHLIAS project is to optimise hybrid joining (Refill Friction Stir Spot Welding, Refill FSSW, with an adhesive sealant) for application in aircraft structures. Refill FSSW is a solid-state joining technology especially applicable to lightweight alloys in similar and dissimilar configurations. The process has been successfully applied to difficult-to-weld and non-weldable alloys and is considered a potential replacement of mechanical fastening. Overlap joints in aircraft structures require the use of sealants for corrosion protection reasons. The developed in the project adhesive sealant perfectly seals the overlapping area and increases mechanical strength of the welding. Furthermore, special surface preparation and protection scheme enhances adhesion with the adhesive sealant and Cr-free structural primer.
Corrosion and mechanical tests performed on the welded specimens met the requirements of the Topic Leader. Two Technology Demonstrators of a fuselage structure and a bulkhead were manufactured and finished with the developed technologies.

Fatigue performance evaluation of a LPBF Ti-6AL-4V bracket for aerospace application: an experimental study

Mr. Alok Gupta (University of Nottingham), *Chris Bennett, Wei Sun*

The light-weight parts are desirable to improve operational efficiency of an aeroengine and to reduce carbon emissions. The aerospace parts, made using the Laser Powder Bed Fusion (LPBF) process, should meet the stringent certification specifications set out by European Aviation Safety Agency (EASA) [1]. The Low Cycle Fatigue (LCF) and High Cycle Fatigue (HCF) performances of a weight optimized LPBF aeroengine bracket in Ti-6Al-4V (Fig. 1) are studied. Displacement controlled LCF testing was performed at room temperature, first for a displacement range of ±1 mm for a target 3000 cycles and subsequently at a displacement range of ±4 mm to induce fatigue fracture in the bracket (see the LCF test set-up in Fig. 1(a)). Furthermore, the HCF performance of the LPBF bracket was studied through shaker table testing (see the HCF test set-up in Fig. 1(b)), to establish the acceleration 'g' capability of the bracket. The LPBF bracket exceeded the targeted performance of 3000 cycles for the maximum displacement loading expected during typical engine normal operation (set at ±1 mm). The first failure of bracket happens at 211th cycle at displacement level of ±4 mm, a loading which is expected under the extreme conditions only. Also, the LPBF bracket was found to meet its performance targets under HCF, where it not only avoided the critical excitation frequency range of the engine but also demonstrated the minimum targeted 'g' load capability. Also, it was demonstrated that the LPBF bracket has sufficient redundancies in its load transfer paths. The results of LCF and HCF tests, summarized in Table 1, demonstrate that the LPBF bracket meets its fatigue performance targets.

Synthesis and characterization of bulk mechanical properties of a bio-based resin filled by graphene and cellulose nanofibers

Prof. Konstantinos Tserpes (University of Patras), *S. Lagkousi, E. Tourountzi*

In the present paper, a novel bio-based resin derived from epichlorohydrin was reinforced by graphene and cellulose nanocrystals in different weight ratios and characterized experimentally through tension tests and fracture toughness tests on bulk specimens. The nanofillers were applied separately. The experimental results showed that the neat resin has a Young's modulus of 3.29 GPa, a tensile strength of 45.15 MPa, a stress intensity factor of 0.61 MPa m1/2 and a critical strain energy release rate of 0.091 kJ/m2. The level of the properties reveal that the bio-based adhesive can be used for cosmetic and for some structural applications. The addition of cellulose nanocrystals in the epoxy resin didn't improve the mechanical properties of the neat resin mainly due to the development of intense aggregation of cellulose nanocrystals. On the other hand, the addition of graphene has led to the increase of the Young's modulus and the fracture toughness and to the decrease of the tension strength of the resin. Development of agglomerations of graphene were also present in this case. The contradictory findings on the mechanical properties of the reinforced resin gives a clear message about the need for optimizing the manufacturing process. Both nanocomposites have undergone a complete life-cycle analysis which has shown that they are far more environmentally friendly than a conventional epoxy resin.

Aerostructures: Part II

Session Chair: Prof. Konstantinos Tserpes (University of Patras, Greece)

Development and design of tiltrotor nacelle's (NGCTR)

Mr. Magdalena Gronowska (Institute of Aviation - Lukasiewicz Network), *Marek Tabor, Jacek Dudziak, Michał Furdyna*

Attempts to build more efficient, environmental friendly and light weight aircraft are daily goals for aviation industry. Through many years of aircraft design, general configurations were optimized many times and they reached a certain convergence. All innovations that could be implemented with significant profit concerns relatively smaller parts or areas of an aircraft – for example wing tips or canopies. There is still plenty to do: from optimization of geometry itself, through noise reduction, higher reliability and safety of application of new materials. These improvements are goals to achieve within programs like Clean Sky. The Next-Generation Civil Tiltrotor demonstrator (NGCTR) is one of such projects. In general, the aim is to design, manufacture and demonstrate in flight innovative Civil Tiltrotor technologies enabling future prototype development. One of the goal is to develop new nacelle with constraint of non-tilting engine and split gearbox drivetrain. This paper details nacelle's structure, division of fairings, design of transition panel, kinematics of its rotation, weight analysis and application of newer composite materials. New design is also put in context of past airframe structural layouts.

Towards numerical simulation of fatigue damage detection in CFRP laminates by modeling of stochastic vibration response

Ms. Niki Tsivouraki (University of Patras), *Konstantinos Tserpes, Spilios Fassois*

Due to the widespread use of composites in aerospace applications, there is an increasing need for developing Structural Health Monitoring (SHM) systems for composite structures. In this process, simulation models can play a crucial role by contributing to the optimization of the experimental techniques and to understanding of the physical mechanisms. The objective of this work is to numerically simulate fatigue damage detection in laminated composites subjected to random vibration through a white gaussian noise. To this end, the ANSYS FE code has been used. The developed FE model represents an experimental set-up consisting of the composite specimen, the speakers producing the white noise and the measuring equipment. 24 specimens were modelled in total, a healthy one and 23 damaged ones. The white noise was modeled by introducing a normalized sequence of numbers adapted to the free vibration eigenfrequency range. Fatigue damage in the form of matrix cracking and delamination was modelled based on C-Scan images of fatigued specimens by degrading the appropriate elastic properties of the layers in specific groups of elements. The modeled damage differs in geometry, size and type. Power Spectral Density (PSD) diagrams were derived from the analyses, as natural frequencies, eigenfrequencies and contour plots. Any change in the PSD diagrams can be associated with the presence of damage. Before the model is used for damage detection, it has been verified against experimental results on the basis of the healthy specimen. The numerical results show a change in the vibration response even in the presence of a small damage, which is an indication of the sensitivity of the method. The maximum deviation between the numerical and experimental eigenfrequency values was 7%. A significant decline in natural frequencies of the specimen with the damage accumulation is observed.

Bird strike simulation on a bonded Ti/CFRP leading edge of an engine fan blade and numerical implementation of damage detection using FBGs

Prof. Konstantinos Tserpes (University of Patras), *Kosmas Papadopoulos, Ioannis Floros*

Bird strike represents a critical loading scenario for aeronautical structures, especially for engine fan blades. It is, therefore, of great importance one hand to protect the leading edge of the fan blade from impact damage and on the other hand to be able to detect impact damage in time. In the present study, an explicit finite element (FE) model was developed using the LS-DYNA software to simulate bird strike on the leading edge of a CFRP fan blade protected by an adhesively bonded Ti layer. The model accounts for damage on the CFRP blade through a progressive damage modeling scheme and for debonding through a cohesive zone modeling scheme but not for damage on the Ti layer. For the modeling of the bird, the smooth particle hydrodynamics (SPH) method was used, due to the large deformations that were expected. Using the model, a parametric study on the effects of bird mass and impact energy was performed. The numerical results show that impact damage depends more on impact velocity than the bird mass. In all cases, debonding of the tip of the leading edge was predicted, while for combinations of small bird mass and large impact velocity a more extensive debonding of the protective layer was predicted. Regarding damage in the CFRP, only matrix cracking on the leading edge has been predicted. Aiming to assess the effectiveness of FBGs to detect debonding of the Ti layer due to bird strike, an FBG network has been modeled into the bondline and a study was performed on the correlation of the measured strains with impact damage.

Effects of Sweep on the Flutter of Wraparound Fins

Mr. Harun Levent Şahin (Middle East Technical University), *Elif Demir, Vedat Ziya Doğan, Yavuz Yaman*

As in almost all fields, due to weight, storage, stealth and economic constraints, an efficient missile/rocket configuration is desired by designers. Due to the compactness and usefulness, wraparound fins (WAFs) have been used for years in order to control the trajectory of the missiles/rockets. However, being structurally more flexible, the dynamic behaviour and aeroelastic response may be adversely affected, which leads to catastrophic instabilities such as flutter. Therefore, in the design phase, it is very important to couple aerodynamic and structural models of the WAFs to avoid such a effect. Therefore, in this study, flutter speed and frequency of WAFs with respect to several structural design configurations by changing the sweep angle have been investigated in order to understand the aeroelastic performance of the WAFs.

High dielectric breakdown strength of nano- and micrometer-thick magnetron sputtered AlN films probed by conductive atomic force microscopy

Dr. Z.R. Kudrynskyi (Faculty of Engineering, The University of Nottingham), *T.P. Cooper, M.D. Wadge, J. Kerfoot, V.V. Korolkov, D.M. Grant*

The rising industrial requirements of high-power density electrical machines require new generations of electrically insulating coatings with high temperature (T > 500°C) and high voltage (V >1 kV ac/dc) ratings. Aluminium nitride (AlN) is regarded as a promising engineering ceramic material thanks to its useful physical properties: both some of the highest thermal conductivities and the highest electrical resistivities among all known materials. However, presently a coherent picture of the overall dielectric breakdown mechanism in thin films of AlN and its thickness dependence from nano- to micrometre scale is yet to emerge. Here we employ conduction atomic force microscopy to undertake a dielectric breakdown failure analysis of polycrystalline hexagonal AlN films of different thicknesses grown by reactive dc magnetron sputtering. A systematic statistical approach is used to study the breakdown strength through the Weibull distribution and to provide insights into the process of defect generation and dielectric degradation in both the progressive and hard breakdown stages. It is found that at high applied field the dominant pre-breakdown conduction mechanism is Fowler-Nordheim tunnelling. The Weibull slope decreases as film thickness increases, indicating that the defect generation is not random but occurs preferentially at specific locations. The critical field for the dielectric breakdown ranges from 0.9 to 1.1 kV/µm. The breakdown voltage statistics follows a tight monomodal Weibull distribution, indicating the material suitability as a high voltage electrically insulating material. Breakdown effects extend over an area of ca. 400 nm in diameter and evolve by defect generation in AlN, with increasing conductance under repeated stressing. It is also shown that the breakdown current−voltage characteristics differ from ultrathin films of other conventional insulators, such as hexagonal boron nitride (h-BN) and silicon oxide (SiO2). High dielectric strength and adhesion to nickel/copper of sputtered AlN thin films make this purely inorganic material a promising candidate for thermally stable electrically insulating coatings (e.g. insulation of magnet wires and lamination of stator/rotor cores) which meet the demanding requirements of the next generation of high temperature electrical machines used in the aerospace and automotive industries.

Session Chair: Prof. Konstantinos Tserpes (University of Patras, Greece)

A second-generation finite element method for the analysis of multifunctional composite structures

Dr. Enrico Zappino (Politecnico di Torino), *Erasmo Carrera, Matteo Filippi, Alfonso Pagani, Marco Petrolo*

The widespread use of composite materials in developing aeronautical structures brought out a lack of numerical models able to deal with the complex behavior of laminated structures. The classical theories of structures, on which the current finite element codes have been developed, are suitable for the analysis of metallic structures but lose accuracy when heterogeneous laminated materials are considered. The development of multifunctional composites that have sensing and morphing capabilities has made the scenario even more complex since active material and new physics must be considered. Classical models are even more inaccurate when the failure of composite structures is considered since they do not predict the complex stress fields that appear at the different material scales. The use of accurate three-dimensional models has only partially solved the problem since the computational costs limit their use to a small portion of the computational domain. Many attempts have been done in the literature to improve the actual models by enriching the kinematic approximation, one out of all is the model proposed by Reddy for the analysis of laminated plates, but most of them have found application only in academia.

The introduction of the Carrera Unified Formulation, CUF, has been a game-changer in the development of higher-order kinematic models. The CUF offers a compact and unified formalism that can be used to derive any order kinematic model without the need to derive a new formulation and can be easily implemented in a computational code. CUF-based models have been extended to many multifield problems making this approach a unique tool for the design of multifunctional panels. The present work aims to show the main features of the Carrera Unified Formulation and the impact they can have on the analysis and design of complex multifunctional aerospace structures. Different kinematic models (equivalent single layer and layer-wise) will be compared to highlight the advantages offered by higher-order theories with respect to classical finite element models. Linear and non-linear applications will be considered. A fully coupled multi-physical model has been considered to predict the effects of different fields, typically piezo-electric and thermo-elastic, and hygro-elastic. The results show the capability of the present approach in terms of computational efficiency and accuracy.

Abstract of Determination and Validation of Low Velocity Impact Behavior of GLARE for Different Energy Levels and Specimen Thicknesses

Mr. Eren Çalış (student), *Mustafa Yurdakul*

In the competitive environment of the aerospace industry, maximum performance with minimum weight is the most fundamental goal of the design process. In this sense, new materials and production methods are constantly worked and developed by the companies and institutions. Such a group of material is Fiber Metal Laminates, i.e. FML, which are basically hybrid composite materials composed of very thin metallic sheets and glass, carbon like fiber/epoxy layers. ARALL, CARALL and GLARE are several well-known Fiber Metal Laminates. Inherently, FML materials aggregate the characteristics of the constituent materials so that their combined mechanical and fatigue properties are higher than the constituents' individual values. For this reason, they have wide area of usage in aircrafts such as wing lower skin, fuselage skin etc. Since the skins of an aircraft are potential zones of impact during ground maneuvers and maintenance, it is needed to investigate impact properties of these materials. In this study, by considering wing lower skin as a potential zone of application, GLARE is investigated for impact resistance. First, an analysis model is created for simulations. Then, low velocity impact test plan is designed, and tests are conducted with different levels of energy and different specimen thicknesses. Test results are used to validate analysis tool and create a statistical model. After, the numerical analysis model is validated, the numerical and statistical models will be used for determination of low velocity impact behavior of GLARE material for aircraft skin part.

Effect of Temperature on Low Velocity Impact Behavior of GLARE Material

Mr. Burhan Cetinkaya (Turkish Aerospace), *Ibrahim Ozkol*

In today's competitive aerospace environment, it is very important to design and produce aircrafts with high performance and lightweights and in this context, to find new production processes and new production materials. One of this material is GLAss-REinforced aluminum laminate, i.e. GLARE, which are basically hybrid composite materials composed of very thin aluminum sheets and proper structural glass i.e. S2 layers.

Due to its high impact resistance and fatigue properties, GLARE is used in different parts of the aircraft such as the wing & fuselage skin and cargo floor. When producing GLAREs to be used for different purposes, first of all, the metal layer must be abraded mechanically or chemically (etching with chromic acid or phosphoric acid) in order for the fiber/epoxy layer to adhere better. After the metal and fiber/epoxy layers are laid, the autoclave curing process is applied. In aviation applications, types of impacts encountered in aircraft structures can be divided into three titles; low-speed impact, high-speed impact and explosion. Since GLARE consists of both metal and composite layers; damage types such as plastic deformation, matrix cracking, delamination in composite layers, buckling in metal layers and separation between different layers are observed as a result of impact effect. Since the skins of an aircraft is a potential zone of impact during ground maneuvers and maintenance, it is needed to investigate impact properties of these materials. In this study, by considering wing lower skin as a potential zone of low-velocity impact application. As a preliminary study, within the scope of this research, GLARE 4A material was designed as a flat plate and 16 pieces of 5x5 mm2 defects were placed on certain layers and 3 thermocouples were placed to monitor the temperatures in different parts of the panel during curing. The purpose of placing these defects is to show that damage or cracks that may occur in the inner layers of the GLARE lower skin panel of the aircraft wing can be seen by non-destructive testing. So far in this study, GLARE panel has been designed and the best curing cycle has been determined for the GLARE panel. Afterwards, the defects placed inside the panel were examined by ultrasonic nondestructive testing method.

As future studies within the scope of this research, low-speed impact will be applied to samples prepared according to ASTM standards at different temperatures (-55 and +90 Celsius Degrees), at different energy levels and different thicknesses. Difference from the literature, for GLARE materials, the effect of the temperature of the GLARE material on low speed impact, which has never been studied before, will be investigated.

Repairable Aircraft Structures – Multiscale Modelling of Intrinsic Self-Healing Phenomenon in FRP Composites

***Prof. I. Smojver (University of Zagreb)**, D. Brezetić, D. Ivančević*

In composite aircraft structures, damage occurs at several length scales due to their heterogeneous structure. Dynamic loading such as tool-induced rupture, bird strikes and maintenance damage, can result in matrix failure, delamination and BVID. Intrinsically self-healing FRP composites are expected to be able to successfully deal with these problems, since they can autonomously repair matrix structural damage. Especially prospective for use as the matrix constituent is a self-healing vitrimer tested in whose mechanical properties are comparable to conventional epoxy resins used in aeronautical FRP composite structures. Furthermore, its carbon fibre composites showed good in-plane stiffness under tension and compression and good shear stiffness. In this work two micromechanical models are compared for modelling of intrinsically self-healing FRP composite structures. The micromechanical model is based on the principles of the Rule of Mixtures (ROM) and it is previously validated for the case of Three Point Bending (3PB) test in and for the case of healing after Low Velocity Impact (LVI). At the microscale, the matrix constituent is modelled using the micro-damage healing model coupled with von Mises linear isotropic hardening plasticity model, previously developed and validated for pure polymer matrix constituent in [4]. On the other hand, reinforcing fibres are modelled as linear transversely isotropic with Hashin failure criterion and progressive fibre damage. The developed micromechanical models are implemented in Abaqus/Explicit user material subroutines UMAT and VUMAT. Comprehensive parametric analyses for the cases of LVI and 3PB test are conducted whereby advantages and disadvantages of each multiscale approach are discussed and improvements are proposed. The research is carried out in the framework of the ACCESS project (AdvanCed CompositE Selfhealing Simulation), funded by the Croatian Science Foundation (HRZZ).

AICHAIN project session

Session Chair: Mr. Javier Busto (SITA FOR AIRCRAFT, Spain)

The project motivation assumes that Air traffic management (ATM) operations could greatly benefit in terms of capacity, efficiency, predictability, or safety if certain operational systems were powered by machine learning models. To train them effectively, such data-driven models need access to large high-quality datasets. However, some relevant datasets owned by different ATM actors (e.g. airspace users, airports, etc.) cannot be accessed through traditional data sharing mechanisms due to their privacy requirements. The AICHAIN project has investigated a novel approach, referred as the **AICHAIN solution,** to enable the privacy-preserving exploitation of large private datasets from different stakeholders to enrich operational machine learning applications. This is achieved through **privacy-preserving federated machine learning,** where the training and serving of the federated models can be done at the data owners' facilities in a cyber-secured and trustworthy manner without sharing any data. Thus, private data owners can remain in full control of their dataset's privacy. A novel **Blockchain**-based mechanism enhances the federated learning platform with two key features: i) an audit trail to support model **trustworthiness**, as required for operational AI applications in ATM; and ii) a **system of tokens** to implement direct incentives for the participants and fairness policies. To develop the solution, the project has been committed to the following **three research objectives**: i) to prove the technical feasibility of the concept; ii) to prove its value for ATM operations; and, iii) to explore governance and incentive mechanisms to foster the data owners' willingness to participate. The research conducted has delivered the following **key outcomes**:

- **The AICHAIN solution architecture**, designed to exploit private and non-private datasets in a federated way while preserving privacy, trust, and scalability.
- **The AICHAIN prototype**, developed and used to demonstrate the solution through federated learning experiments and cyber-security assessments of the platform.
- **Proof of operational value of private data**, evidenced through two ATM use-cases of high relevance for operations that were enhanced with private data from a federated airline.
- **A framework of customisable tokens to implement rewarding policies**, aimed at encouraging the effective collaboration of the private data owners in the federated processes.

These results could now be used to implement large scale experiments with more airlines in the federation and under more realistic operational conditions.

The AICHAIN solution: Improving air traffic management through machine learning collaboration on private data sets

Mr.Javier Busto (SITA), *Dr. Sergio Ruiz (EUROCONTROL)*

Project context, problem statement and solution approach. The AICHAIN solution and the designed solution architecture will be presented, which has been conceived to exploit private and non-private datasets in a federated way while preserving privacy, trust, and scalability.

The AICHAIN solution proof-of-concept prototype and demo showcases

Dr. Salman Toor (SCALEOUT), *Fredrik Wrede, Andre Rungger*

Presentation of the AICHAIN proof-of-concept prototype, developed to demonstrate the solution through federated learning experiments and cyber-security assessments of the platform. Several demos will be presented showing the different capabilities of the prototype, for both the training and serving of ML models in a federated way.

The AICHAIN research use cases in the ATM domain (for demand and capacity balancing)

Dr. Sergio Ruiz (EUROCONTROL), *Ignacio Martin, Andre Rungger*

Proof of operational value of private data has been evidenced through two ATM use-cases of high relevance for operations that were enhanced with private data from a federated airline: i) the case of take-off time prediction model improvement; and ii) the case of flight plan route-selection prediction model improvement.

The AICHAIN approach to enable governance and incentives policies in the machine learning collaboration

Dr. Ignacio Martin (NOMMON), *Sergio Ruiz*

Discussion about the need for incentives of the ATM actors that own key private datasets to participate in the federated processes. Presentation of a framework of customizable tokens to implement rewarding policies, which is aimed at encouraging the effective collaboration of the private data owners in the federated processes.

AICHAIN conclusions and directions

Dr. Sergio Ruiz (EUROCONTROL), *Javier Busto*

Overall project results, technology readiness level, future research needs and directions. Question and answers.

Air Traffic Management (ATM) and Airports: Part I

Session Chair: Prof. Octavian Thor Pleter (University Politehnica of Bucharest, Romania)

Flight Trajectory Efficiency Analysis Using Brachistochrones

Mr. Cristian Emil Constantinescu (University POLITEHNICA of Bucharest), *Octavian Thor Pleter*

Flight trajectory efficiency metrics currently in use with EUROCONTROL is based on comparing the actual flight trajectories to the great circle routes (orthodromes) connecting each airport pair. This algorithm established in the 1990s is obsolete and ignores the benefits of the use of the wind to reduce the time of flight. Brachistochrones are those flight trajectories which minimize the headwind and/or maximize the tailwind over the entire duration of the flight. Brachistochrones are the minimum time of flight trajectories given a choice of cost index of the flight (consequently the cruise Mach number), and they ensure the minimum fuel burn for the flight. This paper aims at finding what would be the advantage of flying brachistochrones instead of great circle routes for a certain airline, taking advantage of the Free Route airspace emerging in Europe. Based on the results, the paper concludes on the opportunity to change the flight efficiency metrics from a great circle reference to a brachistochrone reference.

Machine Learning Supporting Enhanced Optimized Spacing Delivery between Consecutive Departing Aircraft

Mr. Luca De Petris (Euranova), *Ivan De Visscher, Guillaume Stempfel, Arnaud Jacques, Massinissa Saidi, Catherine Chalon Morgan*

Prior to the covid pandemic, airport capacity was considered one of the major bottlenecks in the European ATM system, with several major European airports being capacity constrained during the peak traffic periods. This in turn impacted the capacity of the overall European network. Traffic predictions show that traffic level will rise back and exceed 2019 traffic levels in the future putting significant pressure once again on the European Airport and network capacity. Runway throughput directly depends upon the applied spacing between successive aircraft on the final approach or on departure. The applied spacing is constrained by separation and spacing minima between aircraft either related to Wake Turbulence (WT) rules, runway spacing, radar separations or specific spacing minima when aircraft are using same departing routes. These separation requirements are expressed either in time (e.g., for WT between departures) or in distance (e.g., radar surveillance minima). Within the Single European Sky ATM Research (SESAR) programme, EUROCONTROL has been developing solutions to increase runway throughput at those airports that are capacity constrained without the need for additional infrastructure. These solutions have involved the development, for both arrivals on the final approach and departures, of optimised separation / spacing minima, on one hand and, on the other hand, of controller support tools to optimize separation delivery and to enable the application of these more complex but more efficient minima. Amongst those solutions, in SESAR 2020 Wave 1, the Optimised Spacing Delivery (OSD) tool for departures was developed. The OSD tool consists of an automatic digital count down timer which provides an optimized clearance time ensuring that all separation and spacing constraints will be satisfied between the consecutive departure pair. For each aircraft pair, the OSD tool takes into consideration all applicable separation and spacing minima and displays the most constraining on the countdown timer. The calculation of the optimised clearance requires prediction models for the trajectory and the ground speed profile of both leader and follower aircraft both in the air and on the runway. In the OSD tool, these prediction models were calibrated using traditional analytical techniques.

However, due to the variability of aircraft behaviour and wind on the initial departure path, the uncertainties related to the use of these analytical models can be significant. As a result, buffers must be added to the OSD clearance time calculations to ensure they are safe. Yet, these buffers are often over-conservative for some pairs leading to reducing the related achievable capacity benefits. The enhanced Optimised Spacing Delivery (eOSD) tool, presented in this paper, and developed in SESAR 2020 Wave 2, further improves the OSD tool by using Machine Learning (ML) techniques instead of traditional analytical techniques to more accurately predict aircraft departure behaviour i.e. rolling time, rolling distance, airspeed profile and climb profile and the associated model uncertainty. These more accurate predictions allow the eOSD time calculations to be reduced compared to OSD through reductions of the required buffers. This leads to more efficient spacing delivery between departing aircraft and hence an increase in departure throughput during peak operations. This has a direct impact on network delays and on the environment. Furthermore, as the spacings are more accurately tailored per aircraft pair there is no negative impact on safety. The paper describes the eOSD solution and the ML techniques and models used to predict aircraft departure behaviour and the model uncertainty. Based on one year of Zurich airport operational surveillance and meteorological data, it also provides the initial results of the benefits that can be achieved with the use of ML techniques in the eOSD solution compared to the traditional analytical techniques used in the OSD tool.

SEESAW Concept: Data-driven Approach for Safety and Resilience Integration in Air Traffic Management

Prof. Bojana Mirkovic (University of Belgrade), *Doroteja Timotic, Fedja Netjasov, Dusan Crnogorac, Christian Eduardo Verdonk Gallego, Chen Xia*

The traditional approach to safety (Safety I), and its relevant models and methods, have much contributed towards enhancing the safety of industrial systems, but they are limited to deal with safety issues in complex socio-technical systems, like Air Traffic Management (ATM). In this paper we attempts to observe ATM system’s technical, organizational, human and procedural characteristics, where Safety II and Resilience Engineering (RE) have emerged and gained attention over the last two decades. Safety I methods are about finding and fixing causes of an accident, meaning they are designed relying on “what can go wrong” in the system. Safety II and resilience engineering rely on the “what goes right”, learning from system’s ability to adapt in everyday situations. However, it seems that safety professionals, who are familiar with traditional safety concepts, still have some misconceptions about new safety concepts, and how to integrate their knowledge and experiences with the concepts, principles and methods related to them. Traditional safety is in principal reactive, while Safety II and RE are proactive approaches to reduce number of negative work outcomes. Even if we do our best to manage system safety proactively, accidents can still happen. Once they do, we need to find the ways of mitigating the negative effects and preventing its recurrence. That means these traditional and new safety approaches need to be combined. Models for safety assessment are mostly quantitative, while available models for resilient performance assessment are qualitative. In this paper we propose approach to quantify safety in ATM as complex socio/technical system, quantify resilience, and to demonstrate the synergy between the traditional approach to safety and resilience engineering.

Our approach called SEESAW concept, uses an analogy of a lever mechanism to demonstrate safety and resilience synergy and help Air Navigation Service Providers (ANSPs) to better understand the relationship between the two. The proposed concept aims to provide a high-level understanding on the balancing between the demand side (including the uncertainties) and available resources on the supply side (Air Traffic Control - ATC) that considers Air Traffic Controllers (ATCOs) on their working positions within a given Area Control Centre (ACC) unit, tools and working procedures.

The left-hand side represents the demand. Traffic volume represents the load and unit complexity represents the distance from the fulcrum i.e. the resistance arm. These two compose the torque i.e. system expected interactions in unit of time. On the right-hand side (supply side) work-as-done in ATC as a socio-technical system is represented. The area reflects ATC system's adaptive capacity. Its boundaries have been defined and inspired by an application of the Rasmussen's model to the railway system. These are safety boundary, capacity and operational efficiency boundary (+ economic boundary) and workload boundary. The effort to balance against the traffic load is represented by available resources/capacity and the distance from the fulcrum (the effort arm) is unit ATC's control workload. Multiplied they produce the resulting torque, i.e. system output workload in a unit of time needed to balance the system expected interactions. System balance can be maintained with smaller number of resources absorbing higher unit workload, or higher number of resources operating under lower workload. The supply side should adapt to changes on the demand side in order to maintain the system balance at all times. The system's ability to adapt results from how the system responds to anticipated performance variations and how the system copes with unanticipated events with a component of surprise or challenge.

A data-driven approach was used to demonstrate SEESAW concept application on airspace shape changes. Both planned and actual data were used for quantification. Two quantification approaches are proposed – one related to assessing balance, the other for scenario comparison. A range of scenarios was used for concept validation – enabling comparison before and after airspace changes, as well as comparison between high and low traffic demand. Additionally, the validation of the SEESAW concept based on expert opinion was performed through the workshop with aviation stakeholders and followed by online surveys. Most of the respondents found the SEESAW concept helpful for understanding the integration of traditional safety and resilience engineering concepts. The overall opinion is that the concept has "the potential for further development", and it can be used "to communicate ideas between management level and sharp end of the organisation".

Simple airports are not that simple when it comes to airside capacity analysis

Prof. Bojana Mirkovic (University of Belgrade)

A common way to estimate airport airside capacity is by using analytical models and/or capacity and delay simulation models. Transportation Research Board recognizes five levels for runway capacity modelling. Apart from analytical and simulation models they also recognize less accurate approaches for preliminary capacity assessment that are: table lookups, charts, nomographs, and spreadsheets. Runway capacity assumes the capacity of the subsystem consisting of the airspace adjacent with the runway (with navigation aids, procedures and monitoring equipment), including runway exits (their type and location). There are two basic rules for aircraft safe operations on the runway: two aircraft in the air not closer than the minimum distance separation required by ATC and one aircraft at the time on the runway. Well established analytical models (found in modern airport planning and design literature) can be used to calculate landing capacity (originally proposed by Blumstein in 1959), take-off capacity and capacity of the runway used in mixed mode. For the latter, two cases differ: priority of the landing operations, and alternating landing and take-off operations.

When it comes to simple airports with poor taxiway system infrastructure (one connector between runway and apron) the model needs to be modified to include safe aircraft exchange on the movement areas. Ground separation (runway occupancy time) becomes more critical in the case of landing and take-off operations. For mixed mode operations an exchange of aircraft happens on the apron area. There is no circular flow or arrival and departure operations across the movement areas. Both apron and runway 'release' the resources through (single) taxiway. Apron capacity calculation has to be modified accordingly. When it comes to airside operations analysis, common simulation models like e.g. SIMMOD are not always convenient, because some constraints that appear with the simple infrastructure are not build in the models. For example, if the apron is fully occupied, next aircraft is not allowed to land before at least one aircraft takes-off. For analysis of airports with simple taxiway system sometimes it is more useful to develop case specific model for airport operations analysis. This paper presents analysis of the airside capacity at Nis Airport, Serbia, using analytical model. The main bottleneck of the Nis Airport throughput is underdeveloped taxiway system. Airport Nis is currently ongoing manoeuvring area expansion, involving parallel taxiway. Using analytical model expected runway and apron capacity improvement is also assessed.

The concentration values of PM2.5 and PM10 in selected places of the airport, propagation and amount of NOx and CO emitted during take-off and landing cycle of airplanes

Mr. Paweł Głowacki (Aviation Institute), *Piotr Kalina, Damian Maciorowski*

European leaders agreed on December 11, 2020 to reduce the EU's greenhouse gas emissions by at least 55% below 1990 levels by 2030. Although aviation accounts for about three percent of the total emission of harmful gases from human activities, their concentration, especially of carbon monoxide in the limited airspace of an airport, may have an impact on the surroundings and the health of employees directly related to the work on the airport apron. From this it follows that in addition to knowledge about the level of GHG emissions, also data about the emissions amount and propagation of harmful gases like CO and NOx as well as particulates PM2,5, PM10 and their concentration is important. The airport authority should have knowledge of the actual amount and concentration of harmful emissions within it, which will allow the implementation of measures leading to their reduction. Knowledge of the directions of propagation and concentration of harmful components of aircraft engine exhaust gases may be helpful during new airports designing processes. The presentation shows results of the PM2,5 and PM10 measurements in the selected points of the airport. The propagation of emissions caused by the engines of the aircraft operated in the airport was developed with the use of special software and is also presented. Two methods to estimate the amount of CO, NOx emissions from aircraft engines during the take off and landing cycle (LTO) in the airspace of a medium-sized airport are shown. One based on the total amount of the aircraft annually operated in it and second one, more precise, for a specific airline annually operating at this airport. Implementation of the conclusions resulting from these methods can support the introduction of operational and technical procedures reducing harmful emissions in the airport airspace during LTO cycle.

CO2 and non-CO2 balanced Environmental Scores Module for flight performance evaluation and optimisation

Jan Middel, Kinanthi Sutopo, Bart Heesbeen, René Verbeek, Nick van den Dungen, Raúl Sáez, ***Dr. Xavier Prats (UPC),*** *Angelo Riccio*

Aviation has a responsibility to mitigate its climate impact to improve the long-term sustainability of the ATM operations and to contribute to the global effort towards reduction of human impact on climate changes. Although much research is ongoing towards the understanding of CO2 and non-CO2 impacts of aviation, key stakeholders such as airlines, service providers, and regulators are struggling to translate this knowledge into pragmatic metrics which can be used to incentivise reduced climate-impact flight operations. The SESAR2020 exploratory research (ER4) programme CREATE (Grant 890898) aims to find answers on reducing the climate impact of a network of ATM operations. This is done by developing a climate and weather aware Concept of Operations (ConOps) which encompasses a multi-aircraft 4D trajectory optimisation framework. One of the key elements within the ConOps is the CO2 and non-CO2 balanced Environmental Scores Module (ESM). The ESM specifically addresses the CO2 and non- CO2 effects during the en-route flight phase. The ESM provides a computational method to evaluate the “greenness” of aircraft trajectories related to flight and ATC sector environmental performance, which is useful in performance dashboards for airlines and ATC service providers, as well as flight trajectory optimisation. The ESM considers non- CO2 emissions, which impacts are dependent of location and time, and CO2 emissions, which impacts are independent of location and time. In this consideration, the emissions per segment of the flight trajectory are analysed and the various parameters are of relevance for the different emission types. The ESM assigns scores to each candidate trajectory (CT) within the optimisation routine. ESM considers non-CO2; NOx, H2O and contrail formation; a) CO2 is linearly related to the total emitted amount per flight and therefore compared to other CTs; b) in the scope of this solution, NOx and H2O emissions impact are related to altitude of emission; c) contrail formation probability and impact are related to Climate Sensitive Areas (CSA) and interference with other CTs. The current scope considers Contrail Formation Region (CFR) to be relevant for the definition of CSAs, however the solution is sufficiently generic to include other meteorological phenomena as well in future developments of the ESM. A fast-time simulation was done for the North-Atlantic region extending into the European airspace, i.e. ECAC area. Based on historical flight trajectory data, a baseline flight performance reconstruction and performance evaluation were done with the NLR fast-time ATM simulator Traffic Manager (TMX). A trajectory optimisation (TO) module was used to provide candidate trajectories (CT) derived from the baseline flights, which were optimised to evade contrail sensitive regions. The ESM was applied to assign scores to all flights, both the baseline as the CTs. In the next computational stage of the CREATE ConOps, the ESM output was used to select the global optimum of all CTs in the network combined which was based on the trade-off between environmental impact and ATM constraints (e.g. congestion). The presented work shall showcase how the ESM solution was applied to the en-route North Atlantic use-case, what the results were of the numerical fast-time simulation experiment, and how the ESM be could further used to support reduced climate-impact of ATM operations. The CREATE project has received funding from the SESAR Joint Undertaking with GA No 89 0898 under European Union’s Horizon 2020 research and innovation program.

Innovative integration of severe weather forecasts into an extended arrival manager

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The impact of extreme weather on air traffic is a global challenge that results in varying delays to flights depending on climate zone, traffic, and available infrastructure. Due to an observed increase in severe weather events, this impact on air traffic is expected to grow in intensity in the coming years, making it increasingly important to organize airspaces safely and efficiently even under severe weather conditions. In the EU H2020 project ”Satellite-borne and INsitu Observations to Predict The Initiation of Convection for ATM” (SINOPTICA), three new meteorological forecasting techniques - PhaSt, RaNDeVIL and WRF-RUC - were developed and tested to better nowcast severe weather events affecting tactical air traffic management operations. The nowcasts are used to organize the approaching traffic by an Extended Arrival Manager (E-AMAN) generating 4D trajectories to efficient detour around severe weather areas in the vicinity of airports. For this purpose, short-range severe weather forecasts with very high spatial and temporal resolution were elaborated starting from weather radar images, through an application of nowcasting techniques combined with Numerical Weather Prediction (NWP) models and data assimilation. This compact nowcast information was integrated into an E-AMAN to assist Air Traffic Controllers (ATCO) in sequencing and guiding approaching aircraft even in adverse weather situations. The combination of fast and reliable weather nowcasts with a guidance-support system enables on the one hand the 4D trajectory calculation for diversion coordination around severe weather areas, and on the other hand the visualization of dynamic weather information on the radar displays of controllers. An earlier assessment of the concept by air navigation service providers has shown that the presentation of meteorological information must be compact and concise so as not to interfere with the relevant traffic information on the display. Two severe weather events impacting different Italian airports were selected for validation of the E-AMAN. Combining the Vertical Integrated Liquid and the Echo Top Maximum products, hazard thresholds were defined for domains around the airports. The Weather Research and Forecasting model (WRF) has been used to simulate the formation and development of convective events. In order to produce a more accurate very short-term weather forecast (nowcasting), remote sensing data (e.g. radar, GNSS) and conventional observations were assimilated by using a cycling three-dimensional variational technique. The validation of E-AMAN system in SINOPTICA project focused on the aspects of feasibility and efficiency and contained two phases. In the first phase, recorded weather data and realistic air traffic were combined and run in a traffic simulation, where the E-AMAN has to organize and to plan the aircraft depending on the measured and forecasted weather. For the evaluation, flight time, track miles and fuel consumption estimation KPIs were applied. In the second phase, various E-AMAN simulation runs were demonstrated to an international controller team for evaluation. The predictions of the three considered forecast models were surprisingly heterogeneous for the same period and area, so that a comparative statement regarding the support quality of the considered E-AMAN within the project is only possible to a limited extent. However, it is indicated that an E-AMAN is very helpful if there is a possibility for large-scale fly-around planning. For this purpose, longer-term and highly precise forecasts that are precisely tailored to

Air Traffic Control requirements are essential. The forecast model must correspond to the safety perception of the air traffic controllers and pilots on site, so that they can manage the traffic as efficiently and safely as possible. However, with the help of sophisticated nowcast models and the E-AMAN, SINOPTICA was able to show that it is possible to support controllers and pilots in challenging meteorological situations to guide air traffic safely and efficiently, and thus to make planning more reliable and predictable for all stakeholders on ground and in the air. This contribution presents an overview of the final results of the SINOPTICA project.

Enabling UAS BVLOS flights in CTR

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In recent years, the widespread use of drones for the transport of people and cargo in and between cities has become increasingly considered. From the point of view of airspace organization, world capitals with high potential for this operation mostly have one common parameter - airspaces defined as controlled zones (CTRs) are established above them, as an integral part of the establishment of airspace around large, mostly international, civil airports. Given the current state of knowledge and the global degree of implementation of UTM, it is necessary from an operational point of view to solve how to integrate the operation of drones alongside aircraft with crew on board, for which the current rules are defined. On the other hand, the rules for the joint operation of manned and unmanned aircraft, have not yet been sufficiently considered. The aim of this paper is to present the needs for individual solutions for this dedicated part of integration at the level of EU member states and to define the sub-areas that need to be defined and put into operation by regulators and interested institutions. This is achieved through a scientific method of analysis (decomposition) and a case study, which identified individual needs and their classification according to predetermined parameters. The combination of identified needs will allow the creation of a flowchart showing the logical procedure for the gradual adaptation of BVLOS traffic in CTRs.

QAR Data-driven assessment of fuel efficiency in Continuous Descent Operations and evaluation of performance metrics

Ms. María del Pozo Domínguez (MCA Groupe), *Javier López Leonés*

Continuous Climb Operations (CCO) and Continuous Descent Operations (CDO) are aircraft operating techniques enabled by airspace design and facilitated by Air Traffic Control (ATC) that allow aircraft to follow a flexible, optimum flight path which brings reduced fuel burn, costs, emissions and noise levels without reducing safety. These operations allow aircraft to climb or descend continuously to the greatest extent possible, removing intermediate level-offs which result in the aircraft spending more time at more fuel-efficient higher altitudes. Deploying CCO/CDO is an ongoing task that different Air Navigation Service Providers (ANSPs) are undertaking globally. In the US, the Federal Aviation Administration (FAA) has an Optimized Descent Profile (OPD) task as part of the NextGen initiative. In Europe, EUROCONTROL supports the deployment of CCO/CDO with a strong collaboration with different stakeholders such as IATA, CANSO, airlines and aircraft manufacturers among others, and has assessed the implementation of these operations in an annual reduction of 340k tons of fuel, 1M tons of CO_2, €150M in cost and an average of 1-5dB per flight in noise. Despite all this global effort to support CCO/CDOs deployment, it is still not possible to assess how many CCO/CDO operations are being flown worldwide, nor to evaluate the performance and environmental impact of each flight properly. This is due to a lack of harmonized CCO-CDO definitions, metrics and methodologies that would make comparative performance measurements possible. In 2015, EUROCONTROL set up the European CCO-CDO task force to solve this issue and come up with a methodology that would serve to measure CCO-CDOs benefits consistently. However, the limitations of this methodology have not been evaluated accordingly. This work correlates the results of the existent methodology with real fuel and emissions savings. Thanks to the use of Quick Access Recorder (QAR) data, a study performed over 2000 flights covering different aircraft types, tail numbers and terminal areas has quantified the limitations of the current methodology: over 50% of flights with some degree of inefficiency would be classified as efficient. The major driver for these results is the sole usage of surveillance data and an incomplete approach. Through the usage of descriptive analytics, the authors have analyzed the correlation of efficient operations with different types of parameters that can be extracted from QAR and surveillance data, being able to properly classify efficient flights. As a result, a new methodology has been developed and it is proposed with the objective of influencing the final metrics that ANSPs will use to evaluate airline's operational efficiency, ensuring that airlines are correctly instructed (and measured) when using CCOs-CDOs, getting one step closer to sustainable operations. Inaccurate metrics can hide operational inefficiencies and delay the investigation of the real root cause for such inefficiencies.

Analysis of the impact of GNSS disruptions on aircraft operations

Ms. Antonia Ivan (Romanian InSpace Engineering SRL)*, Alexandru Pandele, Bianca Ionescu, Teodor Lucian Grigorie*

The need of implementing safer, greener and more cost-effective flight procedures in the near future is recognized at the international level. In this context, the performance-based navigation (PBN) concept enables the transition from conventional ground-based navigation towards space-based navigation, while providing a harmonized set of requirements for navigation specifications, supporting the efficient and optimal use of airspace. This leads to an increased use of the Global Navigation Satellite Systems (GNSS) in aviation. These systems can be safely and efficiently used in all phases of flight, offering precise positioning and navigation solutions, which makes them important assets in this safety-critical domain. However, the GNSS signals are vulnerable to disruptions, especially to radio frequency interference and their impact is insufficiently studied. In the past years, there was a significant number of reports from pilots who encountered jamming incidents near major airports. This kind of incidents might endanger the safety of an aircraft using GNSS in a critical phase of flight.

In support of the PBN implementation in Romania, the ECHO project has deployed a network of GNSS monitoring and interference detection stations at seven major airports. The stations are monitoring all GNSS signals and constellations and they are continuously logging data at a 1Hz rate. The data is used to provide ROMATSA, the Romanian Air Navigation Service Provider, with periodical GNSS performance reports and real-time warnings about the GNSS signal degradation and the presence of interference near each station. ECHO is a project being implemented by Romanian InSpace Engineering, in collaboration with the Romanian Space Agency and ROMATSA, under a contract financed by the European Space Agency.

The purpose of this paper is to assess the impact of GNSS disruptions on the aircraft operations at the airport. The first step for achieving this goal is to use data recorded by the GNSS monitoring station installed at an airport, over a period of several weeks, and to identify the GNSS degradation and interference events. The choice of the airport takes into consideration several factors, such as the number of flights per day and the proximity to possible sources of interference. For example, the "Henri

Coanda” International Airport in Bucharest is the busiest airport in Romania, with over 300 flights per day. A large number of flights increases the chances of aircraft operations being disrupted by GNSS degradation events. Moreover, the airport is located in between the very busy A3 highway and the National Road 1, which increases the possibility of jamming due to small personal privacy device jammers used by some drivers to disrupt tracking systems. The identification of GNSS degradation events is done by computing the performance parameters recommended by ICAO for GPS L1, GLONASS L1 and EGNOS and comparing the obtained values with the indicated thresholds. Data from the interference detection stations is also used for identifying interference threats. Considering a scenario in which all aircraft operations at the selected airport are based on GNSS, an assessment of how they could be impacted by the GNSS disruptions is performed. The assessment criteria include the possible delays in the flight schedule, the additional costs and the fuel consumption. Finally, mitigation measures and means of increasing the robustness of the current systems are discussed.

The aim of this analysis is to raise awareness about the possible effects of the GNSS disturbances on the daily aircraft operations at the airport and the impacts that these events can have on the safety of the flight procedures. The continuous monitoring of the GNSS performance and interference is of high importance, and, complemented with the provision of timely warnings to the air traffic controllers, it can contribute to safer and more *efficient operations by providing an additional safety net for the adoption of PBN in Romania.*

A new empirical analysis of airport capacity evaluation: insights regarding air traffic design hours

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An important and challenging question for air transportation regulators and airport operators is the definition and specification of airport capacity. Airport capacity is rather difficult to describe due to its multi-faceted and dynamic nature, and it depends both on the available infrastructure, on external factors and on operating procedures. Moreover, annual capacity is used for long term planning purposes as a degree of available service volume, but it poses several inefficiencies when measuring the true throughput of the system because of seasonal and daily variations of traffic. Instead, airport throughput is calculated or estimated for a short period of time, usually one hour. This brings about a mismatch: air traffic forecasts typically yield annual volumes, whereas capacity is measured on hourly figures. To manage the right balance between airport capacity and demand, annual traffic volumes must be converted into design hour volumes so that they can be compared with the true throughput of the system. This comparison is a cornerstone in planning new airport infrastructures, as design-period parameters are important for airport planners in anticipating where and when congestion occurs. Although the design hour for airport traffic has historically had several definitions, it is necessary to improve the way air traffic design hours are selected. By reviewing the relationships between hourly and annual air traffic volumes at several European airports, this paper discusses the problem of defining a suitable peak hour for capacity evaluation purposes. Additionally, we appraise different daily traffic distribution patterns and their variation by hour of the day. The clustering of airports with respect to their capacity, operational, and traffic characteristics allows us to discover functional relationships between design hours and annual volumes. These relationships help us to propose empirical methods to derive expected traffic in design hours from annual volumes. This could be used to properly assess airport expansion projects or to optimise resource allocation tasks. Finally, we provide new evidence on the nature of airport capacity and the dynamics of air traffic design hours.

Session Chair: Prof. Ivo Jebacek (BRNO University of Technology, Czech Republic)

An aeroelastic study of a solar-powered airplane at high altitudes

Ms. Pamela Bugała (Łukasiewicz Research Network - Institute of Aviation)

Solar High Altitude Long Endurance Unmanned Aerial Vehicle (HALE UAV) are increasingly being developed due to battery and photovoltaic panel technology developments. They are cheaper than geostationary satellites and can perform missions requiring more flexibility while being closer to the ground so they can take over some of the tasks from the satellites in the future. Requirements for this type of aircraft include reducing the vehicle-induced drag and reducing the lift-loss at the wingtip caused by the wingtip vortex. Therefore, the HALE wing is usually designed with a high aspect ratio (HAR). The structure of the HAR wing (HARW) itself becomes more elastic, which can give large deformation when the aerodynamic loads are applied. The challenge related to HAR wings is their relatively large deformations that can cause a significant change in the aerodynamic load affecting the wing performance. In this connection, HARW should be modeled, considering the aeroelasticity. Since the impact of wing aeroelasticity is getting increasingly important, there is also a growing need to consider such phenomena as early as possible in the design process. Often not precisely defined, the structure can be modeled using equivalent models, e.g., the beam model that was used at the early beginnings. The beam model allows for carrying out the analyzes without the exact knowledge of the wing structure and with a limited number of necessary parameters. This paper describes the numerical simulation of a flexible HALE UAV wing using the low-order two-way fluid-structure interaction (FSI) method. This method is based on low-order aerodynamic (VLM) and structural models (beam model) to limit the complexity of the problem and reduce computational cost. The simulations are performed with various bending and torsion stiffness representing the different structures of the wing for the different elevation angles of the wing.

Preliminary feasibility analysis for a "Class I" loitering munition UAV

Mr. Eleftherios Karatzas (University of Patras)*, Vassilis Kostopoulos, Vaios Lappas*

The continuous efforts on research and development of unmanned aircraft vehicles (UAVs), raise new potentials, capabilities and challenges in the tactical, operational and strategic environment. Recently, loitering based unmanned aerial platforms, which belong to class 1 (NATO classification), have increased situational awareness at small tactical units. These cost-effective applications can be used for reconnaissance, surveillance and strike operations. Carried and operated by a single operator or a tactical team, makes loitering systems easy to operate and reduces the time needed for deployment. Considering these advantages, more and more researchers and defence industries are focused on the development of canister and catapult based loitering UAVs. In terms of simplicity, those platforms are equipped with electrical propulsion system instead of gas-powered engines. Moreover, NATO based platoon and organization, tried to include loitering systems in order to improve the existing Command, Control, Communications, Computers and Intelligence System (C4I System). The paper presents an overview of loitering munitions at present, along with a comparative study about two different types of loitering UAVs a small and a mini which will be used both from small tactical units.

Sizing Approach with Flight Time Comparison of An Electric Multirotor Propulsion Chain with Batteries and Fuel Cells

Mr. Saad Chahba (ESTACA Campus Ouest), *Rabia Sehab, Ahmad Akrad, Guillaume Krebs, Cristina Morel*

The concept of electric vertical take-off and landing (E-VTOL) aerial vehicles is gaining more and more attention, thanks to their non-polluting operation and simple air traffic management. Indeed, around the world, there are currently more than 500 projects that concern the development and improvement of their performances. However, to successfully complete the certification and commercialization stage, several challenges remain to be overcome, particularly in terms of performance, such as range and endurance, and safety. The optimal selection of the propulsion chain components (Figure 1) directly influences the desired performance given in specifications. Rigorous methods for selecting these drive components, namely propellers, motors, ESC and energy storage for E-VTOL aerial vehicles are not readily available. In this paper, an approach for sizing and selecting the propulsion chain components of an E-VTOL aerial vehicle is developed and validated on a reduced-scale prototype of an electric multirotor vehicle of 15 kg. This methodology consists in selecting the pair propeller/motor allowing to maximize the specific efficiency η_PM (N/w) of the propulsion chain. For this purpose, a global nonlinear optimization is carried out based on the simulated annealing algorithm (SAA), to locate the point allowing to maximize the thrust efficiency of the propulsion chain, as shown in figure 2, with constraints on the diameter and the pitch angle of the propeller. Consequently, the selected pair propeller/motor makes it possible to size the ESC and the energy storage system satisfying the overall mission of the drone. Figure 3 gives the flowchart of the sizing approach. In order to evaluate the influence of the energy storage system on the drone performances, in particular on flight time, two energy sources are sized, namely a lithium polymer battery (LiPo), and a hydrogen fuel cell (PEMFC), keeping fixed the total mass of the drone. As shown in figure 4, the hydrogen fuel cell allowed to obtain a flight time of 30 min, while the battery allowed to get only 14 min. Indeed, the hydrogen fuel cell remains the best solution for long-flight missions at low altitudes. The last step of the sizing approach consists in calculating the mass of each selected component of the propulsion chain, using a regression model based on supplier data, in order to check whether the imposed gross take-off weight (GTOW) is respected.

Determination of the Parachute Harness Critical Load based on Load Distribution into Individual Straps with Respect of the Skydiver's Body Position

Ing. Robert Grim (BRNO University of Technology), *M. Horak, I. Jebacek, R. Popela*

This article evaluated the redistribution of the forces to the parachute harness features during load and defines ultimate limit of the personal parachute harness. The main objective of this study was not only to detect critical element but also get overview about forces redistribution during parachute opening load. To capture all the phenomena of the parachutist's body deceleration, study include also loading of the body out of the steady descending position and asymmetrical cases. Thus, the result represents not only idealised loading, but also realistic limit cases such as asymmetric canopy inflation or system activation when the skydiver is in a non-standard position. This brings information about dimensioning options to bring new, optimised and lighter equipment not only for military usage but also for sport class parachuting. The results of this paper will be used for follow-up testing with possible robustness optimization of the harness.

Use of flexible architecture and automation language to ease testing of controllers and functionality of unconventional architectures

Riccardo Rocchio (Italian Aerospace Research Centre), *Gianluigi Di Capua, Luca Garbarino, Nicola Genito*

In Platform 1 of the Clean Sky 2 Large Passenger Aircraft - Integrated Aeronautics Demonstration Platform (LPA-IADP), WP1.6 aimed at discovering a strategy to reduce emissions of Large Passenger Aircraft. In this frame, the use of Hybrid Electric Propulsion (HEP) was identified as a possible solution and, specifically, Distributed Electrical Propulsion (DEP) was found as an important enabler for HEP future development. To foster DEP adoption for large passenger aircraft architectures, a strategic roadmap was implemented including flight testing of a flying demonstrator called D08 “Radical Configuration Flight Test Demonstrator”.

Within this plan, Italian Aerospace Research Centre (CIRA) oversees developing an aircraft Guidance, Navigation and Control (GNC) system to be integrated in a dedicated testing framework for supporting demonstration with the D08.

This work benefit from the GNC system already developed by CIRA in the WP1.3.5 of the same project for support flight testing of a dynamically scaled vehicle demonstrator called D03, as described in [1]. The D03 testing framework was originally developed with the objective of supporting demonstration campaign of innovative aircraft configurations, pursuing modularity and scalability of the SW and repeatability in flight-testing. Differently from current commercial autopilots, that offer full turnkey solutions for remote piloting of unmanned aircraft but with limited possibility of being customized for new aircraft configurations, the proposed autopilot solution offer and increased experimental flexibility. Moreover, repeatability in flight-testing was increased through the inclusion of an instruction language that allows performing complex missions and test maneuvers automatically. This paper describes how this autopilot was updated in order to test the DEP demonstrator D08 presenting how this procedure was facilitated thanks to the modularity of the SW architecture and the development framework, designed to allow users to integrate their modules following a sequence of simple steps.Moreover, it will be presented how repeatability and modularity can be also combined together thanks to the flexibility of the GNC SW and to the automation instruction language mentioned earlier that allows selecting custom control modules instead of the available standard ones for performing an automated sequence of experimental maneuvers. Finally, it will be presented how various components of the Ground Remote Pilot Station (GRPS) were updated to support demonstrations of the D08 for verification and validation purposes allowing fast-time testing of the custom developed control laws and of the whole GNC SW. In addition will be presented how the GRPS can also be used to train a remote pilot to operate this E-demonstrator. Such GNC, together with the development framework, supported the design of control laws architectures and strategies and automated flight tests of unconventional DEP demonstrators. Thanks to this platform, the flight campaign of the D08 can be executed reaching the goal of demonstrating feasibility of HEP in large platform aircraft attempting to reduce their impact on the environment.

Aircraft Design: Part I

Session Chair: Prof. Michael Weigand (TU Wien, Vienna, Austria)

Multidisciplinary design optimization of a fully electric drone along flight mission optimal trajectory

Mr. Rémy Charayron (ISAE Supaéro / ONERA), *Thierry Lefebvre, Nathalie Bartoli, Joseph Morlier*

Nowadays, drones can be developed for a wide range of use cases, from infrastructure monitoring to sea rescue, urban mobility or military purposes. Which drone design better suits for a specific mission? In order to address this question, we need to solve a constrained optimization problem based on a multidisciplinary design model that takes the mission into account. The model generally being a computationally expensive numerical model whose gradients are not available all the time encourages us to consider a Bayesian optimization approach. Such strategy is well known to do a trade-off between exploitation and exploration in order to find interested minimal area with a reduced number of function evaluations. A multi-fidelity approach can improve even more the computational efficiency of the Bayesian optimization strategy. In this work we aim at designing a fixed-wing drone (fully electric) for long range surveillance mission. Two fidelity level electric drone models are developed. For a given mission requirement, the final battery state of charge is optimized with respect to drone design variables. Optimizations are performed on several missions leading to different drone configurations. Both a mono and a multi-fidelity Bayesian optimization strategies were used to compare the performance of the two methods. The interest of using multi-fidelity methods for overall drone design will be evaluated. The multi fidelity super efficient global optimization (MFSEGO) algorithm has been used to assess the usefulness of taking advantage of various available fidelity level.

Experimental Performances Evaluation on Counter-rotating Coaxial Performances for Multirotors

Mr. Nicola Russo (Sonora Srl), *Aniello Daniele Marano, Giuseppe Maurizio Gagliardi, Michele Guida, Tiziano Polito, Francesco Marulo*

Multirotors are gaining great importance in the layout of innovative and more agile mobility; in this framework, multiple companies are developing a new aircraft model based on coaxial rotor configuration. To exploit the several possibilities linked to coaxial rotors, a scaled experimental model is designed to evaluate the performances of the counter-rotating propellers system, concerning the distance between the two propellers. Both thrust and noise are considered parameters of interest. Two brushless motors are deployed whereas the propeller's angular velocity, in terms of round per minute (rpm), is controlled by an external control system. A LabVIEW-based program, interfaced with a myRio-1900 board, has been created to measure the thrust. Tests are conducted on single isolated propellers and on the counter-rotating system: the two propellers and their respective motors have been characterized concerning the thrust. Furthermore, a comparison with a numerical model is performed. Noise evaluation on the single propeller has shown a motor contribution prevalence at a low rpm regime (1140-1500 rpm) and a propeller prevalence for angular velocities higher than 1860 rpm. By varying the distances between the propellers, a sensitivity analysis is performed to identify the optimum configuration considering both noise and thrust performances.

Overall Aircraft Design: from the open source FAST-OAD to its training branch

Ousmane SY, ***Dr. Birame SY (Ecole Polytechnique de Thiès),*** *Abdoulaye SARR, Emmanuel BENARD*

Reducing the environmental footprint of commercial aviation to a manageable level, is a formidable challenge for the whole aeronautical community. In particular, new aircraft configurations could drastically reduce the environmental footprint. Training of engineers in Overall Aircraft Design (OAD) is, therefore, an essential step to be considered in order to take environmental issues into account from the preliminary design phase. ONERA and ISAE-Supaero have developed FAST-OAD (Future Aircraft Sizing Tool – Overall Aircraft Design), an open source platform for the analysis, sizing and optimization of aircraft, emphasizing on user-friendly and modularity. The open source version provides a flexible and practical framework that allows researchers and industrial actors all around the world, to extend the entire aircraft design process to new challenging aircraft configurations, in-house models and higher fidelity approaches.

In this contribution, the authors present a brief state of the art of existing open-source software for OAD. Then, the focus is set on the most commonly used pedagogical approaches of the OAD (Roskam, Torenbeek, Raymer, Kundu) while evaluating each of them with regard to training requirements. From this basis, a training branch of FAST-OAD, to help trainers to build classes and tutorials with the aforementioned pedagogical approaches, will be presented. Situation scenarios involving aerospace engineering students will be proposed, in order to assess these new developments. More specifically, an approach will be put in place to demonstrate OAD sensitivity with respect to simple parametric changes.

Application of the enhanced Advanced Morphological Approach in a hierarchical conceptual design of aircraft, subsystems and components

Mr. Vladislav T. Todorov (Technical University of Berlin), *Dmitry Rakov, Andreas Bardenhagen*

The aviation industry currently chases the ambitious goals to reduce emissions and become significantly more efficient. These put in focus the introduction of revolutionary or disruptive technologies such as entirely new aircraft concepts. In this context, previous work has presented the Advanced Morphological Approach (AMA) for the generation and evaluation of innovative aircraft concepts by decomposing the problem and synthesizing a wide solution space. Subsequently, enhancements to the AMA have been suggested which aim to account for uncertainties and organize the problem by applying hierarchical structures. The current article expands the application domains of the enhanced AMA by demonstrating its capabilities not only for the conceptual design of entire aeronautical systems (aircraft, system-level) but also for the conceptualization of subsystems and components. For this purpose, the enhanced AMA is used to analyze selected use cases from different system levels.

Aircraft Design: Part II

Session Chair: Prof. Michael Weigand (TU Wien, Vienna, Austria)

Enabling the digital thread for aeronautical structures

Mr. Sébastien de Longueville (ISAE-SUPAERO), *Joël Jézégou, Emmanuel Bénard and Yves Gourinat*

In the last decades, data-driven applications have greatly benefited from the rise of powerful smart systems, collecting an increasing amount of data during all the steps of their lifecycles. This data is used inter alia to improve the design performances of those systems by characterising more accurately their actual state and environment. Amongst the data-driven architectures that emerged thanks to this background, the 'digital thread' [1] opens new perspectives for the design of aeronautical systems under uncertainty. In that respect, this study investigates how the design of complex aeronautical structures could benefit from a digital thread. More specifically, this study focuses on the implementation of a digital thread dedicated to the Vertical Tail Plane (VTP) of an A320-like aircraft. To this end, three main features have been identified for this digital thread. On one hand, it aims at reducing the uncertainty related to real state of a system of interest. This is achieved by merging the knowledge and information coming from measurements, design decisions or digital models. In addition to that, this data structure is enriched by interfacing the knowledge about this system with different models providing knowledge-based information regarding the geometry, the structural and aerodynamic properties or the cost required to manufacture this system [2]. Finally, this digital thread contains an optimiser, whose purpose is to identify the best design choice, based on the level of uncertainty related to the knowledge of the real system. For the first feature, a Bayesian filter is used in order to improve the knowledge of the system and its environment, based on measurements performed during the different phases of the lifecycle of the system (manufacturing, operation...). Those measurements are then used to infer the real state of the system. To this end, this use case focuses on the following states: the loads experiences by the structure during operation, the properties of the materials that make up this system, as well as the detailed geometry resulting from the manufacturing process. Since this information is not directly measurable during the operational life of the Vertical Tail Plane, the filter uses indirect methods in order to infer the state of the system based on those measurements. This is achieved thanks to the second feature of the digital thread, which allows it to interact seamlessly with physical and empirical models linking the measured quantities with the actual state of the system. As an example, the states of the digital thread stem from the analysis of the strains measured on the system in operation, the fail stresses of the materials acquired during coupon tests and the duration of the different steps of the manufacturing process. Finally, dynamic programming will be used to compute the optimal decision policy, depending on the knowledge collected by the digital thread. This policy will provide decision aids in order to reduce the production cost of new generations of this VTP, based on the mass of this system and the time required to manufacture it. On the other hand, those policies must ensure that the design suggested will not lead to a structural failure of the system during normal operation. This is achieved by introducing failure criterion in the constraint function, based on static deformation and buckling considerations applied to the loads specified by the digital thread.

Automated sizing chain of aircraft structures : a Vertical Tail Plane use case

Mr. Sébastien de Longueville (ISAE-SUPAERO), *Miriam Scarano, Ana Gines-Martinez and Emmanuel Bénard*

Introduction: The constant increase of computational and sensing power brought by the 'industry 4.0' provides the opportunity to consider multi-disciplinary models of higher fidelity during the early design studies. In this respect, early aircraft design phases can benefit from this technological breakthroughs in order to embed automated parametric studies to the design framework. Those parametric studies can rely on multi-physical environments, integrating for example flight dynamics considerations, more exhaustive aircraft structure and aerodynamic models or certification constrains. This study will therefore discuss the development of a parametric aircraft model that can provide decision aids during the design phases. This tools is made of an automated generator, creating the Finite Element Model of an aircraft structure based on its design parameters. This model is then enriched with flight loads[1], computed thanks to aerodynamic considerations and derived according to the flight conditions of the aircraft. Finally, those flight conditions are determined through an analysis of the certification requirements.

Methodology: This study offers to investigate how high fidelity structural models can be used to support the preliminary aircraft design phase. This is achieved thanks to the implementation of a parametric environment allowing to generate automatically the structural model of an aircraft wing. This model is created automatically, based on the high-level properties of the wing (airfoil, span, dihedra, number of ribs,...). An example of Vertical Tail Plane structure created automatically by this environment can be observed on Figure 1 which shows the model that has been generated for an A320 reference aircraft. This model is then enriched with aerodynamic considerations, using the panel method in order to compute the pressure loading to apply to the structure based on the flight conditions. This environment aims at computing the static deformation and buckling behaviour of the model under the loadings defined previously. The results computed by the model are then used to ensure that the structure is neither buckling, nor failing under those loadings. Based on this environment, a use case has been developed considering the Vertical Tail Plane (VTP) of an A320 aircraft. In addition to that, the loading cases applied to this structure are derived from the sizing flight manoeuvres defined by the certification specifications of large aeroplanes[2]. The load cases corresponding to those manoeuvres can be grouped according to the following categories:

1. Loads due to control reversal conditions (e.g: CS25.353)
2. Unsymmetrical loads due to engine failure (e.g: CS 25.367)
3. Gust and turbulence loads (e.g: CS 25.341)

The connection between the aerodynamic conditions applied to the model and the operations defined in the CS25 are then derived from the dynamic models of the aircraft, of its actuators and from the flight control loops. For further details, Figure 2 depicts the complete framework of this integrated environment, relating the sizing flight manoeuvres to the structural failure criterion.

Finally, the study investigates currently the use of surrogate models in order to reduce the complexity and computational time of the models. Those surrogate models would be derived from the simulation results provided by the parametric model defined above and they would allow integrating models of lower complexity into the final environment.

Parametric model of aircraft external geometry as a component of FAST-OAD aircraft preliminary design system

Mr. Wojciech Grendysa (Warsaw University of Technology), *Emmanuel Bénard, Joël Jezegou*

Rapid evolutions in fields such as aerospace propulsion, materials engineering, geometry modelling tools or optimization tools provide the opportunity to search for novel configurations of future aircraft in an expanding domain. In order to effectively explore the space of variables of constantly expanding size, one needs tools that give the ability to automate this process. Such a tool is the Future Aircraft Sizing Tool for Overall Aircraft Design or FAST-OAD. FAST-OAD allows for rapid estimation of aircraft size, based on set, so-called Top Level Aircraft Requirements (TLARs) by using multi-disciplinary and multi-fidelity analysis and optimization. An essential component of such a system is a module capable of modelling the external geometry of the calculated case. This article describes an attempt to use a powerful commercial Computer Aided Design software, Siemens NX, to model the aircraft external geometry based on the results of the analysis performed by FAST-OAD. This approach, compared to previous works, brings some limitations but, on the other hand, gives the possibility to base the geometry on a mathematically consistent model and helps to better understand the set of parameters necessary to describe the geometry correctly. The main objective of this research is to provide a tool that allows the automatic generation of aircraft exterior geometry based on the output parameters received from the FAST-OAD package. An additional goal of this activity is to determine the parameter set necessary to properly define the external geometry, but at the same time not containing redundant, dependent geometric parameters. The minimum number of independent parameters necessary to completely describe the external geometry is sought.

ALTERNATE project session

Session Chairs : Dr. Gustavo Alonso (Polytechnic University of Madrid, Spain) & Dr. Jordi Pons Prats (Universitat Politècnica de Catalunya, Spain)

Policies and regulations to promote the use of Sustainable Aviation Fuels (SAFs)

Prof. Gustavo Alonso (Universidad Politecnica de Madrid), *Arturo Benito, Ana Nieto*

The use of sustainable aviation fuels (SAFs), with a life-cycle carbon footprint substantially smaller than the present fossil-origin kerosene, is the most promising and probably the only short-medium time measure allowing the aviation industry to reduce its emissions, helping to reach 2015 Paris Agreement targets.

ALTERNATE (Assessment of alternative aviation fuels development) is a H2020-funded project that aims at developing a framework to increase the possibilities of using SAFs in commercial air transport and, consequently, reduce its impact on climate change. This Chinese and European cooperation project is investigating means to stimulate a wider SAF utilization, considering both technical and economic aspects, including the possible use of more diverse feedstocks and sustainable production pathways beyond the existing ones. New fuel candidates are being evaluated according to improved modelling methods, considering LCA and economic modelling to examine climate change effects and technical, economic, and environmental consequences of their use. However, none of those new SAFs has proved to be produced in an economically competitive way versus fossil kerosene. It is generally accepted that some type of incentive mechanism needs to be implemented to make sustainable fuel attractive for the airlines in addition to the CORSIA and European Emissions Trading System (ETS) provisions. In addition to research on new feedstocks and pathways, as well as testing and modelling the effects of the use of sustainable fuels on combustors and engines, ALTERNATE partners are evaluating the different options available for the introduction of SAFs in the normal operation of the airlines and proposing and evaluating mitigation strategies based on the use of alternative jet fuel pathways, for instance exploring the effects of the three possible approaches of the ReFuelEU Aviation proposal in the EU countries and analysing the advantages and disadvantages of each option. Preliminary results show important differences among countries since some of the EU members have a very centralized airport network due to the country configuration while others have a more disperse one. This means that in some cases, forcing providers to make SAF available in all the airports would suppose a great logistic challenge that would not provide a big difference from making it available in the main airport while in others, it might be necessary in order to reach the percentages of SAF established by ReFuelEU Aviation. However, there seems to be a remarkable difference between the airlines that have a very strong hub-and-spoke strategy vs. those that operate a point-to-point model, since the latter need the product available in a higher number of airports.

ASSURED-UAM project session

Session Chair : Mr. Bartosz Dziugiel (Lukasiewicz Research Network - Institute of Aviation, Poland)

ASSURED-UAM. Acceptance, Safety and Sustainability Recommendations for Efficient Deployment of UAM. Toward 2035 UAM implementation

Mr. Bartosz Dziugiel (Lukasiewicz Research Network - Institute of Aviation), *Vittorio Di Vito, Sandra Melo, Jens ten Thije, Michele Giannuzzi, Gabriella Duca, Raffaella Russo, Adriana Witkowska-Konieczny, Jens ten Thije, Marta Tojal, Aniello Menichino*

The idea of Urban Air Mobility (UAM) has become very popular research topic in the last years. There are more than 50 projects funded by only H2020 program, addressing various aspects of implementation of third dimension into urban mobility system. Great majority of them focus on particular technologies and solutions enabling launch of operations over densely populated areas. Very few initiatives address the trends and direction the UAM development aims. The main objective of the ASSURED-UAM H2020 CSA project is providing cities with knowledge concerning deployment of UAM services and definition of necessary standards and recommendations assuring common acceptance, safety and sustainability within integrated metropolitan transport system for three time horizons (2025, 2030 and 2035). In other words, its goal is to answer the question what UAM is going to be in short and medium time horizon regarding the evolution of all domains affecting or determining its success or failure and guide the decision-makers in a way minimising the risks. To meet those goals the ASSURED-UAM project addresses the following tasks:

- Knowledge block covering the technology progress, regulatory review and integration of UAM into existing and operational urban transport systems to better understand UAV industry. Knowledge block will conclude with concept of operation and definition of up to 10 of the most promising and credible UAM use cases.
- Look into the future of urban aerial transportation. Foresight of UAM deployment covering detailed scenarios for the development of UAM and divided into three main areas: operational constraints, Life Cycle Cost (evaluating the real cost of system deployment and operation, including the cost for the natural environment), as well as financing and public acceptance aspects.
- Set of requirements to be implemented with regard to UAM system components. Standards and recommendations for UAM components, products and processes, covering integration, environmental objectives and city planning aspects.
- Cooperation with three urban locations involved in the process of UAM deployment. Three individual and independent cities' projects development support as well as technical assistance.

All activities are supported by more than 60 experts gathered in Extended Advisory Board (EAB). They represent all stakeholders groups directly and potentially affected by the process of Urban Air Mobility implementation. The ASSURED-UAM project will end with issue of a set of learning materials dedicated to decision-makers. It will cover both video lessons as well as written guidelines prepared in 8 languages. All the project content will be there available in user-friendly form.

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ASSURED-UAM: UAM in future integrated urban mobility system. Toward 2035 UAM implementation

Maciej Maczka, ***Mr. Bartosz Dziugiel (Lukasiewicz Research Network - Institute of Aviation),*** *Adam Liberacki, Vittorio Di Vito, Sandra Melo, Gabriella Duca, Aniello Menichino, Jens ten Thije, Marta Tojal*

Urban Air Mobility (UAM), according to common understanding, refers to transportation by air within or between urban areas. Using mobility environment conditions trends we checked if different UAM types of services, fulfilled using different vehicles possibly available within three time horizons (2025, 2030 and 2035), are fit to be competitive among other modes (costs, transport time, emissions). In the first stage of the WP presented within this abstract we simulated the predefined use cases in three metropoles (GZM, Bari and Porto) that served as a sample to develop three subsequent scenarios, in its opening version to be extended with conclusions from other WPs at the end of the project. Initial observations indicated that starting in 2025, a gradually increasing scale of commercial and non-commercial services (direct last mile delivery) could be very successful. But on the other side, UAM cannot compete with mass transit now or even in 2035, when we envisage its passenger operations. Walking access to train stations and bus stops, reliability of service, large passenger groups prevail, in calculations, over potentially weather fragile four-seat UAS. However, passenger UAM seems to be primary selection for high value of time travellers (Millennials, Generation Z business travellers) or people in need to avoid crowds. Certain conditions, like radical increase of annual operations, improve UAM costs results. Yet, a large number of UAS flying even larger number of operations have to maintain the safety levels typical for the aeronautical sector in general.

Cities support on UAM: Demos and lessons learnt from the ASSURED-UAM project

Prof. Sandra Melo (CEiiA), *Adriana Witkowska-Konieczny, Michele Giannuzzi, Bartosz Dziugiel, Vittorio Di Vito, Jens ten Thije, Gabriella Duca, Raffaella Russo, Jens ten Thije, Marta Tojal, Aniello Menichino*

Advances in technology have led to a progressively interlinked global market and reduced the costs of moving goods and people around the world. The integration of information and communication technologies to transport systems and the need to enhance the safety and energy efficiency of transport networks are now key elements in the emerging trends in e-commerce, automated and electric vehicles. On ground transport, the increase in e-commerce transactions resulted in a major demand for domestic courier services, most evident in urban areas, with implications in the cargo supply chains. In recent years, the boom in e-commerce has led to a sizeable increase in home delivery packages, with a considerable surge in the number of orders shipped and hence in urban freight traffic. All this calls for a process of constant innovation involving small packages delivery solutions. Drone deliveries will expectably be one of the outputs of the upcoming delivery solutions that is being shaped by digitization and sharing. Good practices will also be presented on how to prepare municipal decision-makers for the introduction of the third dimension of mobility Therefore, in spite of other unmanned solutions that are expected to experience a significant improvement in terms of their development and implementation in the short- and medium-term, the paper will focus on the role that can be played by cities to accommodate the deployment of drones deliveries, which includes health related cargo and others.

To approach the challenges and first steps that cities are facing and performing, the paper describes experiences from the three cities involved in the ASSURED-UAM project: Bari (Italy), GZM (Poland) and Porto (Portugal). The three case studies will present different outcomes and levels of maturity, as not all the cities are embracing UAM at the same pace. Examples from recent drone tests will be provided as well as surveys conducted on the public acceptance towards the use of drones for delivering packages. These examples, and most of all, the description of the obstacles and challenges that cities faced when trying to implement it, will provide a context for what is the current scope towards the UAM deployment.

Support for the cities authorities: recommended standards for UAM components and operations

Mrs. Anna Mazur (Lukasiewicz Research Network - Institute of Aviation), *Bartosz Dziugiel, Vittorio Di Vito, Aniello Menichino, Jens ten Thije, Hans Brants, Henk Hesselink, Gabriella Duca, Barbara Trincone, Anna Stańczyk, Teresa Idzikowska, Katarzyna Barańska, Kamila Swiątkowska*

Urban Air Mobility (UAM) is a means of transport in urban areas for the delivery of goods and the transport of people by aircraft. These aircraft may be controlled by a manned pilot on board, or by a remote pilot. The requirements for flying over densely populated areas are more stringent then those for flying over scarcely populated areas. UAM operations are part of a logistic chain that also includes surface operations, and UAM operations maybe affected by the environment and vice versa may have an impact on the environment. Hence process of standards and recommendations definition covers four main areas: UAM operations and the facilities and infrastructure for performing UAM operations, UAM integration with urban surface transport, the impact of UAM on the environment, policy and urban planning. Infrastructure for UAM is expected to include items like heli/verti-pads, ground stations, energy supply system, passenger and emergency response facilities, etc. and are necessary to serve the use cases. Due to the fact that deployment of infrastructure will be probably one of the main and early cities' tasks in the process of UAM service preparation, the standards definition process was carried out thoroughly to provide requirements which enable both safe and efficient operation. Urban Air Mobility has to be integrated with both manned regular air traffic and city surface transport. Standards and recommendations provided by ASSSURED-UAM, dedicated to the six defined use-cases and refined based on the overall project results, covers: traffic management, data-exchange, travel information and payments, as solutions assuring efficient deployment of mobility as service. Process of standards definition was proceeded by broad study on possible environmental impact of massive UAM operations: emission restrictions, energy consumption in aircraft components production and utilization phases and interaction with urban natural environment. Additionally urban planning issues and sustainable transport deployment were addressed including the role of regulatory and standard authorities. The purpose of this paper is to present especially for cities and metropolitan area the regulations and standards regarding topics directly related to the UAM components and operations deployment. Another aim of the study is to give a better overview on the current regulations and standards regarding integration of UAM and urban surface transport including the impact of UAM on the environment. This document studies UAM components which are expected to be implemented and regulatory obstacles preventing common deployment of UAM operations.

The views of key stakeholders on the future of the Urban Air Mobility

Dr. Barbara Trincone (ISSNOVA), Gabriella Duca,Bartosz Dziugiel, Sandra Melo, Raffaella Russo, Vittorio Sangermano

Considering the important and complex challenges that today's and tomorrow's cities should face to meet the needs that the Planet and liveability of people demand from us, considering the innovative segment of Urban Air Mobility (UAM), represents an important viewpoint. In the context of the ASSURED-UAM project financed by the Horizon 2020 Programme, there was the opportunity to organise many activities involving the direct involvement of relevant UAM stakeholders, to gather their expert views and experience. A preliminary foresight online survey was conducted out involving 34 experts from the Extended Advisory Board (EAB) of the project, with heterogeneous expertise and affiliations, to explore beliefs and expectations about the deployment of UAM in the near future; interviews were conducted on the topics of Operational Constraints, System Components and Strategy, Financing and policy making; three workshops were held on these topics and three Extended Harmonised Workshops in presence. This complex activity allowed us to reconstruct an interesting picture of the thinking of the relevant stakeholders, on 9 issues in particular.

Operational Concepts for Urban Air Mobility deployment in the next decades

Dr. Vittorio Di Vito (CIRA, Italian Aerospace Research Center), *Bartosz Dziugiel, Sandra Melo, Jens ten Thije, Gabriella Duca, Adam Liberacki, Henk Hesselink, Michele Giannuzzi, Aniello Menichino, Adriana Witkowska-Koniecz*

Urban Air Mobility development and deployment into future cities is gaining increasing and relevant interest in the last years, as a new mobility form suitable to meet the future greener, scalable and efficient mobility targets needed to solve the issues today’s big cities are facing in terms of traffic congestion as well as related environmental consequences. In this framework, the ASSURED UAM (Acceptance, Safety and Sustainability Recommendations for Efficient Deployment of UAM) project has been funded by H2020 and is ongoing, with the main objective of providing cities with knowledge concerning deployment of UAM services and definition of necessary standards and recommendations assuring common acceptance, safety and sustainability within integrated metropolitan transport system for three-time horizons (2025, 2030 and 2035). In the project, dedicated activities have been carried out to develop suitable operational concepts for Urban Air Mobility (UAM) deployment in the next decades. The main results from these activities are presented in this paper, which namely includes the main project outcomes in terms of: the identification of the most relevant and promising technologies that can enable the UAM implementation over the next decades, taking into account the currents technological trends and perspectives; the outline of the regulatory framework in which the UAM will be shaped in the next decades; the definition of the most relevant aspects and constraints affecting the UAM deployment from the point of view of integration of such new mobility form in the cities infrastructures; the outline of the foreseen UAM concept of operations and definition of the most relevant use case that are expected to be implemented in the cities over the three time horizons considered in the project, i.e. 2025, 2030 and 2035.

Integrating ATM and air transport into multimodal transport system for Door-to-Door travel: the X-TEAM D2D project proposed approach

Dr. Vittorio Di Vito (CIRA, Italian Aerospace Research Center),*, Bartosz Dziugiel, Peter A. Meincke, Miguel Mujica Mota, Margarita Bagamanova, Gabriella Duca, Raffaella Russo, Roberto Valentino*

Montaquila, Giovanni Cerasuolo, Maciej Maczka, Anna Mazur, Fares Naser, Abdel el Makhloufi, Stefano Proietti

In the framework of the research activities supported in the EU by SESAR JU, dedicated research stream is devoted to investigation of integration of Air Traffic Management (ATM) and aviation into wider transport system able to support the implementation of Door-to-Door (D2D) travel concept. In this framework, the project X-TEAM D2D (Extended ATM for Door-to-Door Travel) has been funded by SESAR JU, with the aim of defining, developing and initially validating a Concept of Operations (ConOps) for the seamless integration of ATM and air transport into an overall intermodal network, including other available transportation means (surface, water), to support the door-to-door connectivity, in up to 4 hours, between any location in Europe, in compliance with the target assigned by the ACARE SRIA FlightPath 2050 goals. The project is focused on the consideration of ConOps for ATM and air transport integration in intermodal transport network serving urban and extended urban (up to regional level) mobility, taking into account the transportation and passengers service scenarios envisaged for the next decades, according to baseline (2025), intermediate (2035) and final (2050) time horizons. In this paper, the main outcomes from the project activities are summarized, with particular emphasis on the studies about the definition of future scenarios and use cases for the integration of the vertical transport with the surface transport towards integrated intermodal transport system and about identification of the barriers towards this goal. In addition, an outline is provided on the specific ConOps for the integration of ATM in intermodal transport infrastructure (i.e. the part of the overall ConOps devoted to integration of different transportation means) and on the specific ConOps for the integration of ATM in intermodal service to passengers (i.e. the specific component of the ConOps devoted to design of a unique service to passengers). Finally, the main outcomes are summarized from the validation of the proposed ConOps through dedicated simulations.

Towards the maximization of Urban Air Mobility research impact: description of clustering activities of the H2020 ASSURED-UAM project

Ms. Raffaella Russo (ISSNOVA), *Gabriella Duca, Mario Ciaburri, Barbara Trincone, Bartosz Dziugiel*

ASSURED-UAM is a H2020 project defined by the EU Commission as a coordination and support action (CSA), as such namely devoted to accompanying measures such as standardization, dissemination, awareness-raising and communication, networking, coordination, policy dialogues and mutual learning exercises and studies, including clustering activities with projects related to the same research topics. To that aim, ASSURED-UAM participated and promoted networking activities since the project start, with the main aim to foster the maximization of the impact to the relevant stakeholders of the research findings in the Urban Air Mobility field. Several activities have been performed with ASSURED-UAM siblings projects such as the launch of a Task force Accelerating Innovation Uptake for Sustainable Transport promoted by 7 HORIZON 2020 Coordination and Support Actions Projects and Initiatives (BOOSTLOG, ENTRANCE, FastTrack, FUTURE-HORIZON, PLATINA3, RECIPROCITY). The task force is mainly devoted to build and increase the awareness on project activities on in order to widespread it to all stakeholders including high-level policy makers, by also facilitating market uptake of innovations and creating cross cooperation among projects thus maximizing achievements' impact. ASSURED-UAM promotes the participation to targeted conferences and during the project participation in the Amsterdam Drone Week (March 29th, 31st 2022) the launch of a Pan-European Urban Air Mobility Projects & Initiatives Community to Foster Sustainable Development of the UAM ecosystem, took place.

This newborn community includes several EU and SESAR Ju projects focusing on Urban Air Mobility. ASSURED UAM is one of the promoter projects that aims to support the European Commission by bringing together local, national, and EU-funded projects, along with initiatives and regulatory bodies focusing on Urban Air Mobility, to cross-share knowledge and lessons learnt. The project is part of the CIVITAS initiative that works to make sustainable and smart urban mobility. All the findings of the networking activities will lead to a report on the activities and contacts collected during the project development, together with a document on the lessons learned on the clustering activities implementation.

ATLAS project session

Session Chair : Prof. Mario Guagliano (Politecnico di Milano, Italy)

Advanced Design of High-Entropy Based Materials for Space Propulsion (ATLAS), an introduction

Prof. Mario Guagliano (Politecnico di Milano)*, Sara Bagherifard*

The development of next generation space exploration propulsion systems requires high temperature materials able to guarantee low density, high strength and ductility, oxidation resistance, good creep properties. High Entropy Alloys (HEA) are an excellent candidate due to their potential high specific strength and oxidation resistance at high temperatures and have been identified as possible replacement for superalloys in propulsion systems components. HEAs are relatively new class of materials and although since 2004 more than 600 HEA journal and conference papers have been published the whole HEA world still leaves un-answered questions. Therefore, in order to exploit these advancements on HEA, further work is needed. The main goal of ATLAS is to take over the present limitations and unsolved issues that limit the utilization of HEA through multidisciplinary materials design framework that advances the state-of-the-art of High Entropy Alloys and related materials compounds towards the practical needs (current and future) of the space propulsion industry. In this presentation ATLAS is introduced and the strategy for getting the expected scientific and design objectives described.

An Integrated Computational Materials Engineering approach to advance AM refractory complex concentrated alloys for ultra-high temperature applications

Mr. Fuyao Yan (QuesTek Europe AB), *Joachim Gussone, Jan Haubrich, Guillermo Requena, Ida Berglund*

Space propulsion performance is greatly limited by the availability of high-performance materials to withstand ultra-high service temperatures. Refractory complex concentrated alloys (CCAs) have exhibited great potential for high thermal stability. By capitalizing on the recent advancements on computational material development and additive manufacturing (AM) technologies, the concurrent development of improved material and seamless structure can be realized and accelerated. This talk aims to showcase the integrated computational materials engineering (ICME) approach to advance the state-of-the-art refractory CCAs for high-temperature applications. Examples from ongoing development of novel refractory CCAs for in-space thrusters in the ATLAS project will be provided, in which the computational framework is built based on the prioritize process-structure-property-performance relationships that are quantified by science-based mechanistic models calibrated/validated against focused experimental testing of prototypes. With the ICME framework, design and development of novel materials with improved balance of conflicting materials properties (e.g., strength, ductility, oxidation resistance and AM processability) can be significantly accelerated while reducing the needs for costly and time-consuming experimental trials.

A multi-physics procedure to identify critical zone of failure in space thrusters

Mr. Marcello Antonio Lepore (University of Derby), *Angelo Maligno*

The combustion process of a liquid mixture inside the combustion chamber of a commercial thruster used for manoeuvring small satellites in space and for controlling their altitude and orbit has been simulated by employing transient Computational Fluid Dynamics (CFD) analyses. These simulations are paramount to establish the thruster operating time required to reach the steady state condition. The heat flux generated by the simulation of the combustion of the liquid mixture and calculated on the inner wall of the thruster has been applied in a finite element model to evaluate the thermo-mechanical behaviour of the thruster. This strategy allows the identification of the most critical regions within the thruster in which high thermo-mechanical stresses are likely to initiate cracks.

Analyzing the effect of feedstock properties in cold spray technology

Dr. Sara Bagherifard (Politecnico di Milano), *Amir Ardeshiri Lordejani, Davide Colzani, Mario Guagliano*

Cold Spray technology has found applications in multiple fields ranging from coating, and repair, to additive manufacturing. The feedstock properties play a major role in the quality of the deposits and thus in their performance for each application. In order to assess the role of feedstock powder features on deposit properties, using experimental trial and error methods can be costly and time-consuming. Herein, we develop multiple finite element modeling approaches including Lagrangian, smoothed particle hydrodynamics, and coupled Eulerian-Lagrangian to analyze the role of the major powder parameters on deposit quality. We have considered both single and multiple impact models. The best modeling practice was identified for assessing the effect of each parameter including particle size, particle shape, oxidation extent, and impact angle. New parametrizing approaches were defined to quantify deposit quality indicators such as critical velocity, particle flattening, and porosity as a function of each powder variable; the proposed definition indexes facilitate incorporating and assessing a wide range of particle features. The results exhibited a good agreement with the reported experimental data, confirming the capacity of the proposed numerical framework to tune the deposit properties as a function of a wide range of primary and secondary powder characteristics.

Laser powder bed fusion of refractory complex concentrated alloys for space propulsion components

Jan Haubrich, ***Mr. Joachim Gussone (German Aerospace Center),*** *Fuyao Yan, Ida Berglund, Andreas Stark, Norbert Schell, Guillermo Requena*

Within the EU project ATLAS – “Advanced Design of High Entropy Alloys Based Materials for Space Propulsion” – refractory-based materials for ultra-high temperature applications as well as their additive manufacturing (AM) strategies into complex components for space propulsion systems are being developed. The performance of space propulsion systems is often limited by material properties such as high-temperature strength, resistance to thermal shock as well as corrosion and oxidation resistance. In order to develop new high-temperature materials for AM, various new alloy compositions starting with the design space TaNbTixWy and extended to seven-component systems that were designed by QuesTek Europe AB using an integrated computational materials engineering (ICME) approach have been produced by arc-melting and investigated. The surfaces of arc-melted samples were remolten using a laser applying different parameters and characterized after solidification to establish a preliminary suitability for laser powder bed fusion (LPBF) processing. The results of the investigation, in particular the amount and type of cracks within the solidified melt pool regions are correlated with the deformation behaviour during in situ high energy synchrotron X-ray diffraction during compression testing. Finally, the investigations are verified with LPBF experiments carried out with pre-alloyed powder of a seven-component refractory complex concentrated alloy system. Simultaneously to the efforts in alloy development and material processing, the DLR pursues the investigation of a building approach for small space thrusters. The activities are closely linked to DLR’s research on build strategies, manufacturing and testing of complex space propulsion systems from small thrusters up to mid-sized rocket engine liners or shrouded impellers for turbo pumps.

Heat and species map prediction for the generic MEA using an air node model derived from high level requirements

Christina Matheis, ***Dr. Victor Norrefeldt (Fraunhofer IBP)***

Current developments to implement the More Electric Aircraft (MEA) result in a fundamental change of the aircraft systems architecture. Components may be resized or new components may be introduced. This results in new challenges for the thermal management and safety assessment of systems. Zonal airflow models subdivide the indoor space into typically 10^2 zones exchanging air. This allows to predict the impact of systems locations, ventilation and cooling strategies on the thermal management and safety considerations in an early design stage. This paper presents the setup of such an aircraft zonal model based on high-level requirements for a MEA of regional airplane size. These requirements cover the number of passengers, the flight profile and system components to be integrated, like e.g. the battery. Additional requirements are derived from standard for example providing information on required airflow rates and temperatures in the cabin. These requirements are translated into a geometry, ventilation pattern and systems layout. The model application is demonstrated on the example of the safety consideration in case of a battery failure leading to exhaust of harmful gas. A parametric relocation of the battery is demonstrated.

Coupling of a zonal air and temperature distribution model with an low pressure ECS ducting model

Dr. Victor Norrefeldt (Fraunhofer IBP)*, Andreas Lindner, Katherine Urzua-Reichl, Patricia Korth, Christina Matheis, Manuel Munoz-Sanchez*

The Regional Cabin Demonstrator is developed within the Clean Sky 2 project and integrates the latest developments in sustainable and high-performance cabin interiors for enhanced passenger experience. Within this project, an innovative low pressure ECS ducting is developed and integrated into the demonstrator. Together with these hardware demonstration efforts, the associated model based development capabilities are strengthened. The goal is to virtually design the aircraft prior to its actual hardware integration. Such integration requires heterogeneous submodels' interaction in an overall aircraft model. The current work presents such a model coupling. On one hand, a component database for 1D system simulation is developed. By connecting these parameterized component models, it is possible to build any desired low pressure ECS system for which the pressure drop and the air outlet flow distributions are calculated. This system model is interfaced with a zonally decomposed indoor environment Modelica-model of the Regional Cabin Demonstrator showing resulting cabin air temperature, stratification and airflow. Both models interact on one hand because the air temperature and distribution in the air outlets generates a boundary condition for the zonal model. On the other hand, part of the cabin exhaust air is recirculated and thus generates a boundary condition for the low pressure ECS model. The coupling is performed by the functional mock-up (FMU) standard allowing to couple different models through standardized in- and outputs while maintaining protection of individual partners' IP. The model application is demonstrated on the example of a cruise condition thermal boundary condition.

Advanced Digital Avionics System for Evtol

Mr. Mohamed Hedi Hamidi (Capgemini engineering), *MArtin Thibault, Hernandez Lopezomoza Mario Andres, LABRACHERIE Laurent*

In recent decades, Urban Air Mobility (UAM) have seen increasingly remarkable and frequent use in different fields, it is a future mode of transportation that will require revolutionary new vehicle concepts and operations. For this the aeronautics industry challenges relies on simulations tools, for many applications: development of the aircraft geometry thanks to flight dynamics models, of the flight control in different flight regimes such as hovering, forward flight as well as transitions between the two and many other embedded systems. In addition to those simulation objectives, an objective of a full capable simulator is of high importance. And to develop new HMI & cockpits for the eVTOLs, the simulation seems extremely adapted, allowing to design and test several prototypes. For this, an advanced digital avionics system (ADAS) is presented as a solution which makes it possible to assist the aircraft pilot by his ability to assimilate the information intended for him. This article discusses the development and evaluation of simplified vehicle operation concepts using representative aircraft models, controls, receivers, and displays, with the aim of having an optimal control of the eVTOL with the methods of new technologies, but without increasing the mental load of the pilot too much. This is the challenge of this article.

Air Ejector Analysis in Extended Operational Perimeter for Control Oriented Simulation of Bleed-Air Aircraft Systems

Prof. Carles Oliet Casasayas (Universitat Politècnica de Catalunya)*, Eugenio Schillaci, Jagadish Vemula, Matthieu Duponcheel, Yann Bartosiewicz, Philippe Planquart*

The integration of ejectors as a component of thermal/pneumatic systems is getting an increasing interest in many sectors, especially in HVAC&R applications, in order to improve the efficiency and reliability of several systems. The aircraft sector has also used or considered air-air ejectors for pneumatic or ventilation purposes. The current research (EJEMOD Clean Sky 2 project) is related to the potential use of an air-air ejector towards a size reduction of the pre-cooler found in the aircraft pylon, by means of a decrease of its inlet temperature thanks to the jet pump mixing effect. This bleed-air system optimization is an important factor for future integration of large-size engines like the Ultra-High Bypass Ratio. The operation and physics of ejectors in normal mode (on and off design, that is, the generation of the usual characteristic curves) is well established, and several simplified models are available. They have been useful for control purposes, as keeping the adequate levels of accuracy and computational time. However, to achieve a robust implementation of ejectors models within a full system level modelling for control purposes, extended 0D/1D models are needed. They should be suitable to tackle abnormal functioning modes (including reverse flow occurrence at any inlet/outlet port of the ejector), and transient operation during transition between different modes of operation. In this sense, the current research done by the authors is focusing on the understanding of the air ejectors under a broader operation perimeter than what can be found in the usual literature. Computational Fluid Dynamics (CFD) simulations and experiments are being collected, to confirm the expected behavior under normal operation, and to extend the knowledge to abnormal operation. All this understanding is being synthetized in new simplified models, that will be implemented in a Modelica ejector object.

This paper presents the current status of simulations, experiments and Modelica model developments concerning the ejector, showing some interesting results working in different steady modes, and the initial results obtained for transient operation.

SBAS-based navigation system for precision approach in CAT II LVC

Mr. Martin Kovar (Honeywell International Inc.), *Lucas Almeida Cypriano, Matej Kucera, Pavel Ptacek*

Due to lack of advanced navigation systems, secondary airports are normally unable to support instrument approaches in low visibility conditions (LVC) more adverse than CAT I, making them inaccessible during such conditions. Incoming flights are then delayed, diverted to adjacent airports, or cancelled before take-off. This paper presents an onboard navigation system, under development in scope of SESAR 2020 Solution PJ02-W2-17.2, which focuses on technology development to mitigate these traffic disruptions by enabling instrument approaches in CAT II LVC with minimum airport and ANSP investments. The concept builds upon GNSS (GPS L1, SBAS), which currently enables operation down to LPV 200 minimums. The designed system includes radio altimeter-based aiding and innovative integrity algorithm to improve navigation performance and to meet stricter requirements for the intended "LPV 100" operation. As no such requirements have yet been officially published, we also defined sets of candidates based on ILS Collision Risk Model and other sources. The team developed and verified a Monte-Carlo fast-time simulation toolset to enable representative and statistically significant evaluation of the concept feasibility via its availability throughout Europe, as well as sensitivity to proposed sets of alert limits. Also, flight data collection and a developed SW prototype allow for further validations. Simulations demonstrated over 95% average availability. The solution enabling operations in LVC allows unlocking of various benefits to business/airline fleet operators (e.g., avoided extra costs, increased predictability), passengers (avoided opportunity loss) and airports (retained profit from flights, less traffic at diversion airports). Technology development also marks an important step towards gate-to-gate autonomous operations.

Clean Sky 2 Special Session on Thematic Topics: Part I

Session Chair : Dr. Jean-François Brouckaert (Clean Aviation Joint Undertaking)

LEAFINNOX: The Lean Azimuthal Flame - a novel low-NOx, low-soot, fuel-flexible combustor concept

Prof. E. Mastorakos (University of Cambridge), *P. M. de Oliveira, I. El Helou, L. Miniero, K. Pandey, N. Noiray, G. de Falco, M. Sirignano, A. D'Anna, D. Fredrich, A. Giusti*

The Lean Azimuthal Flame combustor concept relies on establishing a series of separate fuel injections arranged in a circumferential direction, with the air being mixed with products and the fuel, therefore enabling combustion in the presence of large amounts of hot products. In the LEAFINNOX project, the concept has been extended to liquid fuels (ethanol, Jet-A, Sustainable Aviation Fuels) and Hydrogen (including 100%), demonstrating the large fuel flexibility this combustor achieves. In addition, the NOx is at a single ppm level and, even for heavy liquid fuels like Jet-A, the level of particulate emissions can be very low. The combined theoretical and experimental work achieved in the project will be summarized in the talk. The results of the project, in addition to the robustness and very low NOx and soot emissions demonstrated by the LEAF burner, suggest that this combustor offers a promising novel architecture for aviation gas turbines with SAF and 100% hydrogen.

CHAIRLIFT: Compact Helical Arranged combustoRs with lean LIFTed flames

A. Andreini*, L. Langone, R. Koch, S. Hoffmann, S. Harth, M. Shamma, M. G. De Giorgi, S. Bonuso*

The project CHAiRLIFT aims to study a novel combustion chamber concept for ultra-lean low NOx operations in next generation aeroengines operated with kerosene-like liquid fuels so as to fully address Clean Sky 2 targeted objectives in terms of NOx by 2050 (i.e. ACARE Flightpath 2050). The new combustor architecture is based on the combination of two specific concepts: the adoption of lean lifted flames stabilized by “low swirl” air-spray nozzles and the arrangement of the burners with a circumferential inclination of their axis inside the annular chamber (Shot Helical Combustor, SHC). Lifted flames lead to a high level of fuel-air premixing so as to allow actual lean operations of the reaction with a reduced risk of flashback and thermo-acoustics instability. The use of helical arrangement of the lifted spray flames allows to limit the overall combustor length and to extend the lean blow out limits of the system. In the first part of the project fundamental studies have been carried out to investigate, by the means of experimental tests and high fidelity CFD, the stabilization process of the lifted flames, the aerodynamics of the SHC and the lean blow out limits of the first proposed concept with 45°-degree inclination in comparison to conventional not inclined arrangement. To support the numerical investigations, an advanced liquid film atomization model has been developed which is capable to describe the droplet formation and tracking at early stage of the atomization process. A sensitivity to burner inclination has been conducted with reduced tilting angle of the burners. In parallel a revolutionary method to further improve flame stability has been investigated by dedicated experiments as the use of nano-pulsed plasma discharge coupled to real time flame detector based on ion probe sensor: this strategy will allow to operate with even leaner mixture targeting further NOx reduction capabilities.

DENOX: Adjustment of numerical and physical experiments for the high activity zone of electrochemical combustion

Mr. Dmytro Dolmatov (National Aerospace University KhAI), *Andrii Kukurudza, Sergiy Epifanov, Sergii Nyzhnyk*

The structure of active electrochemical reaction zone in close vicinity of stimulation discharge in hydrocarbon – air pressurized flame is non-stationary and rapid changing. Numerical and physical studies of crucial reactions and key component behavior has shown high variability of existing mechanisms and approved possibility of different flame micro structures for same initial macro parameters. Correct filtration of general reaction balance requires floating criteria and acute adjustment. Also the direct and indirect physical measurements, according to high number of simultaneously existing intermediate species and their short-live exciting states, need rescaling for various conditions and goals. Conjugate studies of electrochemical flames in zone with thermal combustion temperature 1800 – 2500K and corona stimulation discharge length 10 – 40 mm have shown significant influence of real distribution of neutral and ionized intermediate species on the flame micro structure, including atomic and molecular oxygen and hydroxyl radicals. The scale of finite elements for successful numerical modeling of physical and chemical processes in the micro zones with distinctive size 10 – 100 µm is being determined by definitive processes, reaction speed defining basis primary. The UV and IR spectrometry result analysis also should take into account the features of normal thermal and discharge-initiated excited states of crucial species, which possible profiles are modeled during numerical studies with detailed chemical kinetics model. The repeating adjusting of numerical and physical studies provided increasing of experiments accuracy in the field of NO and NO2 generation/decomposition mechanisms and output by 28% in comparison with previously existing methods. The OH-excited mechanisms, competing with NO generation mechanisms, are fitted for corona discharge NO suppression method by elimination of disadvantages on micro structure level of kinetics mechanisms.

UNIFIER19: Flight dynamics simulator of a hydrogen-powered distributed electric propulsion aircraft

Dr. Johannes Soikkeli (Pipistrel Vertical Solutions d.o.o.), *David Eržen*

Distributed electric propulsion offers new performance capabilities for aircraft design while creating both opportunities and challenges for vehicle control. Many of the advanced control design methods require a detailed model of the aircraft aerodynamics and vehicle dynamics. In this presentation, a six degrees of freedom flight dynamics simulator of the UNIFIER19 vehicle is presented. The simulator captures the aero-propulsive interactions using mid-fidelity aerodynamic tool FlightStream, which is validated against high fidelity CFD. Segmented approach is used to capture the wing and v-tail aerodynamics. The resulting aerodynamic model captures the aero-propulsive interactions of the propeller-wing and propeller-flap as well as the delay of the wing wake propagation to the vehicle's tail. The simulator contains also electrical motor models and actuator models to capture the dynamical systems which impact the aircraft control. The simulator is published fully as open-source for academia to explore and use.

CATANA: an open test case for future composite fans - final studies before experiment

Ms. Anne-Lise Fiquet (École Centrale de Lyon), *Alexandra Schneider, Xavier Ottavy and Christoph Brandstetter*

The open test case ECL5/Catana from composite material will be tested by end of 2022. The final preparations for the experiment have been finished and the fan is currently assembled. In the presentation we will show the analysis of intake distortions and the influence of turbulence control screens on performance and aero elastic behaviour of low speed fans. Furthermore we will introduce the benefits of intentional geometric mistuning on expected non-synchronous vibrations. These studies will be validated by end of 2022 with different intake and mistuning configurations of ECL5/CATANA.

Clean Sky 2 Special Session on Thematic Topics: Part II

Session Chair : Dr. Jean-François Brouckaert (Clean Aviation Joint Undertaking)

U-HARWARD project: Recent Achievements in the Design of Ultra High Aspect Ratio Wings of Environmental Friendly Aircraft

Dr. Sergio Ricci (Politecnico di Milano)

It is very clear and evident the need to explore the benefits of novel aircraft architectures to provide a step-change in fuel efficiency is evident. This need has been identified by ICAO, FLIGHTPATH2050 and Clean Sky 2 initiatives in Europe and also NASA, with challenging goals set for reductions in CO2, NOX and noise by the year 2050. Aiming at these goals, in May 2020 the CS2-U-HARWARD project started, in response to the call JTI-CS2-2019-CFP10-THT-07: Ultra-High Aspect ratio wings, focused to the use of innovative aerodynamic and aeroelastic designs in a multi-fidelity multi-disciplinary optimal design approach to facilitate the development of Ultra-High aspect ratio wings for medium and large transport aircraft. The consortium of U-HARWARD is composed of six partners: Politecnico di Milano, the coordinator, IBK-Innovation GmbH & Co. KG, University of Bristol, Office National d'Etudes et de Recherches Aérospatiales, Institut Supérieur de l'Aéronautique et de l'Espace and Siemens Industry Software SAS. The main idea of U-HARWARD project is to combine the modern design and manufacturing technologies to extend the actual span limit of conventional configurations, together with a deep investigation on a new, promising configurations such as Strut-Braced Wing (SBW) and active folding wingtip concept. Recently, the research plan and goals of U-HARWARD project have been retuned, aiming at a more extended wind tunnel test activity. In particular, four main experimental campaigns have been planned, as follows.

1. An aero-acoustic wind tunnel campaign to investigate the combination of the strut ad wing wakes in the generation of the airframe noise.
2. An aeroelastic model, called AE1, composed by wing+strut model will be tested at large wind tunnel of POLIMI to identify the flutter characteristics of SBW configuration and their sensitivity with respect to type and position of the connection between the strut and the wing (Figure 2 left).
3. A rigid, full model, called AA1, for aerodynamic test, mainly focused on handling qualities identification (Figure 2 middle).
4. Finally, at the end of third year of the project, a large aeroelastic half model, called AE2, with a wing equipped with the folding wingtip mechanism will be conducted at large wind tunnel of POLIMI to investigate potential benefits and implementation issues aiming at load alleviation under discrete and continuous gust excitation.

In parallel, the numerical simulation activities have been carried out to finalize the high-fidelity design of the full-scale strut-braced-wing aircraft as proposed by ONERA, together with the deep aeroelastic investigations of high aspect ratio wings carried out by POLIMI and UNIVBRIS. This paper will present the most recent results of all these activities together with the first assessments now available**.**

Design of a wind tunnel model for flutter investigation of strut-braced high aspect ratio wing in the framework of CS2-THT U-HARWARD project

Dr. Francesco Toffol ((Politecnico di Milano)), *L. Marchetti, S. Ricci, N. Paletta, J. Beretta*

The limitation of climate changes affects the air transportation segment, asking to the aircraft manufactures to design low emissions new generation aircraft. It is required not only a reduction of the emission but their decrease by the 2050. This is critical for the civil aircraft market, which is constantly increasing each year. In this framework, the CS2-U-HARWARD project started in response to the call JTI-CS2-2019-CFP10-THT-07: Ultra-High Aspect ratio wings, focused to the use of innovative aerodynamic and aeroelastic designs in a multi-fidelity multi-disciplinary optimal design approach to facilitate the development of Ultra-High aspect ratio wings for medium and large transport aircraft. One of the proposed configurations is the Strut-Braced Wing, which limits the weight penalty mass introduced by the aspect ratio increase using an additional structural element: the strut. The research activities of U-HARWARD project also include four main experimental campaigns, and one of them is an aeroelastic wind tunnel model, called AE1, composed by wing+strut model which will be tested at large wind tunnel of Politecnico di Milano. The focus is the investigation of the aeroelastic behavior of the highly flexible wing (flutter) and the validation of the simulation models. Moreover, particular attention is paid to the interaction between the strut and the wing from the stability point of view. For this reason, ad hoc design choices are adopted to have a model that can investigate the sensitivity of some parameters concerning the wing connection. The 1:10 model is scaled keeping constant the Froude number, so that the model's sizes are maximized to fit in the test room and the flutter speed of the scaled aircraft is inside the maximum operative speed of the wind tunnel. The model is realized with a main structural glass fiber spar that reproduces the stiffness characteristic, while the aerodynamic shape is guaranteed by 3D printed aerodynamic sectors. It will be instrumented with accelerometers to identify the flutter and with a motion capture optical system to measure the deformation of the wing. A dedicated flutter exciter was designed to dynamically excite the wing. The model will be installed on a turning platform that allows to change the angle of attack, hence allowing to study its effect on the flutter boundary. In parallel, some new features of the NeoCASS aeroelastic suite were developed, like a dedicated solver for the non-linear aeroelasticity of highly flexible structures, where the static deformation due to the trim load dramatically affect the dynamic response of the structure itself. The paper will summarize the results obtained in preparation of the test campaign expected by November 2022.

CA3VIAR: Effect of 3D Blade Design on the Aerodynamic, Aeroelastic and Structural Behavior of a Scaled UHBR Fan

Mr. Torben Eggers (Technische Universitat Braunschweig), *Jens Friedrichs, Jan Goessling, Joerg R. Seume, Jens Lindemann, Nicola Paletta*

In the CA3ViAR (Composite fan Aerodynamic, Aeroelastic, and Aeroacoustic Validation Rig) project, a scaled fan stage of an ultra-high bypass ratio (UHBR) engine is designed with composite rotor blades. The aim is to provide an open test case fan that experiences instability mechanisms and to perform numerical as well as experimental investigations on the aerodynamic, aeroelastic and aeroacoustic performance in a wide range of operational conditions. For the structural integration and a specific in fluencing of the structural behavior of the fan blade, considering the intended aeroelastic instabilities, methods of 3D blade design are applied. While the aerodynamic influence of the blade design in the form of sweep and lean is already well understood, the influence on the aeroelastic and structural

behavior in combination with a fiber composite design of the blade has not been widely explored yet. In this paper, the effect of a 3D blade design on the aerodynamic, aeroelastic and structural behavior of a scaled UHBR fan is investigated numerically. First, an initial sensitivity analysis for the geometrical design features sweep and lean as well as an adaption of the thickness position in the fan hub region is conducted. Positive sweep and lean are found to have a beneficial effect on the total pressure ratio or polytropic efficiency of the fan stage respectively. Moving the maximum thickness position upwards leads to decreased flow turning and total pressure ratio. For all investigated blade design configurations, the change in blade eigenfrequency is negligibly small. However, the mode shape and by that the twist-to-plunge ratio of the 1st Mode is significantly influenced by the modifications. Thus, changing the aerodynamic damping of the blade and influencing the flutter behaviour of the fan. Additionally, the fan displacements under aerodynamic and rotational loads are affected. For the presented fan a positive lean causes the blade to bend towards the pressure side when subjected to inertia forces countering deformation from aerodynamic loads. Thickness adaption moves the shear centre of the cross sections to the back. These results are used to optimize the fan blade behavior to achieve the project objectives. Concluding, the final design, which satisfies the aerodynamic, aeroelastic and structrual needs of the CA3ViAR fan stage, is presented.

CA3VIAR: A high-speed Digital Image Correlation (DIC) setup to measure deformation and vibration of fast rotating fan blades

Mr. Jan Goessling (Leibniz Universität Hannover), *Joerg Seume*

Due to ecological requirements, the bypass-ratio of future civil turbofan engines will be increased. This leads to the usage of ultra-high bypass ratio (UHBR) engines, which bring in new challenges concerning the blade material, structural integration and aeroelastic behaviour of the fan. The ambition of the CA3ViAR (Composite fan Aerodynamic, Aeroelastic, and Aeroacoustic Validation Rig) project is to design an Open-Test-Case Fan that experiences instability mechanisms, which are representative for UHBR fans of civil aircrafts, and to perform comprehensive measurements. The optical measurement technique Digital Image Correlation (DIC) allows the spatial measurement of deformations. The aim is to use this technique to spatially measure rotor blade deformation under loading and vibration due to aeroelastic phenomena to get a better understanding of the structural and aeroelastic behaviour of the composite fan. However, the high rotational speeds, blade vibration frequencies and expected amplitudes pose challenges for the measurement setup. In this work, a high-speed DIC system is elaborated and tested to measure such deformation and vibration of a fast rotating fan. First, an introduction is given about the need to measure deformation and vibration of UHBR fans, the state of the art measurement techniques, and the potential of DIC. The requirements for the DIC setup are defined and presented. Expected rotational speeds in the CA3ViAR project are up to 8667 RPM and blade frequencies of interest up to 650 Hz. Particular emphasis must be given to the setup in order to achieve the required frequency and to eliminate motion blur due to the rotation. This leads to a setup with synchronized high-speed cameras and a laser to measure frequency vibrations up to 1 kHz with an exposure time < 210 ns. Test measurements are conducted on a stationary beam and an axial blower, with a diameter of 1 m and maximum rotational speed of 1000 RPM. The different experimental setups and reference measurements are described in detail. A data analysis method is developed and described to eliminate the rigid body rotation, analyse the deformation of each blade compared to a reference condition (e.g. wind-off), and analyse the spatial vibration in the frequency domain. This data analysis method is programmed to handle a high number of data points per time step. The measured displacements are analysed and frequency responses and vibration patterns are calculated. The results of the structural beam are in agreement with the reference measurements and numerical simulations. By analysing the spatial vibration modes of the axial blower, the 1F-flap mode is identified at 38.15 Hz. In conclusion, this DIC-setup shows promising results for future deformation and vibration measurements on a scaled UHBR fan.

SINATRA: Towards seeding-free, non-intrusive aero engine distortion measurements for propulsion integration

Jonas Steinbock, Michael Dues, Peter Gunterman, Sergey Melnikov, Ingo Röhle, Ulrich Doll, Matteo Migliorini, ***Dr. Pavlos K. Zachos (Cranfield University)***

Reducing the environmental impact of future aircraft architectures is a goal of the aerospace research community [1]. In the last decade there has been a notable focus on the development of new aircraft designs with reduced emissions and the noise footprint. Several of the proposed configurations feature a closer integration of the aero-engine into the fuselage [2] with Blended-Wing-Body (BWB) or Boundary Layer Ingestion (BLI) architectures showing notable benefits in terms of flight efficiency [3]. Convoluted intakes, often used for aircraft engine integration, generate unsteady flow distortion [4] which can affect the propulsion system performance [5] and its aerodynamic and mechanical stability [6]. Better understanding of the unsteady distortion aerodynamics is a key requirement for the development of these novel aircraft configurations and require support of numerical means, ground test facilities as well as in-flight testing capabilities. Current practice for aero-engine testing and safety certification relies on only a few intrusive measurements of pressure and temperature (at a low temporal frequency) to quantify the flow distortion levels that the engine face is presented with by the intake. Although unsteady flow distortion has been historically identified as a key detrimental factor to an aero-engine's stability, the relatively low maturity of advanced flow measurement methods in combination with the high risk of integrating complex measurement systems into engine test facilities have prevented the measurement of richer instantaneous data. As a result, the understanding of flow distortions that lead to engine stall events remains a key requirement. This becomes even more critical as industry is moving towards an era of strongly closely coupled aircraft configurations. Given the known limitations of currently used methods (low spatial and temporal resolution, intrusive instruments that interact with the flow), existing technologies are inadequate to sufficiently reduce the risk on the development of future systems. Non-intrusive laser-based solutions such as Particle Image Velocimetry (PIV) or Doppler Global Velocimetry (DGV) can overcome this difficulty. However, such techniques require the use of particles to seed the flow, which comes with a number of caveats including the requirement of uniform seeding distribution across the measurement plane and the installation of seeding rakes within the intake sub-system which are notably challenging in airborne measurements. A promising technology to overcome the above challenges is Filtered Rayleigh Scattering (FRS) [7, 8]. Due to its potential to offer spatial and temporal resolution as extensively as PIV methods, it allows even highly dynamic flow distortions generated by the geometry of the complex intakes to be clearly understood. Depending on the application, the FRS technology can be used with a continuous wave (CW) laser to provide time averaged data which allows simplified steady state flows distributions to be calculated, or when used with a high powered pulsed laser to provide instantaneous distortion data which better reflects the underpinning unsteady nature of the flow. In this context SINATRA's objectives are defined as follows aiming to further mature the FRS technology.

1. Develop and validate up to TRL4 an FRS measurement system prototype, using a CW laser, for time averaged distortion measurements (synchronous total pressure and velocity). Integrate this prototype onto an complex intake test rig setup with representative complex distorted flows to create a demonstrator that will show the potential of FRS technology to be used for ground and in-flight distortion measurements.
2. Upgrade the above prototype, to demonstrate an FRS measurement system working with a pulsed laser thus showing the capability of the technology to measure instantaneous distortions on a fundamental unsteady flow up to TRL3.
3. Provide a ground test inlet distortion facility that will be available to the whole European aeronautical, industrial & scientific community. This will enable a wide range of non-intrusive flow measurements representative of future aeronautic system and novel propulsion systems to be explored.
4. Use the experimental data from the time average FRS measurements to characterise the distorted flows that are pertinent to advanced closely coupled propulsion systems by means of conventional and/or novel distortion descriptors.

In terms of expected impact, SINATRA provides the opportunity to investigate and develop the applicability of FRS technology for the measurement of distorted complex flows which although focused for the purposes of the project on inlet flows can be also useful to various aspects of turbomachinery, both aeronautical and otherwise. Furthermore, it allows the FRS technology to be assessed to a level similar to other non-intrusive technologies currently better mastered within academia and industry such as S-PIV or DGV. The ambition of this project is to lift the steady FRS technique to a higher TRL in order to meet challenging requirements towards system integration, robustness and automation imposed by BLI representative flow configurations. This will lay the foundations for the transition of the technology into a commercially available product. An FRS measurement system demonstrator at a bespoke aero-engine distortion facility will provide a very useful test facility for European organisation for future development of non-intrusive measurement systems in propulsion integration applications.

SOLIFLY: Concepts for integrating electrical energy storage into CFRP laminate structures for aeronautic applications

Frederic Laurin, ***Dr. Helmut Kühnelt (University of Vienna)***

Electrification of aircraft systems is key for increasing efficiency and reducing the climate impact of air transport towards the European net-zero goal. Functional integration of structural capabilities and electrical energy storage, in form of structural batteries (SB), is considered a low TRL technology that has the potential to lower the detrimental impact of battery energy storage on the aircraft overall weight. So far, structural batteries have been mainly studied at material level, neglecting at large their integration into aeronautic structures. The CleanSky2 THT project SOLIFLY develops further structural batteries for aeronautic applications with two cell concepts, one with coated carbon fibres acting as structural and electrically conductive constituents, and another with laminate structural electrodes. The project directs a specific focus on their integration into CFRP laminates that is compatible with aeronautic manufacturing procedures.This paper introduces the structural integration concepts and the methodology for evaluating the impact of structural battery integration on the mechanical properties of CFRP solid laminates considering size and shape of the structural battery insert as well as its location through the laminate thickness. A fully parameterized, computationally efficient numerical strategy for finite element simulation has been implemented to evaluate the mechanical properties (rigidity and strength) as well as, for the first time, the onset of matrix damage when varying the cell's geometry and integration location. First mechanical characterization data of SB cell constituents and cell prototypes has been performed thanks to multi-instrumented tensile tests using digital image correlation and acoustic emission. An initial assessment of the benefits and trade-offs of the SB integration concepts with respect to functionally separated components will be discussed.

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HIVOMOT: Design of a Superconducting High Power and High Voltage Electric Motor for Single-aisle Regional Aircraft

Mr. Pablo Alvarez Santos (CEIT), *Marco Satrustegui*

First, the HIVOMOT European project is briefly presented regarding the study of a partially superconducting, high power, and high voltage electric motor for regional aircraft in the megawatt range. Then, the electromagnetic, topological and cryogenic requirements of the system are assessed, along with the multiphysical design of the electric motor, including the electromagnetic, thermal and mechanical analyses. Afterwards, the proposed technological validator of the superconducting machine is reported. Finally, a study of winding insulation of electrical machines for aviation propulsion under high altitude conditions is presented.

DCADE: Diamond Converter and Arc fault DEtection for high altitude operations

Ms. Carmen Bejarano Espada (SKYLIFE ENGINEERING), *Antonio Leopoldo Rodríguez Vázquez*

In the frame of clean aviation, and all electrical aircraft with zero emissions in particular, DCADE project aims to evaluate two concepts, (1) the potential technologies which will allow to develop higher voltage converters without reducing the current power density and (2) the arc detection techniques that will increase the safety of high-altitude, high-power A/C distribution systems, in the power electronics and electric power distribution areas respectively. As the industry moves towards the electrical propulsion, the amount of power to be managed by the electrical system is expected to be increasing in the following decade from a few Megawatts to power small aircraft to several tens of MWs to power long haul aircrafts. For this reason, the evolution of aircraft electrical power management system to higher power is critical in the next few years to reach the objective of a future Clean Aviation program. Regarding the higher voltage power converter, ad hoc diamond power transistors with a breakdown voltage above 1 kV (off state) and a current capability higher than 1A (on state) is being designed, fabricated and characterised with the ability to work properly at diamond junction temperatures above 175° C. After carrying out extensive numerical simulations to assess the optimal trade-off performances vs risks, the first batch of devices has been successfully designed and manufactured and is being characterized, reaching a breakdown voltage of 750V. Efforts are being now put towards developing a second batch with improved characteristics. A preliminary datasheet has been created and updated, not only with DC parameters but also with nonlinear parasitic capacitors. The information in this datasheet is being used as input to design a bidirectional DC/DC power converter with a topology developed as work platform, which will allow to compare the performances of the diamond transistors with respect to the currently used SiC devices. With respect to the arc detection techniques, the ability of an AI (neural network combined with a reflectometry algorithm) to detect an arc fault and to locate it in an aircraft distribution network is being evaluated. For this purpose, a database containing the arc fault voltage and current signals measured at various locations in the aircraft distribution network has been created. The signals have been produced in series with resistive loads, that simulates the power distribution network of an aircraft (230V AC at 400-800Hz). The information has been used to train a Transformer Neural Network, which is a deep-learning algorithm quicker to train and less prone to gradient vanishing and explosion than other sequence-based models. The model has passed our validation criteria (with a score of 96.3% accuracy at a 2% false positive rate).An electronic board to integrate the neural network and the reflectometer algorithm will now be designed and manufactured. This electronic board will be set at various locations in an aircraft distribution and arc faults will also be produced at various locations in the aircraft distribution in order to evaluate the performance by calculating the detection and false detection rates and the ability of the solution to determine the position of the arc in the network. DCADE project will implement two demonstrators, one related to each topic described. Both will be available at the partners' facilities.

CHYLA: Credible Hybrid Electric Aircraft – Combining Energy Network, Aircraft Design and Credibility-Based Optimization

M. F. M. Hoogreef, ***Dr. V. O. Bonnin (Delft University of Technology),*** *A. Elham*

The aviation industry has committed itself to a scenario of reduction in emissions over the 3 decades ahead, which is especially challenging to fulfil as air traffic is expected to grow in the same time span. On the technical side, this calls for the development of radical aircraft technologies, such as the hybridization of the powertrain, or the use of different energy carriers (battery, hydrogen), which have been increasingly investigated in recent years. To this day however, it is not clear which technology combination could best address a given set of aircraft requirements, how realisable are such prospective aircraft designs within the time frame considered, nor how would those radical vehicle compare against conventional aircraft on the basis of techno-economic performance metrics. The CHYLA project at providing insights on those points, by providing an overview of scaling opportunities, challenges and limitations of key radical technologies where the credibility of underlying technology assumptions is an explicit factor in developing such a landscape. The article presents technical progress made in the project scope on three areas. First on energy network, where the behaviour of individual components of the network are modelled rather than assumed to provide a higher-fidelity design. Then on aircraft design, where a range of radical technology combinations, together with their underlying assumptions, can be tested on aircraft of various top-level requirements. Finally on the concept of "credible aircraft design" and its integration within an optimization framework, in order to find the best-performing vehicle that abides by a certain credibility level.

SIENA: Overview and preliminary results of the Scalability Investigation of hybrid Electric concepts for Next-generation Aircraft

Ms. Ana Garcia Garriga (Collins Aerospace Applied Research and Technology), *Benedikt Aigner, Lorenzo Trainelli, Carlo Riboldi, Costanza Mariani, Mauro Mancini, Gabriele Sirtori*

This paper presents an overview of a project called "Scalability Investigation of hybrid Electric concepts for Next-generation Aircraft" (SIENA). This is a collaborative project being developed under the European Union Clean Sky 2 Program Thematic Topics. The aviation industry has committed to a set of ambitious goals to fly net zero by 2050. To help achieve these goals, new radical aircraft (A/C) system architectures, like new hybrid-electric propulsion systems, must be designed in a way that is not only technically feasible but also operationally and economically viable. However, several technology challenges persist and combinations of Hybrid-Electric Propulsion (HEP) technologies with novel technologies, such as complex aero-propulsive couplings, novel thermal management technologies and non-drop-in fuels (such as hydrogen, or liquid natural gas) are being considered. SIENA introduces an innovative notion of scalable-by-design aircraft concepts by performing a systematic analysis of novel technologies, and their integration in new vehicle architectures. The project focuses on the development of a systematic methodology to review the feasibility of integrating different technologies in novel aircraft architectures in such a way that they can be scaled-up from smaller to larger passenger aircraft. The performance of the different technologies is assessed against classic aircraft performance requirements, as well as studying the economic, regulatory, and operational impact of such technologies and their viability in the aviation industry. The presentation will outline the technical development program, the challenges being addressed, and the approach followed to face those challenges. Additionally, the preliminary results gathered in the first period of the project for a set of given architectures will be shown including combinations of Hybrid-Electric Propulsion (HEP) concepts with alternate fuels for multiple aircraft categories in both Part 23 and Part 25. The analysis is performed on two levels. An initial analysis is performed on conceptual aircraft design level where the impacts of novel propulsion systems on the vehicle are investigated. Figure 1 shows an example of the design solution obtained for the retrofit of a ATR72-600 in which a series HEP system is employed, with a Power Generation System (PGS) consisting of a fuel cell system fed by a liquid hydrogen tank and a Li-ion battery pack. These results may be contrasted with those seen in Figure 2, where a similar retrofit is carried out, but using a parallel HEP architecture. In both cases, the technology parameters for electric motors (EM), fuel cell systems, and battery packs described in Table 1 are assumed, as representative of the maturation expected in the year 2035. Based on the former studies, a systems architecture analysis evaluates different system architecture candidates against each other in more detail. For this presentation a set of initial architectures are preselected based on best practices and engineering knowledge. As part of this project, this analysis phase will be followed by an automated design space exploration on different technology options to fully identify the potential of different technology options for the observed aircraft categories.

Clean Sky 2 Technology Evaluator Session on Aircraft Concepts: Part I

Session Chair : Dr. Jean-François Brouckaert (Clean Aviation Joint Undertaking)

Environmental Impacts of Clean Sky 2 Technologies for Next Large Passenger Aircraft

Dr. Pierre Arbez (AIRBUS)

The Clean Sky 2 Joint Undertaking is committed to alleviating environmental impacts of aeronautics and fostering the competitive advantage of the aeronautical industry and supply chain in Europe. In particular, Clean Sky 2 has set-out an ambitious objective to reduce from 2014 state-of-the-art, CO2, NOx, and noise emissions by respectively 20% for new aircraft entering into service in the 2030-2035 period and by 30% for the most innovative concepts joining the fleet after 2035. This objective assumes a global fleet forecast to grow in accordance with a worldwide air passenger traffic increasing in the coming decades by 4 to 5% per year, considering that approximately 50% of flying vehicles might carry major Clean Sky 2 technologies by 2050. In order to evaluate the environmental impacts and benefits of the most efficient combination of technologies integrated on new aircraft/rotorcraft concepts, the Technology Evaluator (TE) had been created as an integral part of the Clean Sky programme. It will enable quantification of Clean Sky's contribution to the ACARE Flight Path 2050 environmental objectives, particularly on CO2, NOx and noise reductions. To do so, assessments of the new concept aircraft being developed will be performed at three levels, at mission, airport and air transport system levels. They will be carried out using specific Clean Sky tools enabling Partners to build a global evaluation of the environmental benefits of the programme. Among the various concepts addressed in Clean Sky 2, Airbus develops advanced Large Passenger Aircraft (LPA) planned to enter into service either in the period 2030-2035 or after 2035. These new innovative aircraft configurations implement the new Clean Sky 2 technologies to specifically address short-middle range and long range flight missions. This abstract aims at introducing the overview of the environmental targets for LPA concepts, their underlying key enabling technologies, evaluated and compared with reference 2014 technologies considering design criteria like weight saving, fuel saving, maintenance or production improvement, overall aircraft system improvement and noise reduction. These technologies are implemented into virtual aircraft models that enable the prediction of the performances of these newly equipped concepts along defined flights. Their benefits and impacts will be evaluated and then presented accordingly to the final ‘mission level’ assessment handled for the Technology Evaluator.

Aircraft System Design for the Next Large Passenger Platforms

***Dr. Pierre Arbez (AIRBUS)**, Nicolas Sibout*

The Clean Aviation Joint Undertaking (JU) is committed to alleviating environmental impacts of aeronautics and fostering the competitive advantage of the aeronautical industry and supply chain in Europe. In particular, the Clean Sky 2 programme now coordinated by the Clean Aviation JU has set-out an ambitious objective to reduce from 2014 state-of-the-art, CO2, NOx, and noise emissions by respectively 20% for new aircraft entering into service in the 2030-2035 period and by 30% for the most innovative concepts joining the fleet after 2035. This objective assumes a global fleet forecast to grow in accordance with a worldwide air passenger traffic increasing in the coming decades by 4 to 5% per year, considering that approximately 50% of flying vehicles might carry major Clean Sky 2 technologies by 2050.

Among the various concepts addressed in Clean Sky 2, Airbus develops advanced Large Passenger Aircraft (LPA) planned to enter into service either in the period 2030-2035 or after 2035. These new innovative aircraft configurations implement the new Clean Sky 2 technologies to specifically address short-middle range and long range flight missions. Among these technologies, some are developed via the Integrated Technology Demonstrators (ITD) for Systems. Here, Airbus and partners are exploring and maturing new systems contributing to the reduction of the aircraft environmental footprint, with a particular focus on improving the efficiency of energy use on board. This proposed presentation will aim at introducing for LPA concepts the system design trends, their underlying key enabling technologies and their expected impacts on weight, fuel savings, operations and the overall aircraft system improvement.

Design of a People-Mover Aircraft under Airport Constraints and Comparison to Single-Aisle Aircraft Efficiency

Mr. Sebastian Wöhler (German Aerospace Center), *Jan-Niclas Walther, Wolfgang Grimme*

The People Mover aircraft is a known concept that is designed to carry a large number of passengers on short range routes optimized for short haul operations. In the past, the aircraft design was focused on economics but with respect to the European Green Deal, future aircraft designs have to reduce their ecological footprint to be sustainable. The question that arises is whether such a People Mover aircraft can contribute towards the climate targets by replacing highly efficient narrow body aircraft, where preliminary results indicate a disadvantage in terms of CO2 emissions. Therefore, the concept is assessed primarily on its climate impact contribution and secondarily on its economic performance. In this paper, a People Mover design derived from the Airbus A350 is compared to the Airbus A321neo to identify the CO2 emission and cash operating cost saving potential per passenger seat at a comparable technology level. To match the short a range comfort standard of the A321neo and to identify the potential of the People Mover concept, a study on the maximum passenger number to fit the cabin geometry of the Airbus A350 is conducted. Furthermore, the Airbus A350-1000 is redesigned with respect to the revised top-level aircraft requirements derived from the DLR 2050 market forecast and with focus particularly on the anticipated airport compatibility. Two designs of the People Mover concept for a 65m and 52m span constraint are studied and optimized for short haul operation. For a fair and consistent comparison of the wide body aircraft configuration to a state-of-the-art narrow body aircraft, a comparable technology level is needed. Hence, a foreseen technology scenario in 2035 is applied and all aircraft are redesigned for the evaluation of the concepts utilizing the overall aircraft design environment developed at the DLRInstitute of System Architectures in Aeronautics.

The Advanced TP90 and Ultra-Advanced TP130 Regional Aircraft Concepts

Mr. Giovanni Cerino (Leonardo - Aircraft Division)

The work is part of the Clean Sky 2 REG IADP part of the JTP receiving funding from the Clean Aviation Joint Undertaking under the European Union’s Horizon 2020 research and innovation programme under Grant Agreement n° 945548 REGIONAL AIRCRAFT. Regional SPD within Clean Sky 2 has been focused on Regional Airplane Concepts. In detail two sizes of Regional Aircraft have been developed:

90 seats Aircraft – 1200 nm Design range – 0,56 Cruise speed 130 seats – 1600 nm range – 0,62 Cruise speed. The environmental impact has been evaluated for the two platforms by means of a Simulation Model that has been developed to calculate, for every mission of airplane, the following characteristics: • Fuel burn in any point of the mission phase • CO2 and NOx pollutants produced by engines in any time • Community Noise for departure and arrival airport • Operational noise due to any kind of typical airport flight path. With this option we are capable to calculate the noise footprint on ground and from that result to determine the annoyance on the population around the airport area due to aircraft noise. The two Concepts have been included in the Aircraft Model considering also all technologies applied. The new technologies studied in the relevant WP's are divided in sub-groups that have impact on a specified input of Aircraft Simulation Tool. In detail: Structures – the structural technologies have impact on Operating Empty Weight. On Board System Architecture – systems technologies have a double influence on the Model input. The first one regards the Operating Empty Weight, as in the previous case, because it's necessary to consider for the analysis the equipment weights. The second one is concerning the engine interface. When the engine is requested to relevant Partner, the needed thrust in any flight phase together the power off takes related to specified phase (take off, climb, cruise, ecc) in terms of air conditioning requested power, ice protection system power, flight control demand, and so on.

Aerodynamic – Technologies concerning aerodynamic aspect are expressed in terms of polars and stall features in any flap configuration. Any other component as winglet or loads control device, are included, from structural point of view, in Operating Empty Weight Power Plant – The Engine is included in the Aircraft Model by means of Computer Deck requested to Engine Partner specifying the needed thrust in any flight condition. Engine Partner gives us also the power plant weight and geometry in order to associate also a drag. Including in the engine data there also the source noise of the whole engine (in case of turboprop we obtain turbomachine noise plus propeller noise). We couple these data with airframe noise and in this way the Aircraft Simulation Model is capable to calculate the Certification and Operational noise. The Vehicle Model represents the tool that provides the Airplane Simulation Model as global result of all included technologies in a Regional Concept Airplane.

Eco-friendly electric-hybrid small commuter paving the way to near zero emissions in aviation

Mr. Diego Giuseppe Romano (Piaggio Aero Industries S.p.A. in A.S.), *Aniello Cozzolino*

Civilian air transport market is facing two main challenges, related to the increase of:

1) Transportation demand, due to the growing request in both leisure, and business.
2) Aviation sustainability issues importance, since aviation pollution is a great source of global environmental pollution.

In addition, several States, as well as private Companies travelling for business, are studying or have introduced bans and/or special taxes on flights covering short distances that could be travelled by other means of transportations (e.g. high speed trains) in less than 3 hours. These regulations have a major impact on short haul thin routes, which could be covered by small air transport (up to 19 seats). Clean Aviation Joint Undertaking, in the frame of European Union's Horizon 2020 research and innovation programme, funded the Small Air Transport Transverse Activity (SAT TA), aimed at developing a new European small commuter to reduce pollutant emissions and to connect remote areas. SAT TA will help to improve overall European air mobility allowing to meet the Flightpath 2050 target whereas "90% of travellers within Europe are able to complete their journey, door-to-door within 4 hours". During the last years, research activities have been focused on the introduction of electric power-train architecture on small commuter, as next step towards aviation decarbonisation. In particular, activities carried out within SAT TA focused on feasibility study of electric/hybrid small commuter architecture, to understand the needs and the future availabilities of a future electric aircraft, on the basis of the hybrid serial architecture chosen following a trade-off study between different architecture solutions. The present paper describes the E-STOL (Electric/hybrid Short Take-Off and Landing) configuration defined within SAT TA, showing preliminary emission analysis, which show a promising reduction of pollution, mainly for short ranges.

HECARRUS: Operating and environmental cost considerations comparison for hybrid-electric propulsion architecture variants

Mr. Christos P. Nasoulis (Aristotle University of Thessaloniki), Elissaios Ntouvelos, Georgios Protopapadakis, Vasilis G. Gkoutzamanis, Anestis I. Kalfas

Hybrid-electric propulsion is a promising alternative towards sustainable aviation and is mainly considered for small aircraft class, like commuter aircraft. However, the development of hybrid-electric propulsion variants is affected by the Technology Readiness Level of components -mainly electric propulsion components-, that will determine the electrification benefit, compared to a conventional aircraft, and the variant with the closer Entry Into Service date. Within this work, three different Entry Into Service dates are explored, namely 2027, 2030 and 2040, to size three hybrid-electric architecture variants, i.e., Parallel, Series, and Series/Parallel, using an in-house aircraft sizing tool. All variants are compared to a reference aircraft with technology of 2014, with the main comparison metrics being the aircraft block fuel, direct operating cost and environmental impact. Results indicate that, the higher the technological improvement in the electric power system, the greater the electrification benefit is. However, the parallel configuration has the closest Entry Into Service date and a promising block fuel reduction, at a minimum operating cost and environmental impact penalty. Finally, the Series hybrid-electric configuration has the potential to compete with the Parallel configuration, if Distributed Electric Propulsion is applied.

Clean Sky 2 Technology Evaluator Session on Aircraft Concepts: Part II

Session Chair : Dr. Jean-François Brouckaert (Clean Aviation Joint Undertaking)

Concept designs of hybrid-electric 19 passenger commuter aircraft with potential to enable zero-emission regional air transport

Qinyin Zhang, Fabrizio Nicolosi, ***Mr. Valerio Marciello (Università degli Studi di Napoli Federico II),*** *Vincenzo Cusati, Jonathan Menu, Emre Ongut, Maximilian Spangenberg*

Direct emissions from aviation account for about 3% of the EU's total greenhouse gas emissions and more than 2% of global emissions. Due to the constant increase of aviation transport as shown in the last decades and the rapid emission reduction in other industry sectors, the portion of emissions from the aviation sector would raise significantly in the coming decades, if no measures would be taken for emission reduction. For these reasons, the design of new aircraft concepts utilising hybrid energy sources and highly efficient propulsive system is a crucial aspect for the future aviation transports. Clean Sky 2 Programme aims to accelerate the introduction of new aircraft technologies for the timeframe 2025-2035. Within the ELectric Innovative Commuter Aircraft (ELICA) project, as part of the CS2 Small Air Transport Programme, concept design studies have been carried out for 19 passenger commuter aircraft based on alternative propulsion technologies aiming at near-zero emission. For this purpose, the following work have been carried out. Market studies have been performed to verify the economic feasibility of the new aircraft and to derive the Top Level Aircraft Requirements. Utilising validated preliminary design tools, response surfaces for the components of the electric propulsion system have been generated. Innovative system architecture design tools with automated in-the-loop failure analysis were developed. Enabling technologies for commuter aircraft design have been surveyed and their maturities assessed, then the available technologies have been derived for two aircraft design concepts for 2025 and 2035 time horizons. The serial-parallel hybrid electric aircraft concept for 2025 utilises near-term market-ready gas turbine and battery technologies for the power supply, and Distributed Electric Propulsion (DEP) is incorporated in the design to take advantage of the beneficial aero-propulsive effects. The results show that significant reduction in fuel consumption and noise emission could be achieved, however, the values are still missing the target of near-zero emission. For 2035, the availability of hydrogen as fuel and the high-temperature PEM fuel cell technologies were considered to be market-ready. A partial turbo-electric architecture was proposed to further exploit the advantages of DEP. The results show that for the 2035 aircraft design the exhaust emissions could be completely reduced and further significant reduction in noise emission could be achieved.

UNIFIER19: zero-emission regional transport solution for Next Generation Europe

Mr. David Erzen (Pipistrel Vertical Solutions d.o.o.), *Fabrizio Oliviero, Lorenzo Trainelli*

UNIFIER19 has developed a new aircraft concept for passenger and cargo transportation, that would enable new mobility solutions on short and very-short haul routes. These transport service options would be built upon already existing, sparse, and underused small airport network, thus eliminating overwhelming investment burdens for new ground infrastructures. In addition, this aircraft would provide a zero-emission environmental footprint, thanks to its hybrid liquid hydrogen fuel-cell/battery propulsion system. Two new mobility services were explored in the project: the microfeeder and the miniliner. The microfeeder service is intended as a hub-to-spoke air transportation service, used to feed major airports from smaller cities or open country territories, whether the miniliner service would provide an inter-city connection. An exhaustive market research was performed on Belgium, Italy and Latvia territory, representing high-, mid- and low-ground transportation density regions in Europe respectively. Several promising aircraft aero propulsive configurations were sized in one of two independent conceptual design loops and subsequently cross-checked by the other design loop. This approach not only provides cross-validation of the conceptual design loops but also ensures that results from each loop's component, albeit implementing different tools, predict similar values. A winning design was selected based on noise emissions evaluation, production and operating cost analysis and qualitative structural, manufacturability and certifiability assessment. The selected configuration was finalised by evaluating aerodynamics, structure and aeroelasticity, stability and control, and propulsion, at higher level of fidelity, in view of performance verification and possible optimization. Concurrently, noise footprints, life cycle, certification, and costs were assessed in detail, in order to meet both sustainability and marketability aspects. The present contribution details the specifications of the final design solution, its configuration, performance, stability and control, environmental impact, concept of operations, and estimated costs. Due to its liquid hydrogen powertrain system and distributed electric propulsion configuration, the aircraft will enable establishing a quiet and green enhanced mobility service with minimal ground infrastructure investment.

NGCTR: Faster, Further, Cleaner A methodology for assessing the impact of a TiltRotor

Mr. Giorgio Vicenzotti (Leonardo S.p.A.)

In response to numerous environmental and societal pressures, the aviation sector is embarking upon a period of unprecedented technological change that has the potential to revolutionize mobility. Leonardo Helicopters Division (LHD) responded to the CS2 challenge by proposing the Next Generation Civil Tilt Rotor (NGCTR), with the purpose of increasing performance and operational capability over current tilt-rotor configurations. It envisions a substantial increase in productivity and operational capability for various civil missions and public service scenarios, thanks to a cruise speed in the order of 280 kts – about twice the typical helicopter speeds and closer to that of a turboprop aircraft – and a maximum operating range of about 1,000 nautical miles (1,850 km). This aircraft will have dimensions comparable to those of a helicopter and will operate in all weather conditions and comfort level similar to those of an airliner thanks to its pressurized cabin and very high maximum ceiling (25,000 ft), that of an aircraft. This will allow to expand the opportunities to ensure people's mobility and freight transportation, reaching remote geographical areas that today helicopters and airplanes cannot reach easily. This will be achieved by minimizing the environmental impact through reduced emissions (CO2, NOx, noise) and without the need to create large and expensive infrastructures. Also the impact on search&rescue (SAR) operations of this new mean of transportation has been addressed. The advantage of the fast rotorcraft enhanced capabilities is twofold: to cover in a shorter time the actual helicopters coverage area and to extend the actual coverage area capabilities. The latter can be translated into a fleet substitution rate, that is assessing the number of conceptual vehicles required to serve the same SAR coverage area of a reference/existing fleet. All environmental, mobility, and competitiveness outcomes have been evaluated in comparison to a conventional helicopter platform; this means that a dedicated methodology has been developed to overcome the difficulty of comparing the benefit of tiltrotor technology in comparison to a reference helicopter which has, for its nature, dissimilar components.

The Potential of Using Fast Rotorcraft for High-Speed and Environmentally Sustainable Transportation

Ms. Chana Anna Saias (Cranfield University), *Devaiah Nalianda, Vassilios Pachidis, Alf Junior*

Strategic Research & Innovation Agenda (SRIA) goals have been set for the aviation industry to ensure future sustainability while meeting society's needs for fast and reliable transportation. In line with these goals, Clean Sky 2 is actively exploring various concept aircraft and rotorcraft to replace reference technology counterparts at different time scales (2035/2050). In this context, fast rotorcraft are seen as technology enablers to achieve the ambitious environmental and mobility targets set. To ensure the realization of those objectives, it is essential to assess the feasibility of these technologies and evaluate their environmental and socio-economic impact in that time scale. A holistic assessment of the generic compound rotorcraft concepts currently investigated as part of the CS2 project FASTRIP2050 (FASTRotorcraft societal Integration and Performance assessments 2050) is presented. FASTRIP2050 explores and assesses the potential benefits of replacing reference helicopter technology with advanced tiltrotor aircraft and compound rotorcraft configurations over the designated time scales. Further to that, larger capacity fast rotorcraft, also known as Runway Independent Aircraft (RIA) that are foreseen to operate as regional aircraft, are investigated within FASTRIP2050. For these configurations, hybrid-electric propulsion solutions are explored targeting environmentally sustainable operations. The technical activities undertaken within FASTRIP2050 are first introduced and the modelling capability developed within the project for generic compound rotorcraft is discussed. The employed modelling theories and integration of those within a multidisciplinary framework are presented. The developed framework is next deployed for the quantification of the performance and environmental improvements of a generic compound rotorcraft compared to reference helicopter technology. An illustrative case study is presented where a generic compound rotorcraft is compared against a reference state-of-the-art technology at airport and Air Traffic System (ATS) mission level. Next, the hybridization design space is explored for a fast compound rotorcraft and the potential synergies of electrification with hydrogen are discussed.

Conceptual sizing and performance analysis of hydrogen-powered aircraft

Mr. Wim Lammen (Royal Netherlands Aerospace Centre NLR)

Climate neutrality by 2050 is a major objective of the European Green Deal to which aviation will have to contribute. Therefore, reducing greenhouse gas emissions is one of the main challenges for the development of future commercial aircraft. The development of hydrogen (H2) powered aircraft has recently become a topic of major interest, presenting the opportunity to eliminate CO2 emissions. In particular the on-board use of Liquid Hydrogen (LH2) is under investigation). In the frame of the project TRANSCEND (Technology Review of Alternative and Novel Sources of Clean Energy with Next-generation Drivetrains) - a Coordination and Support Action of Clean Sky 2's Technology Evaluator - the impact of aircraft propulsion based on hydrogen was studied. The focus is on aircraft in the 20- 300 seats range, applied to regional and SMR flights. For three ICAO seat classes within this seats range, in-service aircraft were selected as reference aircraft, representing the seat class, see Table 1. H2-powered configurations were derived from these reference aircraft taking into account propulsion based on H2 combustion by gas turbine only, on fuel cell electric power or on combinations of these two. Future entry-into-service (EIS) years were assumed, taking into account that the applicable H2 power technology is not available today. In line with the future EIS assumptions general aircraft technology improvements – in terms of weight, aerodynamic drag and specific fuel consumption (SFC) reductions – were applied to the reference aircraft. The improved reference aircraft were then adapted and conceptually sized for H2-based propulsion and assessed on their gross emissions and energy consumption. In the sizing, the design payload was kept the same, but the design ranges were shortened compared to the reference aircraft, taking into account expected weight penalties that come with H2 technology.

Table 1: Modelled H_2-powered aircraft.

Configuration	Seat class	Reference aircraft	H2 powertrain type	Design range	Payload	EIS
Regional	20-50	ATR 42-600	Fuel cell	1000 km	5 t	2035
SMR Single Aisle	151-175	Airbus A320neo	Hybrid	2000 NM	16 t	2035
SMR Twin Aisle	211-300	Boeing 787-8	Gas turbine	2000 NM	29 t	2040

The analyses were performed using the NLR in-house tool MASS (Mission, Aircraft and Systems Simulation for energy performance analysis). The initially applied models and assumptions were further refined taking into account recommendations from a dedicated workshop with experts in the field of aircraft hydrogen propulsion and its integration into aircraft, including storage. For the derived concept configurations various payload-range combinations have been evaluated and were used to assess the corresponding impact at fleet level as well. The presentation will detail the modelling and conceptual sizing approach, the applied assumptions, and the performance impact results both at aircraft level and at fleet level.

Environmental-impact assessments at airport level of Clean Sky 2 technologies

Mr. Michel van Eenige (Royal Netherlands Aerospace Centre NLR)

Set up in 2014 and capitalising on the success of the Clean Sky Programme (2008-2016), the Clean Sky 2 Programme aims to make a substantial contribution to the ACARE 2050 goals regarding sustainable and competitive aviation by accelerating the introduction of new aircraft technology in the timeframe 2025-2035. Cross-positioned in the Clean Sky 2 Programme, the Technology Evaluator (TE) has been established as an independent technology evaluator. Its main task is to monitor and assess the environmental and societal impact of the technological results arising from Clean Sky 2 activities, specifically quantifying the expected improvements on the overall noise, greenhouse gas and air pollutants emissions from the aviation sector in future scenarios in comparison to baseline scenarios. Clean Sky 2 technologies are clustered in coherent and mutually compatible solution sets, defining Clean Sky 2 concept aircraft. TE evaluates the environmental impact of these various concept aircraft at three complementary levels: aircraft, airport and air-transport system level. The presentation will focus on TE's airport level as addressed in the Clean Sky 2 TE project GREENPORT2050. Building on its predecessor project CLAIRPORT, GREENPORT2050 focuses on the second and final environmental-impact assessment at airport level in TE. More specifically, it assesses the environmental impacts at airport level of the technologies developed in the Clean Sky 2 Programme for fixed-wing aircraft by realistically addressing aircraft movements in the local airspace of airports. These assessments are carried out for timeframes up to 2050 for a representative set of European airports. GREENPORT2050 quantifies the noise and emissions reductions that these technologies can bring, and assesses the extent to which these technologies can be introduced and accommodated smoothly into daily airport operations, while maintaining safety. As its predecessor CLAIRPORT, GREENPORT2050 addresses noise indicators based on Lden and Lnight (e.g. surface area of contours for significant noise levels and population exposed to these noise levels) and emissions below 3,000 ft. It expands CLAIRPORT by enlarging the set of noise indicators with noise energy, extending emissions impact to local air quality, expanding the assessment with third-party risk, and assessing Clean Sky 2 concept aircraft equipped with a more mature set of innovative technologies. GREENPORT2050's basic assessment principle is to compare the environmental performance of two aircraft-traffic scenarios for a given combination of timeframe and airport. The methodology to quantify the environmental performance of such a scenario consists of two steps. Firstly, a realistic simulation of aircraft traffic is conducted, yielding for each flight a complete trajectory in the airport's local airspace respecting the real airport operational procedures and rules. Secondly, the environmental contribution is calculated per flight, based on its trajectory. These environmental contributions per flight are then aggregated to obtain the total environmental-impact results at airport level. With the simulations and calculations now just under way, the presentation will provide an overview of the approach for Clean Sky 2 TE's airport-level assessments in GREENPORT2050 and the types of results that will emerge from these assessments.

Towards a human-centric Digital Twin architecture for Industry 5.0 – Aiding skilled operators with composites production automation

Dr. J.A. de Marchi (Royal Netherlands Aerospace Centre - NLR), *E.H. Baalbergen*

Industry 4.0 uses digitization technologies to collect huge amounts of manufacturing data during production. Digital Twins support processing, mastering and exploiting the plethora of data to assist management in optimizing production throughput, minimizing equipment downtime, monitoring defects, balancing the supply chain, and even aiding sales and marketing. But how can Digital Twins also aid operators on the shop floor? As part of the Advanced Composites Manufacturing Pilot Plant established by the Royal Netherlands Aerospace Centre (NLR) and GKN Fokker, a Digital Twin was developed for the resin transfer molding (RTM) process that is part of the production of complex composite aircraft components. The Pilot Plant is a cutting-edge research facility consisting of multiple semi-automated manufacturing stations. Within the Pilot Plant, the Digital Twin's role is to collate and analyse streams of raw data from several production machines into a focused overview of the overall RTM process and use that to help the operator to monitor crucial operational parameters, and make critical process decisions, with minimal distraction. In order to learn how a Digital Twin can be optimized to assist operators in understanding and controlling complex production processes, the human factors involved are used to drive the overall Digital Twin architecture and design requirements. This stems from the underlying observation that in many situations the operator is the process expert, and has the expertise needed to ultimately optimize other aspects like process efficiency or product quality. So instead of designing the Digital Twin to steer the process directly, it is mainly designed to provide the operator with useful and insightful information needed to optimally steer the process. A fundamental guideline is therefore that the Digital Twin empowers the operator to gain insights into the process that cannot be obtained by looking at the "raw", unprocessed data alone, enabling the operator to fine-tune the process and produce higher quality products, ideally "first-time right". This approach impacts the Digital Twin design process from start to end, beginning with requirements capture, and following all the way through to implementation and testing, with the operator as central stakeholder of the final design at every step along the way. This results in a Digital Twin architecture that not only supports process management and oversight, but also adapts easily to evolving operator needs, and can be readily reconfigured and deployed for new composites manufacturing applications. In our presentation and paper, we review the operator-centric Digital Twin design process from start to end, exploring key elements of the architecture of the user-tailored Digital Twin, and exposing valuable lessons learned from the operator-centric design process. The agile development process and the resultant Digital Twin architecture show how the operator-centric design guidelines were successfully translated into the implementation. This approach has helped transform an otherwise straightforward Industry 4.0 implementation into a state-of-the-art Industry 5.0 implementation, where a Digital Twin supports operator decision-making at the core of the manufacturing process.

An interactive framework to facilitate probabilistic set-based multidisciplinary design optimisation studies

Dr. Gustavo P. Krupa (Cranfield University), *Andrea Spinelli, Timoleon Kipouros*

The upcoming stringent environmental aircraft regulations and the environmental, social and governance (ESG) framework targeting net zero emissions has forced aircraft manufacturers to seek innovative but feasible technical solutions. Often, there is the need to consider entirely radical solutions, such as hybrid-electric aircraft, which are not fully understood when compared with conventional kerosene driven aircraft. A recent development of a probabilistic set-based multidisciplinary optimisation methodology has demonstrated the ability to explore trade-offs when the requirements are uncertain. In this way, the weaknesses and potential to enable the feasibility of hybrid-electric aircraft can be studied from a systems perspective but maintaining the connection with more detailed trade-off studies of components of the sub-systems. We have developed an interactive interface, where the user is guided through the steps of the design methodology and the produced data is visualised to aid an informative decision-making process. In our illustrative case study, decision-makers are enabled to interactively explore the hybrid-electric propulsion design space while considering the impact to the figures of merit from expected improvements in the coming years of key enabling technologies, such as energy storage.

Value impact assessment for interdisciplinary design

Ola Isaksson, Timoleon Kipouros, ***Dr. Arindam Brahma (Chalmers University of Technology),*** *Massimo Panarotto, Julian Martinsson Bonde, Jonas Kressin, Kristina Wärmefjord, Petter Andersson*

To comply with the desired sustainability goals, aircraft engine manufacturers are having to focus on radically new technologies and methods. This has significantly increased the risk for such companies in terms of cost and lead time. Trading-off risk against desired system performance therefore becomes important, so that both the metrics can be optimised. However, the complexity of such a trade-off is because of the potentially high number of disciplines involved. Value-driven design is a methodology which allows for such interdisciplinary analyses, which we use in this paper along with generative and automated design of experiments to provide decision support for design engineers. We seek to evaluate both system-level impact and cost-driving implications, such as welding, in the same design study. In this paper, we therefore present an approach where value-based trade-offs can be generated by conducting digital experiments involving both product and manufacturability parameters. In these digital experiments, product and manufacturability parameters are varied to generate the trade-offs for hundreds of conceptual design variants. This enables manufacturing and possibly other late-stage lifecycle factors to be considered early in the design stage.

Engineering design of a digital twin: towards capturing a viable digital twin definition

Dr. Slawomir K Tadeja (University of Cambridge), *Jerome Jarrett, Timos Kipouros*

Digital twinning is a term encompassing a number of known and emerging technologies that together can provide high-fidelity replicas of physical systems or processes. Thanks to the feedback loop connecting physical assets with their digital counterparts, digital twins yield unique advantages non-existing when dealing with traditional computational models. However, as in the case of any emerging, not yet fully established, and simultaneously rapidly developing technology, we can observe a substantial amount of confusing terminology and definitions, including varying formulations of what a digital twin is. This, in turn, makes finding use scenarios where digital twins can bring the most benefits challenging. The first step toward capturing the robust definition of digital twins is identifying and determining what components and requirements would constitute a viable digital twin. To do that, we have asked several domain experts a series of design questions. The list included queries such as who is going to be affected by digital twins or when and where digital twins will be used. Asking those types of questions is an established design practice that helped us distill and reason about the digital twin definition as it is understood by the industry and academic experts.

Set-based digital experiments for aerospace business and design: a scalable tool

Mr. Massimo Panarotto (Chalmers University of Technology), *Ola Isaksson, Arindam Brahma, Timoleon Kipouros*

The need to drive more sustainable aviation is moving the aerospace industry to consider new disruptive concepts, both in the technology as well as in the business domain. However, the cost-benefit comparisons between these radical concepts results are difficult today due to the new linkages that are created at the system level. This paper presents the initial architecture and implementation of a tool conducting digital experiments of business and design alternative sets. The use of the tool is demonstrated in a case study related to an aero-engine component. In the case study, the cost-benefit impact of the performances, weldability, and supply chain resilience of new concepts are automatically generated and simulated. The results point at the flexibility of the tool to run extensive and automated digital experiments for both business and design, fostering collaborative decision making between business and engineering.

Advanced non-linear models for the design of deployable composite space structures

Dr. Enrico Zappino (Politecnico di Torino), *Erasmo Carrera, Riccardo Augello, Matteo Filippi, Alfonso Pagani, Marco Petrolo*

Future space missions aim to bring back robotic devices and astronauts to the moon and later to Mars. Such challenging goals require overcoming the actual state of the art in many engineering fields and developing innovative solutions able to fulfill the mission requirements. The lightness and compactness of the spacecraft have always been a key aspect of space applications since the volume and payload offered by the launchers are limited. A promising technology that offers a huge reduction in the volume of large space structures is the use of deployable/inflatable structures. These structures can be folded in a small volume during the launch and then can be deployed during their use in space. Even though some demonstrators or small applications have been used in the last years, this technology is still far to be considered reliable to be applied in primary structural components. The design of these structures, especially when they are built using composite material, is very challenging since common numerical tools fail in the prediction of their response. The ineffectiveness of classical analytical approaches can be blamed on the laminated nature of these structures, the extremely low thickness, and the highly non-linear response. The present work proposes the use of advanced numerical models, derived in the framework of the Carrera Unified Formulation, to design composite boom typically used in large space structures such as antenna or truss structures. The present models, one- and two-dimensional, take advantage of an enriched kinematic approximation that led to accurate results even in the case of laminated structures. Equivalent single layer and Layer Wise models of different orders have been considered exploiting the convenient formalism offered by the Carrera Unified Formulation. A total

Lagrangian formulation has been used to derive an efficient nonlinear model able to predict large displacements of composite structures. Different geometries and materials have been considered and the results have been compared with those from literature. The results show the great advantages offered by the use of higher-order models since they can provide accurate three-dimensional solutions with a fraction of the computational cost required using a classical approach.

Session Chair : Prof. Yi Qin (University of Strathclyde, UK) & Dr. Sergio Durante (D4S Group, Spain)

EU FAST-SMART project - Objectives and Approaches for the development of sustainable smart materials, structures and systems for energy harvesting

Dr. M. Rostagno, Dr. A. Malagnino (GAE Engineering), *Prof. Yi Qin (University of Strathclyde)*

FAST-SMART is an international European project funded by EC that gathered together for 48 months top-rated universities, research centres and companies expert in materials, solar panels and transport systems. The objective of the project is to improve the efficiency of the energy conversion process from alternative forms of energies generated by our surroundings (e.g. light, heat, mechanical vibrations) to energy that we can reuse to feed our devices, such as sensors and solar panels. This process is called ENERGY HARVESTING. Energy harvesters are relatively new devices and, at the moment, it is possible to obtain only small amounts of energy. However, these small amounts of energy can already power small devices without the need for plugging them.Energy harvesting is beneficial to our environment because reuse natural forms of energies that otherwise would be dissipated or wasted. At present energy harvesters are produced using toxic material (such as Lead) and other strategic materials classified as Critical Raw Materials (such as Titanium) available in limited quantities in Europe and making our continent vulnerable and dependent from external sources. FAST-SMART project aims to develop energy harvesters based on new materials without elements that can harm our planet or elements no present in Europe mining portfolio. In particular, two categories of energy harvesters will be innovated: piezoelectric and thermoelectric ones. They will be tested in three application fields: sensors for railway track vibration monitoring, solar panels and hybrid engines. FAST SMART project will bring innovation not only in materials but also in the assembly steps, with more efficient low energy consumption synthesis process and faster assembly techniques.

Development, optimisation and testing of a hybrid solar panel concept with energy harvesting enhancement

Amrutha Pattath Saseendran, ***Prof. Christoph Hartl (TH Köln)***

Photovoltaics (PV) is one of the important technologies for electricity generation from renewable energies today and has an excellent environmental sustainability. It is a fast-growing market worldwide. Although the efficiency of PV systems has increased to a certain extent in recent years, a predominant part of the solar radiation acting on a PV system is still lost to the environment through reflection and convection as well as heat radiation from the heated PV system. In addition, the efficiency of these systems decreases with increasing heating. Possible solutions for energy harvesting of this energy loss through thermoelectrics (TE) have been investigated theoretically and in part experimentally in various cases, but have not yet been transferred to larger PV systems. At the same time, cooling the PV system through TE allows its efficiency to be increased. This contribution presents first results from investigations into the design and testing of hybrid PV/TE systems, which aim to increase the efficiency and to improve economic manufacturability of such systems. Among others, the influence of important design aspects on the economic efficiency and the enhancement of the functionality of hybrid PV/TE systems through the integration of IoT elements (Internet of Things) is addressed. The research work is part of the FAST-SMART project, funded by the European Commission.

Pilot-scale mechano-chemical synthesis of newThermoelectric Materials

Dr. Alvise Bianchin (MBN nanomaterialia S.p.A.), *Paolo Matteazzi*

Industrial Mechanical Alloying is an effective approach for the synthesis of thermoelectric materials in powder form, that can be then consolidated in legs and utilised for harvesting energy from sources of waste heat. This process of Mechano-Metallurgy, or Mechano-Chemistry, allows wide formulation possibilities combining the metal elements at the solid state thus overcoming the thermodynamic equilibrium of the materials obtained by liquid processing methods. The powders produced with this technique show an ultrafine grained microstructure, typically nanostructured, with a high concentration of dislocations and grain boundaries which helps in de-coupling thermal and electrical conductivity, increasing the overall performances of the TEG. Four different compositions of P/N junctions have been synthesized seeking the most effective combination of properties and costs while keeping sustainability as the main design paradigm. The Industrial Mechanical Alloying performed in MBN nanomaterialia is based on a proprietary plant design that allows effective scalability from hundreds of grams to tens of kgs of powders, which also gives a wide-ranging possibility to generate material systems properly engineered and designed for specific industrial applications and processing forming techniques

New Air Systems for MEA

Frederic Sanchez, ***Ms. Joan Bonhora (AIRBUS)***

The trend towards clean aviation leads to new challenges to the aviation industry and claims the need for more efficient and innovative systems. More electrical systems are key bricks to achieve this target. This paper presents the AIRBUS and Liebherr activities in developing new air systems for integration into a future short and medium range aircraft with electrical system architectures within Systems Integrated Technology Demonstrators (ITD) of the European funded programme CleanSky 2. It will be shown by which methodologies both AIRBUS and Liebherr are developing new architectures and are demonstrating technology readiness levels in order to achieve the emission reduction targets set by the European Union.

Thermal and mechanical investigation of toughened epoxy resins having auto-repair ability based on supramolecular chemistry

Dr. Elisa Calabrese (Univerity of Salerno), *Marialuigia Raimondo, Carlo Naddeo, Luigi Vertuccio, Liberata Guadagno*

Drawing inspiration from biological systems, nowadays researchers are trying to develop a new class of synthetic materials known as self-healing materials that can automatically repair damages, with the aim to increase the durability of the same materials and reduce their maintenance cost. Many efforts have been effectively directed to impart self-healing properties to a broad variety of materials, including polymers or composites. In this work, we propose a formulation based on supramolecular chemistry capable to give auto-repair functionality to epoxy nanocomposites. In particular, in order to develop materials suitable for aeronautical applications, a tetrafunctional epoxy resin has been toughened by a functionalization procedure, which allowed to covalently bond a rubber phase to the epoxy matrix. The performed functionalization was found to be effective in reducing the rigidity of the resin and favouring the activation of self-healing mechanisms. The intrinsic healing ability of the functionalized epoxy matrix has been improved by the addition of "self-healing fillers" which are endowed with hydrogen bonding donor and acceptor sites able to interact with the hydroxyl and carboxyl functional groups of the hosting matrix, through the formation of non-covalent reversible H-bond. Furthermore, multiwall carbon nanotubes have been dispersed into the matrix with the aim to obtain electrically conductive composites. The formulated epoxy samples have shown conductivity values beyond the Electrical Percolation Threshold (EPT) and healing efficiency values higher than 60%, at room temperature. Thermal and mechanical investigations demonstrated the success of the proposed self-healing strategy which made it possible to take a further step forward the development of smart structural composites.

Nanoscale electrical performance of multifunctional carbon fiber reinforced panels

Dr. Marialuigia Raimondo (University of Salerno), *Liberata Guadagno*

The objective of this work is the investigation of the electrical current map by Tunneling Atomic Force Microscopy (TUNA) of carbon fiber-reinforced panels (CFRPs) impregnated with a multifunctional epoxy formulation. In particular, the formulation has been suitably designed to improve the flame resistance properties and contrast the electrical insulating properties of the epoxy resin. TUNA investigation was performed on the panels before and after the etching procedure for a more effective comprehension of the morphological features of the panels. The multifunctional panels were manufactured by an appropriately modified resin film infusion (RFI) process. TUNA acquisitions were carried out to evaluate the validity of the implemented infusion process. The effects of the different ply numbers (7, 14 and 24) on the TUNA electrical performance were assessed (see Figure 1). In particular, TUNA technique, which is able to detect ultra-low currents ranging from 80 fA to 120 pA [1-3], allowed the identification of the conductive paths which are represented by carbon nanotubes that are tightly attached to the carbon fibers with the typical tendency to accumulate in the areas through which the passage of the resin happens due to the specific infusion process. In this work, for all the manufactured panels, TUNA current images highlight the presence, between the layers of carbon fibers, of conductive three-dimensional networks of MWCNTs that take part successfully to ensure the good electrical performance of the multifunctional panels.

Development of a new generation of composites with Self-responsive functions: Self-sensing, Self-heating and Self-curing

Dr. Luigi Vertuccio (University of Salerno), *Michelina Catauro, Roberto Pantani,Liberata Guadagno*

This contribution deals with the design of composites having integrated self-responsive functionalities based on nanostructured forms of carbon, such as multi-wall carbon nanotubes and expanded graphite. In particular, the study focuses on three different smart functions strongly desired in the field of aeronautical materials: self-sensing, self-curing and smart thermal management. These responsive functions are based on two physical phenomena: the piezoresistivity (changes in the electrical resistivity of the composites resulting from mechanically applied strains) and the Joule effect (heat generated by the current flow through the composite). In the first case, the adopted approach allows the detection of micro-damages in the materials that a visual inspection is unable to detect. In the second case, the heat generated through the joule effect allows avoiding the ice growth on the most vulnerable parts of the aircraft. In the third case, the heat generated through the joule effect in the uncured filled resin is exploited to promote polymerization reactions of the resin (electro-curing). The results evidence that this last methodology can be really very effective, highlighting different advantages with respect to the polymerization of the resin in an oven or autoclave. It is a save-energy process that allows a higher curing degree and as a consequence a better mechanical performance with respect to traditional curing processes.

Ballistic self-healing capability of polymeric materials for aeronautical applications

Mr. Raffaele Longo (University of Salerno), *Luigi Vertuccio, Francesca Aliberti, Marialuigia Raimondo, Michelina Catauro, Roberto Pantani, Liberata Guadagno*

Among all the smart functionalities, self-healing has gained a raising interest in literature over the last few decades. Designing materials with the capability to recover partially or totally their integrity, the lifetime of objects is longer, their use is safer and, simultaneously, the material waste and energy consumption are reduced. In this scenario, polymers in the form of ionomers and copolymers are a valid example of intrinsic self-healing thermoplastic material since, without adding any external healing agent, a thermal stimulus allows a spontaneous restoration of the material integrity after a ballistic impact. This smart functionality makes these polymers suitable for multilayer composites for spacecraft debris protection shields and self-sealing layers in tank reservoirs for low-velocity impact. The present study is aimed at exploring the healing mechanism of this new class of polymers and to understand their applicability according to the aeronautic needs and which are the current limits for their implementations in aeronautical structures.

3D printing of self-responsive polymers for aeronautical applications

Ms. Francesca Aliberti (University of Salerno), *Marialuigia Raimondo, Raffaele Longo, Roberto Pantani, Luigi Vertuccio, Andrea Sorrentino, Liberata Guadagno*

In the present work, a new category of cutting-edge devices for aeronautical applications involving the innovative production process of 3D printing is presented. As an additive manufacturing, 3D printing allows producing objects with complicated shapes simply by adding the building material layer by layer without any material waste and any molds. Among several 3D printing technologies, the Fused Deposition Modelling (FDM) is the most suitable one in the field of thermoplastic materials [1]. With respect to the current literature, the present study aims to extend this technology to self-responsive materials, able to sense external stimuli appropriately [2]. In particular, promising 3D printed self-heating objects have been made of nanocomposite material (Acrylonitrile-Butadiene-Styrene ABS filled with Carbon Nano-Tubes CNT) via FDM. In this case, the external stimulus is the electrical current flowing inside the printed item, while its response consists of an increase in temperature by the Joule effect. Moreover, the electrical properties have been tailored by properly determining the direction of printed filaments allowing the management of the generated heat in different zones of the printed object. The phenomenon of filler orientation in the printing direction has been well documented by properly mapping the distribution of conductive filler and correlating it to the electrical properties of the whole sample.

Mechanical behaviour for aeronautical structures with embedded electric cables under low energy impact

Jean Christophe Walrick (ESTACA), *Thibault VOGEL*

Aerospace manufacturer like Airbus Group has been working on the development of new, innovative and more robust technologies so as to reduce the costs associated with wired networks installation. In this framework, the integration of electrical wires within composite structures gets a real interest. Indeed, the main advantage of embedding electrical wires inside a composite structure is to reduce time on the line as the installation and segregation of the wiring as already been pre-completed. Besides, it confers a protection to the electrical systems from environmental conditions and enables increasing the ratio of electrical functionality to volume, hence leading to significant mass and volume savings. The presentation will deal with the work done by Mr Thibault VOGEL in the framework of his PhD which aims at study such a structure, and as been motivated by a specific use case designed for launcher applications. The foreseen multifunctional structure consists in a composite beam embedding flat electrical cables for power and data transmission. This work investigates the influence of mechanical shocks which may occur during transport and handling operation (drop tools for instance) and temperature on the mechanical behaviour and failure modes of such a structure. The main question is the damage involved by the low level impact, and the influence of the electrical cables layer. The sensitivity of the material to low energy impact leads to failure with no external signs of damage and insulation degradation between adjacent conductors. Experimental campaign by drop tower test are carried out for energy level between 10 and 25 Joules. An hemispherical impact tool (10Kg drop weight) is used for ponctual impact on the top of a clamped specimens with electrical cable layer embedded or without (similar blank). The comparison of the dynamic contact force history curves shows a much more « ductile behaviour » with lower peak contact and higher impact durations (up to 5ms) for specimen with cable layer embedded. The non-linearity is mostly associated to both sliding and inter-laminar damage among the embedded cables. Numerical finite element modelling is achieved to reproduce the damage observed experimentally. It is based on composite progressive damage law coupled with Hashin failure criterion for each composite ply. The embedded cables are given a linear anisotropic behaviour and modelled similarly to a composite ply. Adhesive elements are used to model delamination damage and the sliding between ply at the interfaces. Models for blank and multifunctional material show similar evolutions as compared to the experimental data, as well as the distribution of tensile strains, damage initiation and failure progression across the stacking sequence of plies. This study aims at identifying some mechanical criteria for geometry improvement of functional structures embedding electrical functionalities (electromagnetic compatibility, data & power transmission, etc.).

Self-healing systems for aeronautical application

Dr. Simona Russo (Università Degli Studi Di Salerno), *Annaluisa Mariconda, Elisa Calabrese, Marialuigia Raimondo, Liberata Guadagno, Pasquale Longo*

In order to extend the lifespan of materials, great interest is being turned to the development of self-healing systems. They are smart materials since they have the ability to independently trigger the repair processes by hindering the propagation of microcracks that are generated due to mechanical, chemical or thermal actions. The aviation industry is particularly interested in making composite materials with self-healing ability because they lead to the reduction of fuel costs and overcome difficulties connected to damage diagnosis and repair. Depending on the different approaches that have been investigated to integrate self-healing ability in several matrices, self-repairing systems can be classified in Extrinsic and Intrinsic.

Extrinsic self-healing materials are based on the dispersion of microcapsules or vascular channels containing healing agents within the matrix of interest. When the crack occurs in the material, the microcapsules or vascular channels rupture, causing the release of the healing agent that, first, diffuses along the damaged area and, subsequently, reacts chemically in order to effectively repair the crack. The main problem of microcapsule-based extrinsic systems is that, once repair by leakage of the healing agent has occurred, a new repair cannot occur at that same site. For this reason, the scientific community has been working for a few years on replacing these systems with simpler ones based on reversible interactions, which allow for multiple rounds of repair at the same site. One of the most studied interaction for the realization of self-healing systems is hydrogen bonding.

With this contribution we want to describe our composite self-healing system for aeronautical application. We synthesized copolymers based on methacrylic monomers with different percentages of urea-N-2-amino-4-hydroxy-6-methylpyrimidine-N'-(hexametylen-n-carboxyethyl methacrylate) HEMA-Upy such as 2.5, 5.0 and 7.8 wt %. By dispersing these copolymers, into the epoxy matrix selected for aviation applications, it is possible to impart self-healing ability to the resulting composite material, thanks to the quadruple hydrogen bond interactions between the polymer chains.

ecoDESIGN and Sustainable Productivity: Part I

Session Chair : Dipl.-Ing. Torsten Moll (Fraunhofer-Gesellschaft, Germany)

ecoDESIGN and Sustainable Productivity

Dr. Torsten Moll (Fraunhofer-Gesellschaft), *Rainer Schweppe*

The European aeronautics industry has a large environmental and socio-economic relevance. Its sustainability, productivity and competitiveness will strongly depend on the innovation steps to make economic value and ecologic value come together. Looking at aviation as circular economy, all life cycle phases must be considered closing the loop from end-of-life to material production. Sustainability of materials, processes and resources, efficient manufacturing, lifetime services and the end-of-life challenge will drive the competitive value in the context of environmental services. The presentation provides an overview about the ecoDESIGN Transversal Activity in the Clean Sky 2 programme. This includes an outlook on selected activity domains and demonstrations in scope. The presentation is also the introduction into the EASN Conference Session on ecoDESIGN and Sustaineble Productivity.

ecoDESIGN in Next Generation Aircraft Fuselage

Ms. Marta Solares Canal (Airbus Operations), *Torsten Moll, Laura Costa Lopez, Ralf Herrmann, Piet-Christof, Wölcken, Carl-Christoph Höhne, Peter Brantsch*

Sustainability and competitiveness of next generation large scale aircraft structures will strongly depend on their environmental footprint along the full life cycle. This particularly includes design, materials processes and resources, manufacturing and production, lifetime services as well as recycling and end-of-life for disruptive concepts and innovation. This presentation provides an overview about the implementation of ecoDESIGN in the Multi Functional Fuselage Demonstrator as part of the Clean Sky 2 and introduces a morphology for the LCA Analysis and a first approach to preliminary environmental results. Detailed presentations on contributing projects will be presented separately as part of the EASN Conference Session on ecoDESIGN and Sustainable Productivity.

Stiffened thermoplastic aircraft structures by integral stiffening concepts and continuous ultrasonic welding

Mr. Senne Sterk (Royal Netherlands Aerospace Centre -NLR), *Jan Halm, Bram Jongbloed, Irene Fernandez Villegas*

Composite materials are well established in the latest generation of aircraft, from small clips and brackets to primary structures. For these structures, mostly thermoset matrix systems are used. Thermoplastic resins offer a great potential for even lighter, cost-efficient and more eco-compliant aircraft due to their weldability, toughness and recyclability potentials. Welding can be used to avoid riveting, which minimizes the weight of the structure and increases the recyclability allowing the re-use of material in new components. Within the EcoTECH project, part of Clean Sky2, we explored the application of thermoplastic composites with the aim to reduce energy consumption during manufacturing. We focussed on novel heating technologies for fibre placement and consolidation, stiffening concepts for aircraft structures, increasing the recyclability by using scraps, the low-energy consuming continuous ultrasonic welding process and efficient thermal repair of damages.

In this paper we focus on the topics of innovative stiffening concepts and a welding technology for rivetless assembly. For rivetless assembly, Delft University of Technology (TUDelft) focused on a continuous ultrasonic welding process with low energy consumption with the aim to produce long continuous seems on carbon/PPS coupons and an omega stiffened wing panel. The Royal Netherlands Aerospace Centre (NLR) work presented is focused on the design, manufacturing, and testing of a thermoplastic orthogrid stiffened fuselage section. Continuous ultrasonic welding was shown to be a very suitable technique for making continuous seams to join thermoplastic composite structures. During the welding process a metal horn called sonotrode applies mechanical vibrations to the to be welded parts. The placement of an energy director, a resin rich layer, in between the two parts focusses the heat generation at the welding interface. The research showed that an energy directing mesh increased the weld uniformity. Fully welded seams were obtained at fast welding speeds. To reduce porosity and increase the strength a consolidation shoe was introduced in-line with the sonotrode, resulting in high strength and high-quality welds. Additionally, a round sonotrode design was introduced that would enable the welding of single curved parts. The welding technology was demonstrated on an omega stiffened demonstrator panel. For the orthogrid panel a flat shear panel was developed first. Finite element analysis was used to optimise the layup of the skin and the dimensions of the ribs. A state-of-art automated fibre placement process was used to place the skins and ribs as a single part. Next, the panel was autoclave consolidated. Energy consumption was measured during all production steps. During the shear test the panel failed at a lower load compared to the simulations. This was traced back to manufacturing induced effects like panel distortion, gaps between crossing tapes at rib crossings and porosity. These effects were incorporated into the simulation together with more realistic assumptions and boundary conditions which improved the match between the test and predicted failure. Currently, a larger single curved thermoplastic orthogrid structure is being manufactured which will be tested in the second half of 2022.

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Energy Consumption of Autoclave Curing using Semi-empirical Thermodynamics Based Model

Mrs. Chizoba Josphine Ogugua (Delft University of Technology), *M.D. Larrabeiti, J. Sinke, C.A. Dransfeld*

Autoclave curing is a conventional curing/consolidation method used for fabricating primary aircraft structures. The controlled pressure and temperature in an autoclave result in parts with high fibre-volume content and low voids [1]. Despite its benefits, autoclave curing is one of the most energy consuming processes in CFRP manufacturing [2]. To improve the energy efficiency of autoclave curing, one needs to understand its energy usage and factors that influence it. This work presents a semi-empirical thermodynamic based model to first estimate the energy consumption of an autoclave during curing and also distribute this energy to the different elements contributing to it. This include heat flow to the laminate stack and the autoclave body, the heat absorbed by the gases and heat loss through the autoclave wall. By combining Fourier heat equations with adequate boundary conditions and preset cure parameters, the energy consumption of an autoclave was estimated. Results from the model was compared to an energy log from a case study experimental study and less than 17% difference was noted. The results obtained from this study also showed that the energy required to heat up the entire autoclave body and to compensate for heat loss, summed up to 97% of the total energy consumption during cure. While the energy required to heat up the composite-mould assembly only accounted for

2.9% of the total energy consumption. This showed the low energy efficiency of the autoclave process. The next step was to investigates the influence of design and process parameters on autoclave energy consumption. This was achieved by varying the values of process parameters and noting the resulting changes in energy consumption. By doing this, parameters that significantly influence the energy consumption of autoclave curing were identified. Results show that the temperature cycle and autoclave volume were the most influential parameters followed by the insulation thickness and conductivity. In summary, the model developed in this study is parametric and scalable which makes it easily adaptable to various cure cycles and production scenarios. They can be used to generate energy inventory to serve as inputs in cost estimations and life cycle assessment studies. The results obtained can also serve as a guide to future energy reduction targets as they provide insight into possible design and process changes that can improve autoclave energy efficiency.

Development of a framework to support the preliminary design of eco-efficient aircraft structural components

Mrs. Natália Cristina Gomes de Paula (Delft University of Technology), *Christos Kassapoglou, Roeland De Breuker*

The transition to more environmentally sustainable aircraft systems has required the adaptation of the current design methods. Without tools that allow for the quantification of sustainability aspects and trade factors with performance-related capabilities, sustainability-oriented solutions are likely to be overlooked. Hence, this study introduces an eco-efficiency approach to guide the manufacturing technology selection for application in aircraft composite structures. In this context the term manufacturing technology generically designates a combination of candidate design concept, material system, and manufacturing route. For each technology, the boundaries of the design trade-offs are determined based on a methodology that couples mechanical, economic, and environmental performance assessments. Technical performance evaluation and structural sizing of the part are carried out using analytical and semi-empirical methods. The set of sizing variables includes the laminate layup sequence, the thickness, and the geometry of the individual structural components. All designs shall comply with general laminate design guidelines, manufacturing constraints, and design allowables, as set by the user. Each structural member is checked for buckling and material failure under the assumed load combination. Mass estimations are performed at each iteration of the sizing process and are a part of the multi-criteria evaluation of the design. The eco-efficiency assessment combines an activity-based technical cost model with a process-based life cycle assessment. A preliminary manufacturing plan is used to describe the main activities involved in the fabrication and assembly of the part. Process models are sourced from the literature and managed through a database. The process cycle time is a key parameter in the calculation of the manufacturing costs and it strongly depends on the part's geometric attributes and complexity. Cost estimations are also affected by the assumed operational and financial scenarios. This includes aspects such as resource availability, interest rate, and the unit cost of resources. The final cost of a part is composed of labor, material, equipment, tool, and electricity costs. Evaluation of the environmental footprint is performed with the open-source software OpenLCA. The generation and calculation of the product system is parameterized and information shared by the cost module is automatically transferred. Single scores and selected midpoint indicators, e.g., climate change, are used to rank the manufacturing technologies.

The application of the developed bottom-up framework is also exemplified by a case study that discusses the design of a vertical tailplane torsion-bending box. Two design concepts are compared: a skin-stiffened structure and a sandwich structure, both fabricated with automated tape laying and mechanically assembled. Effects of the internal topology on the structural mass and on the eco-efficiency indicators are also investigated. Variations in layout include changes in rib spacing and in stringer pitch, shape, and dimensions. Preliminary cost analyses suggest that material and tooling contribute most to the overall manufacturing cost. As a result, the most cost-effective layout is not equivalent to the most time-effective design in the investigated scenario. Ultimately, the aim of this case study is to gain insight into how eco-efficiency metrics affect the design of structural parts and demonstrate the importance of early consideration of such trade-offs.

Replacement of Hexavalent Chromium an LCA Study

Mr. Ali Bahwan (Leonardo Company Aircraft)

The work is part of the Clean Sky 2 REG IADP part of the JTP receiving funding from the Clean Aviation Joint Undertaking under the European Union's Horizon 2020 research and innovation program under Grant Agreement n ° 945548 REGIONAL AIRCRAFT. Hard Chrome Plating is a key process which treats components for enhanced hardness, durability and corrosion resistance. While the technology is proven, it is extremely energy inefficient, and incorporates the use Cr(VI), an extremely hazardous chemical which poses risks to both the handler and the environment, this also increases disposal costs, and the total embodied emissions of the process, due to these concerns it is important to assess alternative technologies to achieve the required performance. Thermal Spraying technology namely High Velocity Oxygen Fuel (HVOF) is an appealing substitute, which could satisfy requirements, while increasing energy efficiency and eliminating the use of Cr(VI). The merits of HVOF compared to Hard Chrome Plating in the treatment of steel pins were explored, with a focus on the reduction of toxic waste, energy usage and costs, and conformity to REACh regulations. Life Cycle Inventories and flow charts were produced for each technology, and a Life Cycle Analysis study was performed comparing both technologies. The materials used, energy expenditure, emissions produced and waste materials at each stage of the process were evaluated. The data was gathered through measurements where possible, and theoretical calculations coupled with estimations when necessary. It was then processed into relevant normalised indicator groups. It was found that the switch to HVOF would decrease water pollution and Eco-toxicity, aligning it better with regulation. However, it would increase the Energy Demand significantly while also producing more dust during the process when compared to Hard Chrome Plating, causing an increased hazard on Human Respiratory Health. Certain aspects such as waste stream management were not considered in the model, and thus further detailing will be required for a more comprehensive understanding. Whilst the LCA gives HVOF merit as potential future alternative to reduce exposure to harmful chemicals, nevertheless there was an increase in Primary Energy Demand arising from the powder procurement and processing stages. Potential solutions and paths of research have been outlined to be the topic of future investigations on the maturation of Thermal Spraying from a research technology to a fully-integrated and industrialized one.

Enhanced ecological analysis of aircraft using a combined approach of life cycle assessment and discrete-event simulation

Mr. Kai Wicke (Deutsches Zentrum für Luft- und Raumfahrt e.V.), *Antonia Rahn*

With growing environmental awareness and the resulting pressure on aviation, environmental impact assessment is becoming an increasingly important issue. Life cycle assessment (LCA) has been widely used in the literature as a tool to assess the environmental impact of aircraft. However, due to the complexity of the method itself as well as the long lifespans of aircraft, most studies so far have made strong simplifications, especially concerning the operational phase. By combining the LCA with the approach of a discrete-event simulation, the ecological assessment of the operational phase in particular is enabled with a higher level of detail. In this case, a special focus is put on maintenance. Apart from mapping the ecological footprint of individual maintenance activities, such as individual checks, the discrete-event simulation can also be used to map the secondary effects of maintenance (e.g. reduced fuel consumption due to an engine wash). Beyond the investigation of conventional aircraft configurations, the developed simulation framework is also used for the environmental life cycle assessment of new aircraft configurations, such as hydrogen-based aircraft and their system architectures. In this context, technological changes in the propulsion system, energy management or energy storage require new approaches in maintenance. Due to the given flexibility of the discrete-event simulation, maintenance events can be modified accordingly (e.g. change of a fuel cell based on a given interval) or new ones can be added. By means of the integrated LCA, the ecological effects can then be accounted over the entire life cycle and used for decision-making.

ecoDESIGN and Sustainable Productivity: Part II

Session Chair : Dipl.-Ing. Torsten Moll (Fraunhofer-Gesellschaft, Germany)

A notional engine model approach to address Aircraft Engine Life Cycle Assessment

Kilian Fricke, ***Dr. Maud Lemagnen (Safran Aircraft Engines),*** *Torsten Moll*

Life Cycle Assessment (LCA), based on ISO 14040/44, actually stands as the reference method-ology to assess systems' environmental impact along their lifecycle. Result's analysis notably may lead to the system ecodesign improvement. Nevertheless, LCA requires a huge amount of data input to supply relevant results and the exercise becomes very intense regarding complex system's assessment, such as an aircraft engine. Literature provides a few Aircraft Engine's LCA, which perimeter and assumptions have been very simplified. They lead to macroscopic results that can be controversial when dealing with ecodesign application. Engines ITD, within Clean Sky 2, provides different engine's parts LCA. Regarding Engine LCA state of the art, a question is raised about the opportunity of such studies exploitation: how can results from specific parts could be used and extrapolated to a larger scale component? Our study proposes to set up a methodology to use Part LCAs in order to achieve a notional Engine LCA. The study step will notably address the following key elements:

- How do we link part LCA functional unit to Engine Functional unit, in order to aggre-gate results?
- How do we assess the part's engine representativity and coverage in order to define a repartition key from part's LCA results to a global engine view?

Our proposal will be illustrated by a case study lying on Blisk LCA results.

Life Cycle Impact Assessment of Engine Blisk-Manufacturing

Mr. Kilian Fricke (Fraunhofer-Gesellschaft), *Thomas Bergs, Philipp Ganser, Sascha Gierlings*

The aviation industry has been growing continuously over the past decades. To ensure sustaina-bility and competitiveness for aviation industry, a full understanding of the environmental impacts is required, not only during use phase but along the entire life cycle including Materials, Processes and Resources, Manufacturing and Production, Lifetime Services as well as Reuse, End-of-Life and Recycling. Core engine components, for example integral rotors (Blisks), are comprised of high value metallic alloys that require complex and resource consuming manufacturing processes. The presentation and full paper deals with the methodology and approach for a full size Blisk Life-Cycle-Assessment based on ISO 14040/44. While previously published EASN-papers focussed on the first two stages within an LCA namely the "Goal & Scope Definition" and the "Life-Cycle-Inventory", this publication deals with the "Life-Cycle-Impact-Assessment" and "Interpretation" steps. This includes an overview of the LCI-modelling, the selected impact categories, as well as a presentation of preliminary LCA results for a Blisk-manufacturing process chain. The work is part of the Clean Sky 2 ecoDESIGN Transversal activity and Engines ITD.

CFRP Recycling Demonstrators for Engine Applications

Mr. Ronny Hanich-Spahn (Fraunhofer-Institut für Chemische Technologie ICT)

Carbon fibers are widely used in carbon fiber reinforced plastics (CFRP) for aviation, automotive, windmills, sport and many more application due to their outstanding material properties. Annually, this generates about 62,000 tonnes of end-of-life (EoL) CFRP and CFRP production waste. Current EoL scenarios for CFRPs show some disadvantages: Landfilling and incineration are not sustainable and environmentally friendly. Carbon fiber recovery by pyrolysis damages the carbon fibers and incinerates the plastic material. Mechanical recycling shortens the carbon fibers and is of limited value for thermosets. However, chemical recycling routes like solvolysis offers the great potential to recover damage-free carbon fibers as well as useful monomers for a new generation of plastics. This presentation provides an overview about the solvolysis of carbon fiber reinforced polyurethane material for aviation applications. Additionally, first life cycle assessment results will be presented.

Performances of composites made from different recycled carbon fibres semi-products

Mr. Alexandre Faure (Université de Bordeaux), *Olivier Mantaux, Arnaud Gillet*

Recycled carbon fibres (rCF) are chosen for their low price and environmental features. However, performances of composites made of recycled carbon fibres are often too low to compete with lightweight alloys and composites material. As performances of rCF composites depend on the fibre architecture and their physical characteristics, new semi-products with long and aligned recycled carbon fibre were developed by MANIFICA (Cleansky European Project). The use of long (250mm) and highly aligned recycled fibres now provides rCF composites excellent mechanical properties.

The purpose of this document is to assess performances of composites manufactured with these new rCF semi-products. Semi-products with distinct architectures developed by MANIFICA are first presented. Then mechanical performances of composites coupons manufactured from the different semi-products are evaluated. Results are finally compared in order to identify the effect of the diverse manufacturing parameters of the semi-products on the final composite properties. These crucials information will allow end users to select the right semi-product to design new recycled carbon fibre composites.

Simplification of requalification procedure of outdated carbon/epoxy prepregs and scenarios of reuse

Mrs. Constance Amaré (Université de Bordeaux), *Olivier Mantaux, Arnaud Gillet, Mathieu Pedros*

As a result of their combined high mechanical performance and easy shapability, carbon/epoxy prepregs are widely used in the manufacture of aerostructures. They contain a fibrous reinforcement with a resin in an intermediate cured state and must be stored at -18°C. Two expiry dates are indicated for these semi-finished products: a “out-life” corresponding to the maximum life at room temperature and a “shelf-life” corresponding to the maximum life at -18°C. The Covid-19 crisis led to the reorganisation of the aviation sector and thus the generation of a larger quantity of prepregs that are reaching their expiry date and cannot be used. When a prepreg reaches its expiry date, requalification can be carried out in order to reuse it, but this procedure remains complex and expensive. This is why it is often chosen to send the expired prepreg to landfill. The objective of the European project MANIFICA is to set up the recycling chain of carbon fibre composites “from aeronautic waste to innovative composite parts”. The aim of this work is to make requalification simpler by avoiding unnecessary tests. These studies are illustrated by results obtained on different types of aged prepregs compared to the same compliant prepreg. Results reveal that, in most cases, aging provoke shaping difficulties while mechanical performance remains stable. It is estimated that prepregs can be reused without high loss of performance after shelf life exceeding. Rather than considering expired material as waste, MANIFICA offers reuse scenarios.

Implementation of a holistic MCDM approach to assess and compare novel aircraft fuel technologies towards sustainable aviation

Dr. Dionysios Markatos (Department of Mechanical Engineering and Aeronautics, University of Patras), *Spiros Pantelakis*

To reduce the environmental impact of aviation and achieve the emission-reduction goals of Flightpath 2050, an increasing interest to emerging aircraft technologies is given during the last years. In this context, novel fuel technologies, such as sustainable aviation fuels (SAFs), hybrid-electric or hydrogen propulsion systems, demonstrate the potential to enable a more efficient and sustainable aviation. The inherent differences and characteristics of these technologies create new possibilities for aircraft design; consequently, assessment of the impact of different integrated aircraft technologies may result in several indicators and metrics which are rarely in the same measurement units due to their multidimensional nature, and their individual assessment may lead to contradicting conclusions. To simplify the assessment process and support decision-making, multi-criteria decision making (MCDM) methods are required. Although MCDM have been already applied in the aviation industry for the evaluation, selection, or ranking of different aviation-related solutions at the fleet, airport and ATM level, their application at the aircraft level is very scarce. Moreover, there are no accepted selection parameters in the literature and relevant studies have been found to compare different aircrafts based on different parameters. The current work aims to propose and motivate the use of a holistic methodology as a valid and sound framework for dealing with the assessment and selection of new aircraft fuel/propulsion technologies, towards sustainability goals. To this end, an MCDA model/tool already implemented by the authors to support material selection in a future hydrogen-fueled aircraft [4] is extended and adapted to the aircraft level, towards assessing the overall impact of novel aircraft fuel technologies with regards to technological, environmental and economic aspects, and consequently support an aircraft type selection. The MCDA model combines the Analytic Hierarchy Process (AHP) to derive the weights, and an appropriate aggregation method in order to integrate appropriate indicators into a single index, reflecting a trade-off between potentially contradicting criteria and results. The said tool provides practicality, flexibility and applicability, offering simplified comparisons and rankings of emerging fuel technologies in aviation, which can be used as starting points for further analysis and discussion, towards paving the roadmap for climate neutral air transport by 2050.

ecoDESIGN and Sustainable Productivity: Part III

Session Chair : Dipl.-Ing. Torsten Moll (Fraunhofer-Gesellschaft, Germany)

Aircraft Recycling and Circular Economy

Dr. Thomas Reichert (Fraunhofer ICT)

Research for Recycling and Circular Economy has a long tradition in Fraunhofer; e.g. are the Circular Economy Symposia in the early 90-ies and the new Aircraft Recycling Symposia starting 2013. What are the main tasks at the aircraft end of life?

1. decommissioning,
2. careful disassembly and
3. dismantling.

For economic and ecological reasons, the aim is to achieve the highest possible percentage of reuse and recycling rate. In the case of recycling, a distinction is "differentiate between the use of secondary components and secondary raw materials". Accordingly, a distinction can also be made between a component recycling quota and a material recycling quota. Current aircraft achieve a recycling rate, based on mass, of between 60 % and 85 %, and the aim is to achieve more. In the presentation several Clean Sky projects were introduced to develop and improve the recycling routes of the varios materials used in aircraft components. The presentation will show how the projects are linked to a central cooperation recycling.

Circularity studies on high performance thermoplastic demonstrators for the aircraft industry – End-of-Life concepts for PEKK/carbon fibre composites

Mr. S. Coskun (Altran Deutschland), L., A. S. A. Prado, T. S. G. Das, A. Kötter, S. Sterk, J. Halm

Thermoplastic reinforced polymer composites gained a considerable deal of attention in the aircraft industry, due to their unique set of properties, such as outstanding mechanical, thermal, and chemical stability, possibility of automatic or advanced manufacturing and finally the strong potential for recyclability. In this respect, high performance matrices like poly (arylene ether ketone)s (PEK), poly(arylene ether ether ketone) (PEEK) and most recently poly(arylene ether ketone ketone)s (PEKK) have been receiving a great deal of attention. In a world aiming at reducing the carbon footprint, the use of such materials cab be critical despite the evident advantages due to their lightweight and good strength and stability. In the case of PEK, PEEK and PEKK, the polymerization processes require monomers, which are strongly dependent on fossil fuels cracking processes, which can represent a risk for the supply chain of these materials. Moreover, the polymerization proves often requires also high temperatures and use of aromatic hydrocarbon, which in turn depend also strongly on the crude oil refining process. Finally, the carbon fibers themselves have a considerable carbon footprint, as those are often produced by the pyrolysis and graphitization of poly(acrylonitrile) polymer precursors. Apart from the energy consumption, the elimination of cyanide gases are drawbacks for the use manufacturing of high strength carbon fibres. One evident solution is the reuse of reinforced PEEK, PEK and PEKK parts through a range of end-of-life strategies. Apart from the performance of the recycled/reprocessed parts, there has been little attention paid to modelling or quantifying the efficiency of the recycling processes for PEKK-reinforced composites. In this work we report our initial results on the recyclability of the different end-of-life concepts for PEKK reinforced with high performance carbon fibres. We have two scrapping technologies (electro-mechanical fragmentation and grinding) investigated by NLR and we present several additional approaches, which might be practical for increasing the feed-stock circularity.

For this study, the End-of-Life scenarios for the short fiber window frame and the window frame with continuous fibers are considered to be similar. After the use phase of around 30 years, 70% of the material should be disposed as waste and it is assumed that only 30% of the window frame can be recycled because of the mechanical degradation during use. They can be remanufactured through the compression moulding process for a recycled window frame or other non-structural parts. This cycle can be carried out only once, afterwards the material properties change again. Since mechanical grinding has very low efficiency, the circularity of this scenario was limited. Even if alternative recycling options were considered, the circularity could be increased circa 7% compared to the window frame with continuous fibers. On the other hand, if only electro-dynamical fragmentation (EDF) was used, the circularity increased significantly, since the efficiency of EDF almost 10 times higher than that of mechanical grinding. After that, further scenarios were evaluated with higher recycling efficiency and/or higher recycling ratio after use. According to this, it was determined that a 10% increase in recycling efficiency results in approximately 1% increase in circularity, whereas the same amount of increase in recycling ratio after use results in circa 5% increase in circularity. This clearly showed that in high efficiency processes, the recycling ratio plays a more crucial role in the whole circularity of the product. As a result, the focus for improvements should be on the prevention of the waste for a more circular material flow. For the recycling of the orthogrid stiffened panels, the material properties also change during the recycling; hence, it is defined as down cycling. The length of the fibers is too short for further use as structural parts. So, it can be possibly used for secondary parts, such as Window Frames. If 100% of the scrap from the production was to be used for recycling, the circularity only increased 0.6%, since the amount of the scrap from the actual production process was low. Unlike the window frame, here 100% of the product was downcycled after use. Consequently, different scenarios featuring a higher recycling efficiency and/or a higher amount of recycled raw materials were evaluated. According to these estimations, a 10% increase in recycling efficiency resulted in circa 7% increase in circularity, whereas a 10% increase in recycled feedstock caused an approximately 10% increase in the circularity. Based on these findings, it can be concluded that the use of recycled raw materials in production has a greater impact on the circular economy. Accordingly, for the orthogrid stiffened panels, the focus for improvements should be on the evaluation of the alternatives for increasing the amount of the recycled feedstock during the manufacturing.

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Sustainable scrapping method of thermoplastic composite materials

Ms. Rocío Ruiz Gallardo (AIMPLAS), *Alejandro Sandá, Jan Halm, Senne Sterk, Thomas Reichert*

The SPARTA Project aims to develop an innovative recycling method for thermoplastic composites based on mechanical technology and compression moulding processing. The main objective is to maintain the thermoplastic composites high mechanical properties and reduce the amount of scrap in the end-of-life phase and the number of rejected parts during manufacturing processes. The project goal is to reprocess and manufacture a new product suitable for application in aeronautics based on a complete Eco-Design. The scrapping solution involves recovering thermoplastic composite parts scrap and reducing four relevant aspects: cycle time, production costs, energy consumption and CO2 emissions. The Eco-Design objectives of SPARTA project are the followings:

- Recovery of the scrap thermoplastic composite by 80%
- Reducing the processing time by 50%
- Reducing the production cost by 15-20%
- Reducing the energy consumption by at least 15%
- Reducing the CO2 emissions by at least 30%

The objectives of the SPARTA Project will be monitored from an economic and environmental perspective, and an extensive assessment of the scrapping method will be carried out. The results will be provided to the Clean Sky 2 (CS2) Eco-Design Transverse Activity (TA).

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New EoL routes of Al-Li aircraft integral LBW and FSW welded panels including new Cr-free coatings

Dr. Ana Isabel Fernández-Calvo (AZTERLAN, Basque Research and Technology Alliance (BRTA)), *Clara Delgado, Philippe Dufour, Egoitz Aldanondo and Belén García*

EoL of new aircraft integral welded panels of 3rd generation of Al-Li alloys welded between them by Laser Beam Welding (LBW) and Friction Stir Welded (FSW), including new Cr-free coatings to protect them was investigated. The best EoL route including dismantling and recycling procedures was defined for 10 different combinations of FSW/LBW Al-Li alloys and two coatings. Different cutting strategies, ranging from cutting only for size reduction to full separation of all materials, including the separation of the welded seam were defined with the objective to recycle the maximum amount of material to manufacture high quality aircraft Al-Li alloys. Furthermore, the need to eliminate primer and topcoats and different decoating methods were investigated for TFSAA (Thin film Sulphuric Anodizing) and Sol Gel coatings. The separated metallic fractions of the different EoL routes were recycled and the produced metallic alloys characterised in order to establish a ranking in terms of costs, environmental impact and effectivity, that allowed to select the best option for recycling for each LBW and FSW panels. Fading/enrichment of the different elements were researched, and the recycled alloys were compared with commercial primary Al-Li alloys to determine the compatibility with each of them. Materials and energy flows, emissions and waste generation were inventoried during the new End of Live process tested and provided to ecoTech project for the Life Cycle Assessment (LCA). The best EoL route was defined to valorize as much as possible of the valuable alloying elements and minimize the environmental impact: cutting only for size reduction (6 FSW and 3 LBW configurations) and full separation of all materials (1 LBW configuration).

Best EOL TEchniques for Biocomposited (ELIOT project)

Ms. Nora Lardiés Miazza (AIMPLAS), *Spela Ferjan, Lucie Prins, and Rajesh Mehta*

Because of the advance in plastic materials, society is currently facing one of the greatest challenges of our time, which is to find a useful end of life for the large amount of plastic waste that is being generated, thus reducing the consumption of fossil resources, maintaining the long-term sustainability of the supply chain and the negative impact of these materials on the environment. Composites are very difficult to recycle due to their heterogeneous composition and most of this waste is landfilled, only a small part is shredded to be reused as fillers. To mitigate this effect, bio-FRP (fibre-reinforced polymers) that use natural fibres as reinforcement and resins from renewable sources are being increasingly used during the last decade in sectors like aviation, building & construction and sports, as they are a key technology to reduce environmental impact thanks to their favourable combination of mechanical properties and low weight (reducing fuel consumption and CO2 emissions into the atmosphere). However, the widespread use of these bio-FRP has not improved the End-of-Life (EoL) management, it is even more pronounced in the case of biocomposites, a new material, which, unlike conventional composites, does not contain carbon fibres with a high market value. Therefore, this is a major problem that needs to be tackled as soon as possible. In fact, it is estimated that 10.000 airplanes will be dismantled during the next 20 years all over the world. In the search for new solutions, the main objective of the project ELIOT is to achieve a full-scale demonstration for the best two EoL methods selected after deep research between 12 currently available EoL technologies for two target biocomposites including, their technical validation at pre-industrial scale. These EoL methods will be ready to be further scaled up in industrial environments. The project has been conducted in three stages. Initially, a semi-quantitative multicriteria decision analysis (MCDA) was performed on 12 EoL treatment methods for six types of biocomposites. Next, the four technologies with the best score in the evaluation matrix were experimentally tested. Finally, based on the best-performing experimental results, we conducted screening Life cycle assessment (LCAs) and simplified techno-economic assessments (TEAs) to recycle biocomposite basalt fiber reinforced Polyfurfuryl Alcohol resin with three different recycling methods- pyrolysis, mechanical recycling and solvolysis. In the LCA, environmental impacts associated with treatment of 1 kg of biocomposite waste was studied with ReCiPe 2016 Midpoint (H) impact assessment method. Among the recycling technologies, pyrolysis showed the best GHG emissions performance (net emissions) with -0.802 kg of CO2-eq, followed by mechanical recycling with -0.777 kg of CO2–eq, and solvolysis with -0.644 kg of CO2-eq. Even though the deviations in GHG emissions between the technologies are small, all alternatives perform better than the current practice of landfills (0.751 kg of CO2–eq). Based on the feedstock and product cost assumptions used in this simplified TEA study, we concluded that both pyrolysis and solvolysis present economically viable options. However, simplified TEA showed that the pyrolysis recycling route performed better economically than the solvolysis route. Finally, as the screening LCA and simplified TEA were early-stage assessments with several assumptions, we recommend to conduct a full LCA and detailed TEAs for the three recycling processes in the next phase of the ELIOT project.

Chemical Recycling of Carbon Fiber Reinforced Polyurethane for Aviation Applications

Ronny Hanich-Spahn, Peter Brantsch, ***Mr. Carl-Christoph Höhne (Fraunhofer-Institut für Chemische Technologie ICT)***

Carbon fibers are widely used in carbon fiber reinforced plastics (CFRP) for aviation, automotive, windmills, sport and many more application due to their outstanding material properties. Annually, this generates about 62,000 tonnes of end-of-life (EoL) CFRP and CFRP production waste. Current EoL scenarios for CFRPs show some disadvantages: Landfilling and incineration are not sustainable and environmentally friendly. Carbon fiber recovery by pyrolysis damages the carbon fibers and incinerates the plastic material. Mechanical recycling shortens the carbon fibers and is of limited value for thermosets.

However, chemical recycling routes like solvolysis offers the great potential to recover damage-free carbon fibers as well as useful monomers for a new generation of plastics. This presentation provides an overview about the solvolysis of carbon fiber reinforced polyurethane material for aviation applications. Additionally, first life cycle assessment results will be presented.

GENESIS: Aircraft design, technology foresight analyses and life cycle inventory building for regional class hybrid aircraft systems

*Alexis Laurent, **Dr. Nils Thonemann (Danish Technical University),** Karen Saavedra Rubio*

The project GENESIS is part of the Clean Sky 2 programme and envisions to provide a roadmap towards environmentally sustainable and competitive electric and hybrid aircraft systems, focusing on regional class, 50 pax aircraft and different powertrain technology alternatives that can support hybrid systems. The integration of batteries, fuel cells and their combinations with conventional technologies are therefore explored through 3 time horizons: short-term (2025-2035), medium-term (2035-2045) and long-term (2045-2055+) perspectives. Three research tracks investigate the aircraft design and different scenarios along these time frames, while technology foresight analyses are performed for battery systems, fuel cell systems, turbines, electronics and electric drives and on-ground energy supply systems. Life cycle inventory datasets are generated in parallel to these analyses to allow the future application of life cycle assessment to quantify environmental impacts of different aircraft design and scenarios. This introductory talk will briefly present the overall project aims and scope before outlining the GENESIS-dedicated session programme, which includes an array of presentations addressing preliminary results in the project for the above research tracks.

Building life cycle inventory datasets for a hybrid-electric regional aircraft system in the project GENESIS

*Nils Thonemann, **Dr. Karen Saavedra Rubio, Alexis Laurent (Danish Technical University)***

Life cycle inventory datasets are needed for life cycle assessments to calculate environmental impacts holistically using a life cycle perspective. In the project GENESIS, life cycle inventory datasets are built for the entire aircraft system's life cycle, including the life cycle of the aircraft, the on-ground infrastructure, and the fuels, by focusing on a hybrid-electric regional aircraft accommodating 50 passengers for three different time horizons (short-term, mid-term, and long-term). Specific focus is given to (i) battery technologies, (ii) fuel cells, (iii) hydrogen technologies (including hydrogen production and on-ground and on-board storage), (iv) gas turbines, (v) power electronics, (vi) electric drives, and (vii) on-ground infrastructure (including, e.g., sustainable aviation fuel production). For the life cycle inventory data collection phase, a framework was developed encompassing three steps; (i) planning of data collection, (ii) data gathering process, and (iii) life cycle inventory block finalization. In Step 1, the LCI template for data collection is developed based on LCI blocks drafted according to the data requirements determined in the goal and scope. Thus, this step is initiated in the goal and scope phase of the LCA methodology and continues into the LCI phase. Each LCI block represents (single or multiple) unit processes in an aggregation level that is technology-wise appropriate (e.g., component level). In Step 2, the data exchange between the LCA practitioner and data provider is initiated using the LCI template to direct the data collection. Lastly, in Step 3, the collected data is reviewed, and the LCI blocks are finalized before their assembly and LCI modeling. Finalized life cycle inventory datasets will be presented for the short-term time horizon (reference year 2030).

Design Exploration for Sustainable and Innovative Regional Aircraft

Mr. Valerio Marciello (University of Naples Federico II), *Mario Di Stasio, Manuela Ruocco, Fabrizio Nicolosi*

Nowadays, the growing demand for air transport and the increasing sensitivity to environmental issues creates the need to promptly implement a revolution in today's aviation paradigm. Although aviation is responsible for only 12% of transport-related CO2 emissions, research cannot hesitate to address the unique technological challenges of the sector. In this sense, it is of fundamental importance to evaluate the feasibility of promising hybrid-electric concepts, without neglecting their compliance with market needs. One of the main objectives of the EU-funded GENESIS Project (European Union topic JTI-CS2-2020-CFP11-THT-13, Sustainability of Hybrid-Electric Aircraft System Architectures) is to explore a wide range of propulsion solutions that chart a roadmap towards the complete decarbonisation of aviation by 2050. Three different time horizons are investigated within the project (short-term, 2025-2035; medium-term, 2035-2045; and long-term, 2045-2050+), focusing on a 50-seats regional turboprop aircraft. The outcomes relating to the short-term scenario are exposed here, as the result of the integration of industrial experience within a complete aircraft design chain. Starting from a conventional reference aircraft (the ATR42-500), a serial/parallel partial hybrid architecture with 8 distributed electric propellers has been selected. The design process has been based on the simulation of the flight mission and on compliance with the assigned top-level aircraft requirements. A design of experiment has been performed to identify the best amount of battery, together with its best usage strategy. The masses of electric machines, batteries and power electronics have been evaluated by means of surrogate models provided by industrial partners, and a refined method for calculating the structural mass has been included. Furthermore, a semiempirical model has allowed the redesign of the thermal engine, powered with 100% biomass fuel. The final results suggest that, with approximately 3.8 tons of Li-Ion batteries, up to -30% block fuel can be achieved on the 600 nmi design mission, which rises to -47% on the typical 200 nmi off-design mission. The DoE results also suggest that higher amounts of battery would lead to limited benefits or even the impracticality of the concept. Future developments for the medium and long term will extend the optimization also to geometric parameters and will include technologies such as hydrogen-based fuel cells and different battery technologies.

Battery and fuel cell system design for future hybrid-electric aircrafts

Mr. Bruno Lemoine (Berner Fachhochschule), *Priscilla Caliandro, Thomas Wannemacher, Nils Baumann, Alexe guigemde, Zhangqi Wang, Erdem Akay and Sergio Turteltaub*

Tackling climate change will demand a radical transformation of the aircraft industry as conventional aviation technologies rely on fossil fuels and are responsible for around 2% of the CO2 emissions globally. Europe's vision is to reduce emissions of CO2 by 75% and NOX by 90% in 2050, and to reach this objective, hybrid and "all-electric aircrafts" are seen as the most promising pathways [1]. However, the realization of such systems will have to rely on new and disruptive electrochemical power sources. For this reason, there is the demand to identify and overcome existing gaps and predict future relevant technologies and their performances. Although battery and fuel cell-based hybrid systems represent an enormous potential for meeting the challenges of an environmentally sustainable energy supply for aircraft, research is still at its infancy and tiny implementation in actual aircraft have been realized yet (and none for regional class aircraft). The study presents the conceptual design of a hybrid electric regional aircraft to fulfill TLAR requirements over different time-horizons 2030, 2040, and 2050+.

Initially, a technological forecast concerning the two electrochemical devices was performed based on past experiences and current development trends to estimate the expected performances regarding weight, volume, stored energy, and power density. Subsequently, a bottom-up technology analysis defines the characteristics of the hybrid system along with the different flight phases. The results highlight the level of hybridization of the energy system and the limitations that need to be overcome to enable an electric airplane to take off.

Power electronics, electric drives and on-ground energy supply design in hybrid-electric aircraft systems

Mr. Markus Meindl (Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU))

In a global context, where modern societies need to move towards environmental sustainability, the aviation sector plays an important role. Transition to reduce its environmental footprint (i.e., impacts on ecosystems, human health, and natural resources) stemming from activities in the entire value chain of aircraft has become high on the political and industrial agenda. This transition must go hand in hand with the technological transformation of aircraft systems, moving away from fossil-based fuels to alternative energy sources, like biofuels, hydrogen, or electricity via batteries. Therefore, the GENESIS project is investigating a hybrid-electric regional aircraft to fulfill TLAR requirements over different time horizons of 2030, 2040, and 2050+ to ensure the transition to sustainable aviation. The most efficient energy distribution to the individual components of an aircraft is feasible with power electronics and requires new electric machines. Especially for the different phases of flight, it is important to design these two technologies as efficiently as possible. Finally, an outlook of a ground-based energy supply system is given for a potential future airport, which should also enable the implementation of the aircraft. Some power electronic converters were examined and designed. The efficiency and power density values are determined for each converter type. The choice of HV-DC bus voltage and power semiconductors was discussed. Also mentioned are various possible components that could be used for the different time horizons. A drive motor and optimization option for the time horizons is presented regarding electric drives. Furthermore, a possible design of the electrical primary and secondary machines is given in this study. Finally, ground energy supply options were investigated, focusing on airport electrical energy supply, battery storage options, and ultra-fast DC charging stations. A preliminary study has also begun on developing a suitable charging infrastructure for ground energy supply and evaluating it in advance in simulations.

ecoDESIGN and Sustainable Productivity: Part V

Session Chairs : Dipl.-Ing. Torsten Moll (Fraunhofer-Gesellschaft, Germany) & Mr. Andreas Kötter (Capgemini Engineers)

LCA activities during ecoTECH. From the technology development up to demonstrator level

Luis Prado, T. S. G. Das, Luis A. S. A. Prado, S. Coskun, A. Geß, P. Brantsch and T. Reichert

Evaluation of Adhesion and Laser Stripping Properties of External Aircraft Coatings on Aluminum and Composite Based Substrates

Selen Ünaldi, Mohammad Ayad, ***Ms. Alexandra Karanika (Hellenic Aerospace Industry),*** *Emmanuel Richaud, Marcus Van derGeest, Laurent Berthe*

Aircrafts are painted with several layers to guarantee their protection from external attacks. For aluminum AA 2024-T3 (metallic structural part of the plane) or CFRP substrates, a protective primer is applied. On top of this layer, a polyurethane top coat is applied to better protect the plane from the extreme environmental conditions encountered at high speeds in flight. During the lifetime of an aircraft, top coat stripping has an essential role, which should be operated as an average of every 4 years. However, since conventional chemical stripping processes uses toxic materials, create hazardous disposals and need long hours of labor work, alternative methods have been investigated [1]. Amongst them, laser stripping appears as one of the most promising technique not only because of the reasons mentioned above but also its controllable and monitorable aspects [2]. In addition, upon the maturation of the technology, laser stripping can be used as a universal Solution for both metallic and composite substrates. The application of laser beam from the coated side provides stripping, but the depth of the process should be well controlled in order to prevent the damage of a substrate and the primer. Apart from that, thermal effects should be taken into account on the painted layers. As an alternative, we worked on developing a process that includes the usage of shock wave propagation to create the stripping via mechanical effects with the application of the laser beam. During this procedure as a confinement regime, water has been used since it creates a higher induced pressure within the specimens. For the recycling purposes, water usage and the reuse of stripped paint also make the process as an environmental friendly method. In this work, layer characteristics were determined on specimens in terms of physicochemical properties and thickness range both before and after laser stripping in order to validate the substrate material health and coating properties. Stripping thresholds were extracted as the smallest power density from which the first flight off of the coating is detected. In addition, obtained stripping patterns highlight the importance of paint adhesion tests within the same samples with respect to different epoxy primer thicknesses, applied thermal ageing and used different surface treatments.

This project has received funding from the Clean Sky 2 Joint Undertaking under the European Union's Horizon 2020 research and innovation programme.

Comparison of corrosion behavior between conventional and new materials and manufacturing technologies of aeronautical Al alloys

*Nikolaos Vourdas, **Ms. Alexandra Karanika (Hellenic Aerospace Industry),** Egoitz Aldanondo, Peter Visser, Marcus Van derGeest*

New structural design concepts and innovative materials contribute to the weight reduction of new aircraft structures. New materials used in manufacturing airframe components need to become lighter, more corrosion resistant, cheaper and more eco-compliant. The replacement of conventional materials and their related technologies demand the application of new alloys and the development of new eco-friendly and efficient manufacturing technologies. The use of novel welding techniques and lighter and weldable Al-Li alloys, to avoid riveting, is one of the routes to minimize the weight of the structure. A particular aspect in this context is the surface protection of these new light structures using eco-friendly methods for corrosion protection. EcoTECH, a Clean Sky2 project, explored the application of new Al-Li alloys using new welding technologies and new chromate- free technologies for corrosion protection. One of the key aspects of the project is to verify the corrosion protective performance of these new structures is equal or better compared to the reference materials. This work, presents a characterization of the corrosion resistance performance by comparing the structures using the new Al-Li alloys, welding techniques and surface treatments developed in EcoTECH against the of the existing aluminum alloys (AA 2024), joining and chromate surface treatments The conventional technologies include riveting and Chromic Acid Anodizing (CAA), whereas the new technologies include use of Al-Li (2060, 2099 and 2198) alloys , Laser Beam Welding (LBW) or Friction Stir Welding (FSW) performed by LORTEK, and new surface treatments based on Chromate-free Thin Film Sulfuric Acid Anodizing (TFSAA) or Sol gel AC-131, developed and performed by Hellenic Aerospace Industry and a chromate-free primer/topcoat developed by AkzoNobel. The study comprises a comparison of the different surface pretreatments before and after joining processes, combined with the behavior of the joined parts, during exposure to accelerated corrosion environment. Fast and comparable results were obtained and for all the examined combinations of technologies using the Exfoliation Corrosion (EXCO) test. Although, this is an aggressive corrosion method, no corrosion observed in the joined area of substrate materials. In addition, the sol-gel surface treatment outperformed the TFSAA surface treatment. In combination with a chromate-free primer and a topcoat, the system provides a corrosion protection performance that is comparable with the industrial references based on CAA from corrosion almost as good as CAA.

This study was funded by the European research program Clean Sky. The ecoTECH project has received funding from the European Union Horizon 2020 Clean Sky 2 Joint Undertaking under the AIRFRAME ITD grant agreement 945521.

Design of a full scale fuselage panel by novel Al-Li alloys and manufacturing methods for static and endurance performance evaluation

***Mr. E. Carelas (Hellenic Aerospace Industry S.A),** E. Louizos, A. Abramovich, E. Aldanondo*

The development of novel Al alloys exhibiting higher strength and better endurance performance than the alloys used traditionally in aerospace, along with the advancement of joining technologies such as friction stir welding (FSW), enabled the design of lighter aerospace structures at reduced manufacturing time and cost. Furthermore the configuration of structures such as fuselages of transport aircraft, exhibiting large scale interfaces between skin segments but also at joints of skin to stiffening elements, makes FSW an attractive joining method with a potential for large scale weight reduction for joints. Also

advantageous are the reduced heat impact of the weld process resulting in nearly no distortion at the joined regions, as well as the significant reduction of the number of rivet holes, required at the weld tool retraction mark. This results in reduced probability for defect initiation from the rivet hole edges and thus grow of damage. At the present project a full scale fuselage panel was designed and optimized for weight, taking into account the manufacturing constraints of the above joining method and material. The primary target was to upscale developed manufacturing technologies of novel 2198 Al-Li alloy from the level of coupon and subcomponent to full scale level and at representative loading conditions. For that purpose an existing business jet fuselage design was used as a reference for enabling evaluation of the weight savings of the new design. The fuselage diameter and sizing loading cases were kept common for both designs, resulting to a multi-stringer panel with three frames and a radius of 1150mm. A full scale test campaign was provisioned, in the framework of ecoTECH research activity for two prototype panels that will be tested at both static and endurance loading, representative to that of the reference panel In this aspect the suitability of the developed technologies for application of large scale aircraft structures will be demonstrated. The testing campaign will be undertaken through European funded call for proposals process with the project DEMONSTRATE. Preliminary sizing was performed with FEA at a complete fuselage section, with one dimensional stiffening elements. A sizing priority of manufacturing constraints in the design was accounted, such as stringer and frame minimum flange width for the welding region. Next an optimization was performed for a characteristic panel segment, taking into account the sizing loading case for frames and stringers distance and section profile using HyperSizer software. Finally a detailed level FEA model was constructed for the panel including the exact stiffeners crossection, skin pockets and peripheral interfaces for verification of panel response at full scale level.

Development, Manufacturing and LCA Data Collection for a Biomaterial a/c Interior Demonstrator using the example of a Drawer Box

Prof. Vassilis Kostopoulos (University of Patras)

In the environment of the CleanSky2 project ecoTECH, INVENT developed an alternative sustainable aircraft interior item. The main objective of the ecoTECH project is to explore new solutions to reduce the environmental footprint of aircraft components during their global lifecycles and make these solutions available to the aviation industry. In the Workpackage Biomaterial a/c Interior Demonstrator INVENT leads the development of a drawer box as an exemplary aircraft interior part, made from eco-friendly materials. The benchmark with regard to economic and ecologic aspects is set by a state-of-the-art aircraft interieur item for which the new biomaterial drawer box is developed as a 100% substitute. Along the way to catch up with this commercial example, several challenges that are typical for the use of biomaterials were faced during the different development phases which could be divided into material evaluation and selection, design, testing on specimen level and manufacturing of the demonstrator. Especially the development of the material-appropriated design and manufacturing approach to compensate specific disadvantages of the selected eco-friendly materials to fulfill the same requirements as the state-of-the-art example, were central aspects and took up a large proportion of the overall effort. In parallel with the technical development, also a complete LCA data collection was prepared and later completed during the manufacturing phase of the biomaterials drawer box. In combination with the EoL approaches, evaluated by the associated project ELIOT, the collected information forms a holistic picture of the environmental footprint over the lifecycle of the new interieur part. This data set allows also a comparison with the already existing state-of-the-art drawer box not only under the aspects of weight and stability, but also regarding for example energy consumption, production time and recycling potential.

Environmental Improvement Potential of Flexible Polyurethane Foam for Aviation Applications - A Case Example Analysis

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The analysis of environmental impacts of aviation should include the full life cycle of an aircraft and its parts and should go beyond use-phase emissions. Environmental impacts of the manufacturing stages e.g. related to consumption of resources, pollutions and the use of hazardous materials like environmentally toxic chemicals as well as environmental impacts of end-of-life scenarios for an aircraft must be considered. Based on a case example on polyurethane flexible foams for aircraft seating cushions, an analysis of the environmental impacts supported by the life cycle assessment methodology has been conducted. This analysis covers the production of polyurethane flexible foams with a particular focus on three perspectives being: (a) use of biomaterials instead of fossil based material, (b) reduction and replacement of hazardous chemicals like heavy metal catalysts and flame retardants, (c) use of recycled polyol obtained by chemical solvolysis of flexible polyurethane foam. Selected results of an LCA will be presented for these to show improvement potentials.

Machine learning in aviation: is it possible to predict when an atc sector or air traffic flow will be regulated?

Dr. Francisco Pérez Moreno (Polytechnic University of Madrid), *Victor Fernando Gómez Comendador, Raquel Delgado-Aguilera Jurado, María Zamarreño Suárez, Dominik Janisch, Rosa M Arnaldo Valdés*

At present, a problem of major concern for the ATM system is the increase in demand up to a point where the ATC service does not have sufficient capacity to handle it. When the ATC service cannot handle the demand for whatever reason, ATFCM regulations appear. These regulations affect all traffic scheduled to fly through an ATC sector at any given time, causing a percentage of these flights to be delayed and making the airspace a more complex environment than expected. Related to this, a collaboration between the UPM, CRIDA and Enaire has arisen, aimed at characterising the behaviour of the ATC sectors and the air traffic flows within these sectors. Within this characterisation, the study of regulations is very important due to their great importance in traffic behaviour. If, thanks to artificial intelligence, ATFCM regulations could be predicted, action could be taken before they occur and the complexity of airspace could be reduced, along with the workload of controllers in charge of regulated ATC sectors. In order to predict ATCFM regulations, two machine learning models will be created to try to predict whether a sector will be regulated or not, and whether a characteristic traffic flow will be regulated or not. This machine models will try to find behavioural patterns in the historical operation within the studied ATC sectors to make these predictions. The organisation of these models will be based on two successive steps:

The first step will be the separation into different causes. Regulations appearing due to weather will need additional information such as weather forecasts. This model will focus on the prediction of ATFCM regulations that only need traffic information to be carried out. These are the regulations due to the lack of capacity of the ATC system. Moreover, these are the regulations that will affect the ATC system the most. In 2019, 85% of all ATFCM regulations in Europe were due to lack of ATC capacity for different reasons. The second step is to define the input. Both temporal and operational criteria have been considered relevant in order to develop a complete machine learning model. This information, together with historical regulations, will be sufficient information to try to predict when an ATC sector or an air traffic flow will be regulated in the future. In addition to a model whose results are correct, the explainability of the algorithm is fundamental for the reliability of a machine learning application. Therefore, an important part of the process will be the validation of the learning process. With these models, it will be expected to foresee when regulations due to lack of capacity appear both in an ATC sector and in a specific traffic flow. This will in principle make it possible to anticipate the cause and effects of the regulation. This research project, located within the wide framework of the development of artificial intelligence applications in aviation, represents an advance in the prediction of one of the areas of greatest uncertainty for the ATM system, that of regulations. This approach will help the ATC system to face ATFCM regulations, which are one of the biggest generators of complexity and workload to the air traffic controllers. It is hoped to obtain results that at least allow the initiation of a line of research in a field where progress is minimal due to the great uncertainty and difficulty surrounding this topic.

Evaluation of Extended Projected Profiles impact on vertical trajectory prediction

Mr. Chen Xia (CRIDA A.I.E. AND UNIVERSIDAD POLITÉCNICA DE MADRID (UPM)), *Christian Eduardo Verdonk Gallego, Rosa Arnaldo Valdés, Victor Fernando Gómez Comendador*

The future Air Traffic Management System (ATM) is based on the concept of Trajectory Based Operations (TBO), in which all the stakeholders have access to consistent and synchronised flight trajectory. In TBO framework, the trajectory prediction plays an important role. The inaccuracy of current trajectory predictors caused by the lack of data can be reduced by the sharing of information by the airspace users. A step towards a shared information network is the Extended Projected Profile (EPP), downlinked from airborne to ground via automatic dependent surveillance contract (ADS-C). It contains the flight intent from the Flight Management System (FMS) and other information. This paper explores the EPP messages and the possible performance enhancement they introduce in the predictions of the top of descent (TOD) and the descent vertical profile. EPP implementation is still in an early stage, and the content is sensitive data for airlines, few of them are currently sharing this information and only for research purposes. This paper focuses on the flights for a descent flow of analysis selected from the Spanish Pamplona Upper sector (LECMPAU), where the data sample has 58 flights, including real traffic data and EPP messages. For each flight, EPP messages are reported continuously, updating the current flight states and local conditions - location, current gross mass, guidance modes, level, ground track, speed, actual heading, speed, wind, and temperature etc. - and offering the reference trajectory at the report moment from FMS - estimated level, speed, and time. The reference trajectory contains only a segment ahead the current position. Therefore, the last report before entering to the sector of analysis (msg0) and the subsequent messages before reaching the real TOD (msg1, msg2, etc) are the main objects of analysis. The selected variables for the analysis are reference trajectory, current gross mass (m0), predicted mass at TOD (mTOD) and vertical guidance mode (Vmng). For the flow of analysis, horizontally, the EPP trajectories are similar, most of them follow two recurrent patterns. The geographical TOD locations, that can be determined from the reference trajectory, are also close to each other. But its variation can be significant in updated reports. To explore the impact of the new variables in the prediction of TOD, the problem is discretised. Taking as reference variable the elapsed distance since entering (γ), the location TOD is γTOD. Then equidistant intervals of 15 NM are defined and the interval in which γTOD falls is the TOD interval (ITOD). On the one hand, the intervals according to the EPP (predITOD_EPP) are concentrated in three intervals along the reference trajectories. The messages does not capture the descents shortly after the entering. On the other hand, simple classifiers to predict ITOD are trained with XGBoost (Extreme Gradient Boosting), because one of the advantages of XGBoost is that it can provide a good performance with small training sample. Inputs combinations of RFL - V0 / RFL – ITOD_0 / V0 -m0 / V0 - mTOD show the same behaviour and provide the highest number of true positives and ITOD_0 – m0 / ITOD_0 – mTOD show the lowest Root Mean Square Error (RMSE). Vmng presents unique value, so it does not contribute to the performance with the given sample. In comparison, ITOD_XGB is closer to the true values ITOD in the early descents. In the vertical plane, comparing the vertical profile obtained from radar track and the EPP's, the sample can be categorised into 10 groups. Note that the reference trajectory update depends on the current position, the use of opposite direction level (ODL) is not considered in the projection. For example, a flight cruising at FL370 has descended to FL360 when two flights, at FL370 and FL350, that cross its path were nearby. Once passed the cross point with the other flights, it descended and continued cruising at FL350. In this case, EPP was reported once when the flight was found in FL360 and the reference trajectory it contains kept cruising at FL360, without considering that it is a temporal decision.

Most influential factors in the detection of potential conflicts between en-route aircraft by ATCO

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Due to the high level of safety achieved in ATM, relatively little data is available on negative safety outcomes. For this reason, current knowledge of the determining factors of the occurrence of Loss of Separation (LoS) incidents between aircraft is limited as is the current industry's ability to predict them. To address these shortcomings, a combination of reactive, proactive and predictive analysis is required to harness the potential of safety-related data and provide insight into potential operational risks. From this fact arises the objective of analysing the most influential factors in a Separation Minima Infringement (SMI) in order to be able to predict more reliably the safety levels of the airspace under consideration. This is the framework for the FARO project, saFety And Resilience guidelines for aviatiOn, funded by the European Union in the SESAR 2020 programme. For this purpose, the project will apply knowledge-based and data-driven approaches. The proposed methodology aims to obtain a model capable of characterising and predicting the detection of potential en-route aircraft conflicts (both in level flight and in climb and descent) by ATCO as it is considered a key safety barrier in the progression of an SMI. Thus, firstly, the development of a Bayesian Network Model (BNM) starts with a characterisation of the safety event in terms of safety dimensions (precursors) and their aggregation. The outcome of this descriptive analysis, together with prior statistical knowledge, serves to select potential models that could provide statistical representations of the frequency of safety events. A data-driven approach complements the development of the model. Calibration, tuning and sensitivity analysis of the BNM will also be carried out. The proposed model is fitted and calibrated on real data. The explanatory power of each model and/or independent variable and mixed effects are quantified. The sensitivity analysis considering mixed effects allows characterising the safety performance in terms not only of the independent dimensions, but also of their combinations, identifying the prior thresholds of those dimensions that would reduce the frequency of a safety event. Finally, the influencing factors and applicability thresholds of the model will be identified. The application of the model to a defined scenario will be carried out to quantify the influencing factors for each case study and to determine the criteria and thresholds for their applicability. The developed model brings together analysis and knowledge, as well as predictive capability, to answer what factors influence the detection of a potential conflict by ATCO and what will be its frequency of occurrence. The proposed methodology identifies the cause-effect relationship between certain variables or situations that directly or indirectly affect safety and non-compliance with the minimum separation. The methodology allows for forward and backward analysis. Thus, with this calculation capability, the network allows conclusions to be drawn on the impact that a change in airspace and traffic or operational conditions would have on ATCO detection effectiveness.

Artificial Situational Awareness Assessment of a Novel ATC Support System

Mr. Ivan Tukarić (University of Zagreb), *Kristina Samardžić, Tomislav Radišić, Celina Vetter*

This paper presents the application of an existing situational awareness (SA) framework to a newly developed artificial intelligence system to determine its awareness level. The system incorporates diverse automation techniques, such as a knowledge graph, expert rules, and a machine learning module, for gaining SA and applying it in the field of air traffic control. Since the system was developed to serve as a foundation for exploring automation and artificial SA, the primary result of this work is the determination of the system's overall awareness level and the identification of sub-systems that may be improved for additional awareness. The system is shown to be on the highest awareness level conditionally, with the understanding that the system is on a proof-of-concept level. The findings are expected to translate well to a future operational system. Improved awareness and self-awareness of an air traffic control system could lead to improved safety, efficiency, and quality of service in air traffic management. By introducing a machine to air traffic control team SA, perception and understanding of the traffic situation may be preserved or improved. To achieve that effect, every team member should be acquainted with the other members' actions and reasoning. Research presented here provides insight into the current system state, the extent of system support, and potential improvements. Highest priority awareness-related improvements are those dealing with robustness, whose implementation would substantiate the current awareness assessment. The specific framework that was used was chosen in the fundamental project documents and its use proved beneficial as it enabled the demonstration of how general guidelines can be interpreted for a specific system, identification of difficulties encountered during the process, and possible routes for improvement of the process. The awareness assessment includes the examination of presented awareness concepts' definitions, assessment of individual awareness condition fulfillment, and assessment of individual awareness level fulfillment. The high level reached by the system is contingent on awareness concept and condition interpretations. With the appropriate assessment of the system, implementation in an operational environment is more feasible.

Design Assurance and Architectural Approaches for AI-driven Autonomous Flight

Mr. Miguel Martin Acosta (Airbus Defence and Space), *Luis Santiago Garrido Bullón, Luis Enrique Moreno Lorente*

Autonomous flight capability has traditionally relied on the use of navigation instruments, as well as classical technologies and architectures that have hardly evolved in recent decades. The need for enhanced autonomous flight capabilities for new applications, such as urban air mobility or cargo drone delivery, makes it necessary to leverage emerging technologies in the field of AI. Deep learning and reinforcement learning, together with new vision sensors and increased computing capacity, will improve perception, navigation, computer vision, and decision-making in autonomous flight. However, the application of AI, and more specifically machine learning, poses numerous challenges in design assurance and certifiability of autonomous flight systems. This paper researches and develops the optimal approaches for the architecture, functional allocation and technologies, both AI-based and classical, of a future fully autonomous flight system. The methodology based on reliability and safety analysis, widely used in aviation, and EASA AI trustworthiness concept, to meet the authorities' objectives: flight safety, design and learning assurance, as well as other aspects such as explainability, redundancy, integrity, and performance.

Innovative, multinational, multidisciplinary UAV Design Education Collaboration

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Simulating real-world challenges and collaboration that allows Engineering students to experience a globalised industry and develop their creativity and innovative thinking is fast becoming the measure of success in Higher Education. The international student team AREND (Aircraft for Rhino and ENvironmental Defense) is one such initiative that has developed over the last 8 years, and incorporates international, intercultural and industry collaboration, spanning across 5 engineering disciplines. Undergraduate and graduate students are tasked with complex, ill-defined problems surrounding an unique UAV design as a solution for rhino poaching In the Kruger National Park, South Africa. The team originated and was managed by the University of Colorado in Boulder, US, towards participating in a competition in 2013. The team consisted of 4 institutions which included the Helsinki Metropolia University of Applied Sciences, Finland; the University of Stuttgart (US), Germany; and the University of Pretoria (UP), South Africa. The competition was cancelled and the University of Pretoria took the lead of the initiative. The programme has grown to include a seamless structure where South African and international students can participate in the team and collaborate with local industry. Currently, in addition to hosting students from the original participating institutions, the programme has hosted students from ENSMA (France) and University of Tromsø (Norway) and also forms part of the international Vertically Integrated Project (VIP) consortium (44 Institutions across 13 countries). The initial project considers a custom designed UAV capable of conducting remote surveillance of large park areas with diverse intelligence gathering sensors, along with a network of ground sensors. The overarching problem statement for AREND is: "Team AREND will design a technological solution to aid Kruger National Park (KNP) rangers in the protection of black and white rhinos from poaching. The solution shall constitute, but not be limited to, an unmanned aircraft (18kg, 4.2m wingspan, cruise speed 20m/s, stall speed 15m/s) capable of conducting, efficient, quiet and remote surveillance of large park areas such as KNP. The drone shall be operable from a central base within KNP, have extended flight endurance (~120 min), and be able to detect/distinguish humans and animals with on-board sensors. Design modularity is encouraged." Since 2017, the primary focus has been on aerodynamic aircraft design. The ability for the fuselage and the wing to be considered as interconnected modular components allows the team to experiment with novel configurations. The first configuration was a fixed wing inverted V-tail design designed around the internal structure. In regards to some ongoing research at the University of Pretoria on alternative aircraft configurations the aircraft configuration was adapted to tailless aircraft with a self-stabilising wing. Emphasis was placed on the design, manufacturing and testing of the new wing shape. After the first iteration winglets were added to correct for the yaw stability concerns and at present the early stall angle of the wing is being considered. The team is facilitated to cultivate innovative attitudes, professional skills and early cross-subject synthesis in participating students. This is achieved through a robust articulation of project-based and work-integrated learning in a formal curriculum structure. Secondly, the longevity of the project depends on committed students who prioritise their contributions to AREND over multiple semesters. A "learning pathway" establishes alignment for a student at each academic level. Every innovation context is different and would thus emphasise different innovation processes. This paper will not only describe the detail of the design evolution but more importantly focus on four pertinent innovation processes unique to this framework.

Case study of 9/11 vs Covid-19 and their impact in the number of flights and passengers

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The aim of this paper is to study the consequences of the 9/11 terrorist attacks and the COVID-19 pandemic in passenger air transportation. The effects of both events in the evolution of air traffic and number of passengers are compared, using data from 1980 to 2021. Mathematical and statistical models are used to quantify the effects of both events. In particular, dynamic models of the behavior of air transportation after the events may be used to predict the recovery year of this industry.

How can Urban Air Mobility contribute tomore sustainability in global cities?-A joint case study of respective plans in Paris

***Mr. Nabil Hagag (PLM Analyst),** Nico Brieger, Markus Engelhart, Bastian Hoeveler, Thuy Dao, Veruska Rodrigues Dias, Nihal Sari*

This white paper aims to assess the sustainability of urban air mobility (UAM) in the wider framework of sustainable urban development.Therefore, Paris has been chosen as an interesting and relevant case study context: Firstly, the city has announced its intention to become the greenest city in Europe by 2030. With a hostof progressive proposals and green policies, Paris' city council is making huge leaps towards turning the French cap-ital into a "less polluted, greener, more peaceful and safer city". In the process, a major focus lies on reshaping the city's transportation and mobility infrastructure to incentivize changes in the popula-tion's mobility behavior. Simultaneously, the Paris Region has announced plans to have air taxis and drones in commercial operation with the start of the Summer Olympics in 2024 already. For this goal, the regionhas entered partnerships with various private and public stakeholders to create the nec-essary eco-system as part of their "ReInvent Air Mobility"project.This studyinvestigatesthe sustainability of UAM with a context-wide perspective.Insteadof life-cycle assessmentsof the aircraft and other necessary products and components, it focusesonthe impact of operations of air taxis and dronesin Parison sustainability criteria. This includes flight operations of these new typesof vertical take-off and landing (VTOL)aircraft as well asthe requiredinfrastructure (e.g.,vertiports, charging infrastructure), the impacton the mobility landscape,the effects on popu-lation as well ascustomersand various other aspects.Thus, Paris' four top-levelsustainability criteria (i.e., less polluted, greener, more peaceful, and safer) represent the framework with which the impact of UAM on theoperational level is to be measuredsystematically. Therefore,the top-level criteria are broken down into various key indicators (e.g., traffic congestion, city noise levels, light pollution, global and local GHG emissions) in whichUAM has poten-tial impacts. For the purpose of this paper, several Olympic venues are connected with various mobility hubs to create an exemplaryUAM network. Based on this assumed network in operation, the sustain-ability impact of the various use casesof UAM isdefined and measured with a data analysis against specified baseline values for the identified key indicators.The result of this analysis is answering the question under which conditions UAMcan support the transition to moresustainable cities. Beyond these conclusions, guidelines for the operational deploy-ment and implementation of UAM networks from a policy perspective andrecommendations for rel-evant stakeholders are provided(e.g., manufacturers/ private service providers, governmental insti-tutions, city councils, other mobility providers). This study is the result of the collaborative work of the FIA / TCS Drone & Vertical Mobility Academy, Accenture Industry X and umlaut Consulting.

Continuing education in green chemical processes for aerospace manufacturing: the case of drag-out

Dr. Nikolaos Vourdas (Hellenic Aerospace Industry), *Dimitra Peta, Maria Aptoglou*

Chemical processes are being utilized in a wide range of industrial manufacturing from nano to macro scale. In aircraft manufacturing, in particular, chemical processes are included in the list of the so-called Special Processes, among other mechanical and metallurgical processes. In this case, chemical processes are being employed mainly for plating, corrosion protection and surface finishing and involve chemical cleaning, deoxidizing, metal plating, anodizing and chemical conversion coatings. These chemical processes, however, are responsible for the majority of the environmental impact of the Special Processes in total, because hazardous substances are being used, process baths are typically large and therefore the effluent loads are high and difficult to manage. Therefore, green chemical processes should be implemented, and the respective Training Curricula should be developed. One, quite important, aspect in such chemical processes is drag-out, namely the volume of the solution that is being carried out from one process bath to the next one, typically a rinse bath [1]. Drag-out has several impacts ranging from economical and environmental to process control and quality. Drag-out was typically treated as a minor issue in Special Processes. However, green chemical processing dictates increased attention and drag-out minimization. Unfortunately, the main engineering design rules and prediction models for drag-out which are currently in-use are inaccurate [2] and do not take into account recent scientific advancements in the active field of wetting phenomena.

In this work we present the outline of a comprehensive and integrated Course for the drag-out issue in Special Processes, applicable for continuing education Curricula [3]. This has been developed in Hellenic Aerospace Industry, within the Education Curriculum offered to external customers. The course outline for the Drag-out will be presented as well as the practical exercise in the laboratory. Drag-out measurements from metallic coupons taken from various process steps are presented [4,5], thus elucidating the effect of the surface roughness, surface chemistry and the related wetting phenomena. Cases in which the main prediction models fail are being also demonstrated.

From sensors to systems

Session Chair : Dr. Cezary Szczepanski (Warsaw Institute of Aviation, Poland)

Data acquisition unit for suborbital rocket vibration measurement

Mr. Konrad Wojciechowski (Lukasiewicz Research Network - Institute of Aviation), *Hubert Graczyk, Michał Piwowarczyk, Patryk Rękawek, Rafał Truszkowski*

Suborbital rockets and space launch vehicles experience high levels of vibration. They are caused by various factors, such as aerodynamic effects on the external surfaces and engine combustion instability. The second factor is especially pronounced in hybrid rocket engines, such as the main engine of the ILR-33 AMBER 2K rocket. In order to ensure the correct operation of all the equipment and payload on board, vibration testing of the devices is necessary as part of pre-flight qualification. For such tests to be truly indicative of in-flight performance, the vibration environment of the vehicle must be analysed. A conceptual measurement method was proposed, along with a prototype measurement system. The system is adapted to be integrated into the modular ILR-33 AMBER 2K on-board computer or work independently as a separate module. The device measures vibration in three axes in several key points onboard the rocket, with the possibility of connecting multiple units in a daisy-chain configuration. This paper presents the design of the module, including the key aspects of integrating it as part of the avionics package. The means of acquiring and storing of measurement data are presented. The method of validating the system’s data acquisition capabilities is described in detail. Qualification testing results and identified issues are discussed. Possible future improvements are proposed.

Initial Flight Verification of HIL Simulations of the Flight Stabilisation System

Mr. Albert Zajdel (Łukasiewicz Research Network - Institute of Aviation), *Michał Welcer, Cezary Szczepański, Mariusz Krawczyk*

Previous research on the automatic stabilisation system has shown many benefits of retrofitting PZL-130 Orlik aircraft with it. Because the system is electric, it fits into the More Electric Aircraft concept and contributes to reducing aircraft weight, engine power consumption, fuel consumption and gas emissions. Moreover, the system doesn't require modifying the pilot's primary manual controls. That was achieved by the innovative idea of using trim tabs instead of the aircraft's primary control surfaces. Model-based design methodology for the automatic stabilisation system project has been adopted. The initial phases of aircraft, environment, actuators, control system modelling, automatic code generation and hardware manufacturing were followed by simulation tests at various levels of advancement: Software in the Loop (SIL) and Hardware in the Loop (HIL). Finally, the stabilisation system was installed on the aircraft and passed the ground and flight tests. The article presents verification of the Hardware in the Loop simulation results by comparison with results obtained from the flight test. The main goal of this comparison is to assess the differences in the behaviour of stabilisation systems implemented in hardware in the laboratory real-time simulation test stand and real aircraft during flight. Finally, the study will evaluate the usefulness of HIL test simulations prior to flight tests.

Initial Flight Verification of SIL Simulations of the Flight Stabilisation System

Mr. Michał Welcer (Łukasiewicz Research Network – Institute of Aviation), *Albert Zajdel, Cezary Szczepański, Mariusz Krawczyk*

The More Electric Aircraft concept and aircraft electrification is accelerating. One of the key factors in unlocking significant improvements in aircraft weight, engine power consumption, fuel consumption and reduction of gas emissions is changing its control system into an electric one. Previous research on a cost-effective and energy-saving electric automatic stabilisation system has shown many benefits of retrofitting an aircraft with it. Its innovative feature is no need for modification of the pilot's primary manual controls. That was achieved using trim tabs instead of the aircraft's primary control surfaces. A stabilisation system was developed using a Model-based design methodology. At first, a model of the target aircraft PZL-130 Orlik was created. Then a model of the control system, actuators and control laws were synthesised using classical methods with linearised aircraft models. The next stage of simulation testing allowed to check the stabilisation system performance with nonlinear models of aircraft flight dynamics, actuators, wind disturbances and also automatically generated code from the system models. Due to this fact, these simulations are named Software in the Loop (SIL). This paper presents the results of SIL simulation verification compared with flight test results of the automatic stabilisation system. Flight tests were planned and performed according to civil aviation authority requirements. Results comparison will confirm the accuracy of models and parameters used in the simulation. Furthermore, the design team will get valuable insight into stabilisation system behaviour compared to simulation environment and the mechanics of how the control law gains have to be returned during the flight test. The next stage of system design verification will be the comparison of Hardware in the Loop simulation results with flight test data.

GNSS Denied Navigation System for the Manoeuvring Flying Objects

Dr. Cezary Szczepanski (Warsaw Institute of Aviation), *Krystian Borodacz*

Flying objects require continuous and accurate information about their position and orientation. For this purpose, integrated INS/GNSS navigation systems are commonly used. INS provides reliable continuous measurements of motion parameters to determine an object's position and orientation, but with accuracy that deteriorates with time. On the other hand, GNSS provides consistent accuracy, but the signal is unreliable, as it may be lost, jammed or spoofed, which is unacceptable for critical systems. This issue is addressed by a research project started in the avionics department of the Lukasiewicz Research Network -- Institute of Aviation, which aims to develop a navigation system relying on inertial measurements supported by correction data other than GNSS. A guided tactical missile with a range of up to 60km was adopted as the target for the developed system. This paper presents the results of the research obtained to date. The performance analysis of existing missiles shows that small and relatively inexpensive MEMS-type inertial sensors are required. However, devices of this type suffer from measurement errors that do not allow to achieve the delivery accuracy expected from precise missiles. Furthermore, the analyses carried out show that navigational errors in an object manoeuvring with high dynamics are largely due to the object's motion profile rather than navigation duration. Hence, after examining the suitability of various solutions, it was decided to use a vision-based correction system. Further work in the project aims to develop integrated navigation algorithms and a prototype of the device, which will be tested during SIL and HIL laboratory tests, and ultimately during flight tests on an aircraft.

Design and production of a paint graphene-based sensor system for distributed aeronautical structural monitoring

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Assessing the health of structures and devices has always been a topic of interest in various fields of engineering, from building to aircraft structures. Thanks to the development of increasingly high-performance technologies and integration with IoT systems, in recent years, scientific research has been able to make predictions about the remaining life of structures thanks to artificial intelligence algorithms. The aim of this article is the production of a highly sensitive piezoresistive graphene-based sensor system for structural monitoring that can withstand external stresses and detect possible impacts on aeronautical structures. An epoxy paint loaded with graphene nanoplatelets is proposed; one of the main advantages of which is its low cost, ease of application and the possibility of creating arrays of sensors for studying impacts on the entire structure under examination. The proposed solution was applied to a CFRC plate on which commercial piezoelectric sensors were placed, used as a reference. By means of a piezo hammer, impacts were simulated on the plate and the results demonstrated the effectiveness of the solution in terms of detecting impact events and their locations.

Monitoring icing in aircraft by acoustic emission and surface plasmon resonance spectroscopy

Dr. Helge Pfeiffer (KU Leuven), *M. Stamm, J. Reynaert, D. Seveno, P.J. Jordaens , Ö. Ceyhan, M. Wevers*

Due to condensation while flying or when filling tanks with kerosene, significant amounts of liquid and solid water (ice) accumulate in fuel tanks. This can lead to misreading of fuel meters or, for certain aircraft types, ice can block the suction nozzle of fuel supply tubes from tanks to engines. Moreover, water promotes microbial corrosion in the tanks that can even affect structural elements, leading to major and costly repairs and long flight time. There is not yet a generally accepted "non-invasive" method of determining when to drain the water. Also, it cannot yet be determined whether maintenance after draining can guarantee that all the water has been drained and there are no ice cubes or water left in the tank. Another issue concerns ice accumulation on the outer surfaces of aircraft that affect, for example, air resistance. Early detection of those processes would therefore provide important information to take appropriate measures to improve safety and fuel efficiency. A promising ice detection technology uses acoustic signals generated and emitted during ice melting or freezing. With acoustic emissions in the ultrasonic frequency range, a large number of events can be recorded and used to characterize stress relaxation processes that occur during conversions between liquid and solid water. The entire process can be analysed with respect to energy and frequency distributions and the total number of events measured. Proper mathematical treatment of the data collection also allows distinguishing between real ice formation and ambient noise that may be present simultaneously.
Another technology presented uses the surface-plasmon resonance technique whereby ice formation in a liquid phase can be identified by optical parameters related to the refractive index. Not only the freezing or melting of ice can be determined as such but also the presence of water in the tank which is important for all operations where no ice formation takes place. Research leading to these results has received funding from the "NDTonAIR" project (Training Network in Non-Destructive Testing and Structural Health Monitoring of Aircraft structures) under the action: H2020-MSCA-ITN-2016- GRANT 722134 as well as the "Fighting Icing" project (COOCK – VLAIO, Belgium). Part of the research is furthermore supported by the FUTPRINT50 project academy (No 875551) as well as the "SurfIce" project, a H2020-MSCA-ITN "Smart surface design for efficient ice protection and control" GRANT 956703.

Fault-tolerant Switched Reluctance Motor Propulsion System for eVTOLs

Mr. Marcin Biczyski (Cranfield University / ESTACA), *Rabia Sehab, James Whidborne, Guillaume Krebs, Patrick Luk*

eVTOLs are gaining a lot of attention as a potential solution to Urban Air Mobility (UAM) challenges. However, the basic configuration of a multirotor is open loop unstable, therefore very susceptible to actuator failures. Due to usually short mission duration (20-30 min), fault-tolerance of the propulsion system is of greater importance then reliability. Thus, novel approaches to enhance this capability are required. This study proposes a new fault-tolerant propulsion system using 4-phase Switched Reluctance (SR) motors. It is designed for an 8-10 kg scale multirotor eVTOL, to replace redundant coaxial BLDC motors with a single fault-tolerant drive. Acknowledging the role of fault-tolerant control algorithms, the propulsion system is validated in terms of the Loss of Effectiveness (LoE) metric, typically used in the evaluation of control solutions. Switched reluctance motor propulsion system was found to be highly resilient to open phase and current sensor faults, but susceptible to position sensor faults. This can, however, be mitigated with sensorless control solution. In addition, an argument is made on extending the findings to full-scale eVTOLs.

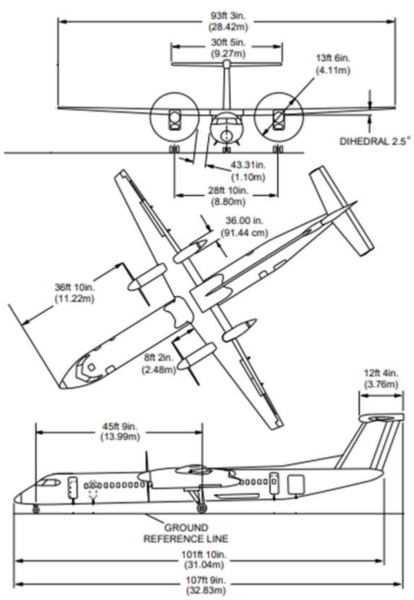
FUTPRINT50 Academy

Session Chair : Prof. Andreas Strohmayer (University of Stuttgart, Germany)

Regional Aircraft Hybridization

Mr. Campo Alfio Alessio (UniCusano University)

This technical report aims to demonstrate the benefits of a turbo propeller hybridization for a regional 50 seats aircraft by modifying it in a hybrid powertrain concept, analyzing it within the fly mission, flight phases, power and efficiencies involved in. As a basis for this study, a double turbo propeller Bombardier Dash8 Q400 is taken as a reference (here below its major characteristics):



This aircraft was chosen for its important features such its starting good aerodynamics and powertrain efficiency and for the designed capacity of 78 passengers: because hybridization integrates an electric powertrain with a conventional combustion engine to provide the necessary propulsion, the resulting system combines the zero-emission power of an electric propulsion system with the extended range and high power of a turbine propeller system. However, those advantages come to a cost: increased complexity, power management and, obviously, mass. So, starting from a larger structure suitable for 78 passengers, the integration of the hybrid system allows us to remain in adequate structural parameters without having to do major structural changes, but, of course, at a certain cost of a worse passenger transport capacity.

To generate the adequate amount of electric power, an exhaust heat gas recovery system, fuselage solar panels and vibration reclamation technology systems was integrated all in one in the new powertrain arrangement to make feasible the project. All the results, assumptions and calculations are taken thorough literature, research papers and podcasts to supports author decisions made by simplified analyses during the design process to adopting the most promising and feasible hybrid architecture.

AAPE-98 Hybrid Electric Aircraft

Mr. Leo Emanuele (University of Salerno), *Gravili Pierluigi Antonio, Marzanese Antonio, Musardo Antonio*

The growing concern with global emissions has brought many governmental and international agencies to elaborate aggressive emissions and noise reduction targets for the future. "Flightpath 2050" and the "Green Deal" set highly ambitious goals for emissions of CO2, NOx and noise. Specifically, a reduction of 75% in CO2 emissions per passenger kilometer, a 90% in NOx emissions, and a 65% in perceived noise relative to aircraft of the year 2000. Electrically powered machines as means of propulsion could reduce the emission impact of future aircraft through a combination of a higher energy conversion efficiency and synergies with the overall aircraft system. AAPE-98 is a regional hybrid-electric aircraft powered by a conventional turboprop engine and battery-powered electric motors connected to each other in a parallel configuration. The use of two energy sources in the propulsive system opens the design space and allows for the experimentation with novel aircraft configurations that could lead to interesting fuel and energy consumption reductions, taking advantage of the degrees of freedom introduced by the hybridization of the propulsive system. The main findings underline the importance of choosing the right power-to-energy ratio of a battery according to the flight mission. Performance and weight estimation leads to interesting and promising results, also in the perspective of future studies that will be focused on improving energy densities of today's batteries and superconducting technologies. Gravimetric energy and power density of the electric storage will determine the technical feasibility of the hybrid concept.

Conceptual design and optimization of the LEAF hybrid aircraft: a step towards the future

Mr. Vincenzo Mazzone (Università del Salento), *Andrea Fiorino, Francesco Antonio Marrocco, Vincenzo Donato*

In latest years, environmental policies have been conducted for the aviation sector to obtain less polluting propulsion. All-electric aircraft offer the possibility to eliminate direct fuel combustion emissions, but their development is blocked by battery energy limits and power density. Therefore, hybrid propulsion systems have emerged as a potential solution, as they have demonstrated a good compromise between performance and low polluting emissions. This work proposes an alternative solution to the powertrain of a regional aircraft by testing a hybrid configuration created with the aid of technologies that can be developed by 2040. Using the ATR 42 aircraft as a reference, the propulsion system was equipped with two turboprop and four electric motors, powered by both batteries and supercapacitors, the latter used in the take-off phase due to the high power density, they also have a structural function thus allowing a reduction in weight. The Wing-Load is estimated by the most critical condition that is the take-off phase through the take-off parameter to respect the required field length; the needed engine power is calculated for each flight phase. Finally, an analysis of the fuel consumption during the mission, of the emissions produced based on the origin of the energy sources, a survey on the costs, safety and environmental impact due to the disposal of the storage systems are reported to verify the sustainability of the solution.

The future regional aircraft

Mrs. Jona Eissele (University of Stuttgart), *Stefan Lafer, Cristian Mejía Burbano, Julian Schließus, Tristan Wiedmann*

In recent years, the rapid growth of air transportation and therefore the rise in air pollution and greenhouse gas emissions has generated a need for sustainable propulsion concepts in aviation. Therefore, hybrid-electric aviation propulsion technologies promise an environmentally friendly solution to meet the Paris Climate Agreement. As a contribution to the reduction of aircraft emissions, the design team of the University of Stuttgart is proud to present their concept for a sustainable regional aircraft as entry to the FUTPRINT50 Aircraft Design Challenge 2022. Benefiting from technological progress, this aircraft provides a sustainable solution for future air transport in the regional sector. This study assesses the efficiency advantages arising from the integration of a hybrid-electric powertrain. Within this design process, the mainly considered primary energy storages are sustainable aviation fuel and liquid hydrogen in addition to the electric battery for secondary energy storage. Hereby the future rise of the conventional jet fuel price as well as possible penalties on emissions were taken into account. As conceptual propulsion components the conventional gas turbine, the fuel cell and the electric motor were observed. While the gas turbine benefits from high volumetric and gravimetric energy densities, it still emits greenhouse gasses directly into the higher atmosphere. Concerning the fuel cell and the electric motor, these approaches provide greenhouse gas -free propulsion alternatives. However, liquid hydrogen and chemical batteries suffer from relatively low volumetric and gravimetric energy densities, leading to higher costs per passenger-km and reduced cargo capacity. Within this project, different concepts are subsequently assessed and evaluated to realize substantial synergetic effects between the propulsion approaches. Furthermore, the focus of this aircraft design process lies in efficiency improvement, increasing passenger comfort and overall, in the sustainable integration into the surrounding environment to compete in the future market of regional aircraft.

The First Step towards Green Aviation

Mr. Yi-Kai Peng (Universiteit Delft), *Egon Beyne, Katarina Grubbe Hildebrandt, Ozaif Ali, Carlo Rotundo*

Although currently a small portion of the market in terms of both flights and emissions, regional aviation is an interesting gateway towards hybrid-electric propulsion. The small ranges allow the implementation of technologies that are currently infeasible for a larger aircraft. By switching to a hybrid-electric propulsion system, gains in fuel consumption and emissions are possible, together with a larger design freedom in propulsion integration. In this study, a regional aircraft with a capacity of 50 passengers is designed with a maximum range of 800 km, targeted for entry into service in 2040. A trade-off analysis was carried out on several aircraft subsystems, including the propulsion system architecture, fuel type, fuselage, wing, and tail configurations. The trade-off criteria included sustainability, aerodynamic performance, cost, weight, safety, and technology readiness. A secondary trade-off was made by combining the best systems from the subsystem trade-off into different aircraft concepts to prevent unfeasible combinations of subsystems and to exploit synergies. Consequently, an initial sizing was performed on all aircraft configurations, using constraint analysis to find the required wing and power loading, considering the key parameters of propulsion integration. Weight, fuel consumption, technology readiness, cost, and operations were as trade-off criteria. The best concept was designed and analysed in detail with respect to the propulsion system, aerodynamics, stability and control, performance, and structures. A detailed propulsion system architecture was devised along with an elaborate aerodynamic wing design examining the effects of the propellers. The aircraft is also designed to minimise emissions and to allow the world to take its first step towards green aviation.

FUTPRINT50 project session: Part I

Session Chair : Prof. Andreas Strohmayer (University of Stuttgart, Germany)

Experimental Investigation of the Energy-Harvesting Performance of an Existing Aircraft Propeller

Mr. Robert Nederlof (Delft University of Technology), *D. Ragni & T. Sinnige*

The use of electric motors, together with propellers as propulsors, gives rise to distributed electric aircraft concepts, which can improve overall system efficiency by beneficial propulsion integration. The distributed propellers could be used as means of achieving high-lift conditions by blowing the wing, or for control and stability purposes using differential thrust. Furthermore, the propeller(s) could be used to recuperate part of the gravitational potential and kinetic energy of the aircraft by acting as small wind turbines. This energy-harvesting process could be used to partially recharge the batteries in flight phases where no energy input is needed. For highly cambered blade sections of conventional propellers, large negative angles of attack are needed to create the negative torque that allows for energy harvesting. The negative lift force on the blade sections also means that the propeller creates negative thrust, hence drag. The aerodynamics of both propellers and wind turbines are well understood when they are operating in their conventional regime. Wind turbines are specifically designed for energy-harvesting operations, having an inverted blade camber compared to propeller blades. Hence, when the propeller is used to harvest energy, the blades will operate in off-design conditions and this will have a negative effect on the blade loading. The positively cambered airfoil sections will be prone to separation at the negative angles of attack, limiting the energy-harvesting output power. Furthermore, it is uncertain what the most optimal propeller operation is to achieve the best balance between energy-harvesting power and associated negative thrust of the propeller. To characterize the energy-harvesting performance of a propeller that is designed for positive thrust conditions, a wind-tunnel experiment was performed in the Low-Turbulence Tunnel at Delft University of Technology. The experiment featured a 3-bladed version of the TUD-XPROP and can be seen in Fig. 1. Different blade pitch settings were tested at a fixed free stream velocity of 30 m/s. The different advance ratios were achieved by changing the rotational speed of the propeller. The propeller forces were measured using a six-component internal load cell to determine the energy-harvesting efficiency. This efficiency is defined as the amount of power that is being extracted as fraction of the total incoming available power in the freestream flow, reference to the area of the propeller disk. This definition is often used in the analysis of wind turbines and it is limited by the Betz limit. Furthermore, the negative thrust, that the propeller produces at a specific energy-harvesting condition, was measured. In this way, a correlation between energy-harvesting power and associated drag could be found. Another efficiency that was defined, is the turbine efficiency, which is a measure of the propeller’s ability to convert negative loading into energy-harvesting power. So this efficiency describes the energy-harvesting power as fraction of the created drag (i.e. negative thrust) power (P/TV), which is the inverse of the propeller efficiency. The experimental results showed that the maximum energy-harvesting efficiency was obtained at low blade pitch settings. The maximum value was found to be around 11%, for a blade pitch setting of 10◦ defined at 70% of the blade span. Increasing the blade pitch showed a continuous decrease in the maximum energy-harvesting efficiency, where the 30◦ blade pitch setting showed a maximum energy-harvesting efficiency of only around 6%. However, the relatively high energy-harvesting efficiency at low pitch settings comes at a cost of a large negative thrust. The turbine efficiency showed an opposite relationship between blade pitch setting and maximum efficiency compared to the energy-harvesting efficiency. For low blade pitch settings, a low turbine efficiency was observed, meaning that the negative thrust is large for a given energy-harvesting efficiency. For higher blade pitch settings, the negative thrust was smaller for a given energy-harvesting compared to the low pitch settings. Concluding, if maximum power is to be extracted from the incoming flow, the propeller should be operated at a low pitch setting, which then also leads to large negative thrust values. Increasing the pitch setting leads to a decrease in negative thrust for a given energy-harvesting efficiency, although the maximum obtainable energy-harvesting efficiency will also be less than at low pitch settings. Hence, for small negative thrust values, the propeller can most efficiently harvest energy at a high pitch setting. These results are useful for aircraft design studies in which energy-harvesting power would be traded against total aircraft drag.

An optimal battery sizing algorithm for future aircraft systems studies

Dr. Boris Berseneff (CEA), *Lionel De Paoli*

The path to climate-friendly aviation is a difficult way that needs to be traveled fast. A considerable and immediate drop of fossil fuels consumption is necessary to respect the Paris Agreement. Hybrid-electric and full-electric aircraft are part of the solution but developing a reliable and profitable hybrid-electric regional aircraft is a complex task. The European research project FUTPRINT50 aims at developing methods and tools to help to achieve this goal. The battery system is one of the key elements of aircraft electric architectures as it stores energy for propulsion and auxiliary systems. Among other challenges, optimal sizing (including mass, electric performances and aging) and safety are the two most difficult aspects to overcome. Herein, we propose a battery sizing algorithm, integrated to a plane level optimization tool (SUAVE), which, for a given power profile, optimizes battery systems sizing including all above cited parameters. The sizing algorithm is based on a three steps strategy:

1. Optimal battery sizing for a given power profile: Optimal series/parallel configuration that includes battery aging and nominal thermal management. At this step the total battery mass is estimated with a scalar coefficient. This is the standard approach for mass evaluation. It gives high uncertainty.
2. Optimal battery sizing including thermal runaway non propagation: We assure that in case of a thermal runaway of a cell, there is no propagation inside the battery pack. Two parameters are taken into account: cell-to-cell distance and thermal insulation material. Total battery mass is then refined a first time.
3. Optimal battery sizing including battery casing sizing. Based on actual experimental data, an analytical model of the battery casing helps to determine the optimal casing thickness. Besides Finite Element Analysis models based on a CAD battery casing under pressure, contributes to supports the analytical model through several safety module tests, including thermal runway of a cell inside the casing. A refined battery mass evaluation is then possible.

The reduced battery cell model is built up using several simulations of an electric equivalent circuit model of a cell (fixed chemistry, format and specifications) parameterized by testing. This model is then used to run an optimal battery sizing, finally taking into account performance targets (mass, volume, voltage, power), aging and safety.

Development and Analyses of a Thermal Management System (TMS) for a Hybrid-Electric Aircraft – FUTPRINT 50

Mr. Felipe Reyes Barbosa (Embraer), *Ricardo Gandolfi, Walter Affonso Jr., Ricardo Jose Nunes dos Reis, Michele Fernandino Westin, Carlos Roberto Ilário da Silva, Higor Feltrin Teza, Timoleon Kipouros, Panagiotis Laskaridis, Hossein Balaghi Enalou, Maria Coutinho, David Bento, Alain Souza*

One of the main challenges on the design of Hybrid-Electric Aircraft (HEA) is the high heat dissipation caused by the extensive use of electric equipment. Unlike gas turbines, in which most of heat is removed in the exhaust flow, electrical devices need cooling systems capable of removing the excess heat dissipated. However, each component has its own temperature and cooling restrictions. Therefore, a Thermal Management System (TMS) must be developed to handle all different requirements and, at the same time, minimize drag, weight and make the best use of the space available inside the aircraft. This paper discusses the different cooling requirements of the main propulsive components/systems to be found on a HEA, suggests possible TMS capable of operating under these constraints and discusses the main advantages and downsides of such thermal architecture.

Investigation of the operational flexibility of a regional hybrid-electric aircraft

Dr. Andrea Spinelli (Cranfield University), *Gustavo Pedro Krupa, Timoleon Kipouros, Boris Berseneff, Anh-Linh Bui Van, Ricardo Jose Nunes Dos Reis, Felipe Reyes Barbosa, Michelle Fernandino Westin, Ricardo Gandolfi*

The complexity of hybrid-electric aircraft propulsion systems is also characterized by the greater number of degrees of freedom of the energy management system, whose objective is to split the required power to fly the aircraft to the different available powertrains (i.e., gas turbines, electric motors, fuel cells, etc.). Typically, a single design mission is considered for the purpose of assessing the performance of a hybrid-electric propulsion system, often with a simple constant split power between the batteries and gas turbine. A probabilistic set-based design space exploration methodology is used and allow us to study the effects of lifecycle analysis of the battery pack of a hybrid-electric 50-seater turboprop, while different mission scenarios are considered. Using this approach, it is possible to flexibly find multiple families of energy management strategies that can satisfy battery lifing requirements and the reduction of emissions simultaneously. Furthermore, the generated data can help the designers to understand the hierarchy of the requirements that drive the design of the propulsion system for a range of operating scenarios, and with emphasis to the energy storage system. Hence, the airliners are offered with an enhanced operational flexibility of the aircraft for different and desirable mission profiles.

Design and Off-design Performance Analysis of Thermal Management System (TMS) for a Parallel Hybrid Electric Regional Aircraft

Dr. Hossein Balaghi Enalou (Cranfield University), *Jacob simon, Timoleon Kipouros, Panagitos Laskaridis*

A Thermal Management System (TMS) for a hybrid electric regional aircraft is designed. Hot day take-off condition is considered as the worst ambient condition, which results in the requirement for refrigeration cycles for low-grade heat dissipated from the electric components such as batteries and converters. A thermodynamic model of the vapor cycle system (VCS), as well as a finned ram air heat exchanger (HEX) are developed. A parametric study of the VCS cycle parameters and HEX models for various heat loads and operating temperatures of components are conducted. A simplified method is developed for estimation of HEX weight which is used to optimize the TMS at system level in terms of

weight and required power. Finally, a TMS is designed and optimized for a 50-PAX hybrid electric aircraft. Results offer weight and power per kW of dissipated heat which can be used as system level parameters for future studies.

FUTPRINT50 project session: Part II

Session Chair : Prof. Andreas Strohmayer (University of Stuttgart, Germany)

Design and off-design space exploration of advanced turboprop engines for future hybrid electric propulsion system

Mr. Hossein Balaghi Enalou (Cranfield University), *Evangelia Pontika, Panagiotis Laskaridis*

The trend for future gas turbines is operating higher Turbine Entry Temperature (TET) and Overall Pressure Ratio (OPR). In this paper, the thermodynamic cycle of future turboprop engine at various TETs and OPRs is investigated. The engine geometry is affected significantly mainly by higher TET, resulting in smaller engine core. The engine flow path is designed with an in-house software. Smaller cores have higher losses mainly at the blade tips. Simplified empirical correlations are used to estimate the losses. Having smaller core also motivates the use of centrifugal compressor which is studied by simplified correlations for losses. Finally, the baseline engine performance at off-design condition in terms of fuel consumption, NOx emission and engine lifing is presented for selected energy management strategies.

Preliminary Hybrid-Electric Aircraft Design with Advancements on the Open-Source Tool SUAVE

Mr. Jonas Mangold (University of Stuttgart, Institute of Aircraft Design), *Dominik Eisenhut, Felix Brenner, Nicolas Moebs, Andreas Strohmayer*

Environmentally friendly and sustainable air transport is necessary to mitigate climate change. A hybrid-electric propulsion system could be one opportunity and solution. Within the project FutPrInt50, the entry-into-service of hybrid-electric regional aircraft by 2035/40 seems feasible to reduce emissions, achieve acceptable ranges and to be commercially competitive. SUAVE is a preliminary aircraft design environment used for sizing and includes common handbook methods. As an open-source tool, it enables the usage and improvement of existing methods and the implementation of new ones. For the already complex aircraft design process with constraints like the center of gravity, sizing of single components and the iterative mass estimation, hybrid-electric propulsion brings new variables to the design. Adding electric components to the propulsion system and a battery as a secondary energy source will affect the design and the sizing algorithm. The advantage of SUAVE is that the propulsion architecture is independent of the mission calculation. Therefore, different combinations of propulsion components and strategies are possible without using the Breguet equation for range calculation. Changes in the iterative design loop for hybrid-electric aircraft and the implementation of a propulsion network, which defines the combination and interaction of single components, are the focus of this presentation. The sizing of the different components of the powertrain is shown by a preliminary analysis of the top-level aircraft requirements in a sizing chart. Other aspects and systems come into consideration resulting from hybridizing the propulsion system. The flexible energy network can adopt the thermal management system and energy management strategies in SUAVE. A variation of the hybridization of power, energy sources and boosting/harvesting are possible at every numerical control point throughout the mission. This variation enables for example, a minimized energy usage or emissions during flight. Furthermore, the hybrid-electric powertrain and battery sizing considering regulations and certification standards for one engine inoperative become challenging. The electric part of the propulsion network allows for additional solutions to converge the mission during the sizing (e. g. fulfilling power requirements in different mission segments). Subsequently to the sizing of the aircraft, the postprocessing by assessing predefined figures of merit is implemented as well. Therefore, conventional and hybrid-electric aircraft can be compared by their emissions, aircraft introduction and cash operating costs index. The component fidelity levels can be easily adapted and thus allow for fast initial results and detailed sensitivity analysis on various parameters. Detailed results of the preliminary aircraft design will be shown in the continuing presentation "Case Study on Hybrid-Electric Aircraft Designs Enabled by an Enhanced SUAVE Version" by Dominik Eisenhut.

Case Study on Hybrid-Electric Aircraft Designs Enabled by an Enhanced SUAVE Version

***Mr. Dominik Eisenhut (University of Stuttgart,** Institute of Aircraft Design), Jonas Mangold, Nicolas Moebs, Felix Brenner, Andreas Strohmayer*

Climate change and governmental restrictions challenge the aviation sector to become more environmentally friendly. Depending on the aircraft size and mission, different concepts can be foreseen. For regional aircraft, hybrid-electric propulsion looks most promising when it comes to reducing emissions while achieving acceptable range. This presentation will focus on a case study for various hybrid-electric aircraft designs. Different sizing and operational parameters will be varied on aircraft and subsystem level to identify favourable regions in the design space. This will include for example different energy management strategies, hybridization & technology levels and more. For each concept, a converged aircraft design, fulfilling predefined top-level aircraft requirements, is necessary. This task is carried out with the help of an enhanced SUAVE version which is part of a corresponding presentation. The flexible toolbox with similar underlying models ensures the comparability of different hybrid-electric and conventional reference aircraft designs. Conclusions on the impact on aircraft performance will be drawn for all analyzed designs. To this end, different measures can come into play such as for example, overall mass and component masses, as well as power and energy requirements for given missions. Another important aspect is the interplay of different subsystems and their impact on aircraft level including potential synergies. For instance, increasing the specific power of an electric motor might impose additional challenges on the thermal management system (TMS), which lowers electric motor weight but adds complexity and thus probably mass on the TMS side. Parameters to assess different aircraft can be for example the maximum takeoff mass, energy usage for different missions, or emissions. All in all, this presentation will highlight aircraft design as a complex task where optimizing every single subsystem alone will not necessarily result in an optimal solution on aircraft level. This presentation is a follow-up to the presentation "Preliminary Hybrid-Electric Aircraft Design with Advancements on the Open-Source Tool SUAVE" by Jonas Mangold which covers the enhancement of SUAVE.

Deriving a Year 2040 Reference Aircraft from a Modern Turboprop, Implemented and Calibrated in SUAVE

***Mr. Felix Brenner (University of Stuttgart),** Jonas Mangold, Dominik Eisenhut, Nicolas Moebs, Andreas Strohmayer*

The FUTPRINT50 project aims at preparing grounds for a 50-seat regional aircraft with hybrid-electric propulsion, intended for an entry-into-service in 2035/2040. Two conventional reference aircraft - one state-of-the-art and one extrapolated to an Entry-into-Service (EIS) 2040 - are used to assess and calibrate the design concepts. With a maximum seating capacity of 50 passengers and a design range of 840 NM, the ATR 42 was selected as the modern-day reference aircraft for FUTPRINT50. As part of the FUTPRINT50 project, the open-source aircraft design tool SUAVE is adapted for hybrid-electric aircraft. To calibrate the preliminary aircraft design, the ATR 42 therefore is reverse engineered in SUAVE, using official manufacturer manuals and publications as well as aircraft data collections for calibration. From this data, a list of top-level aircraft requirements was derived, which the SUAVE model converges to. The environmental impact of each aircraft is represented by an evaluation of the CO2, NOX and noise emissions. By applying calibration factors to textbook aircraft design methods implemented in SUAVE, the model resembles the real-world data with an error of less than 1%. Since the ATR 42-500 and -600 in operation today will be outdated aircraft by 2040, a comparison to the hybrid aircraft designed in the frame of FUTPRINT50 would not be meaningful. Hence, a conventional reference aircraft with an EIS in 2040 is defined. This aircraft is based on the ATR 42, but includes several technology factors, reflecting a higher wing aspect ratio, more efficient engines and improved materials. This conventional reference aircraft meets the same top-level aircraft requirements as the FUTPRINT50 hybrid-electric aircraft. The presentation has a focus on the calibration process and the resulting aircraft data compared to real-world and manufacturer information. Furthermore, the performance of the two reference aircraft is analyzed.

Electrified Propulsion System Modelling and Performance Considerations for FutPrint50 Regional Aircraft

Dr. Bahareh Zaghari (United Kingdom), *Tianzhi Zhou, Abhishek Kiran, Hossein Balaghi Enalou, Evangelia Pontika, Andrea Spinelli, Timos Kipouros, Panagiotis Laskaridis*

The paper presents the development, integration, and the use of a generic simulation framework for future electrified propulsion systems. The framework has been partly developed and used under the FutPrint50 project and is used for evaluating the impact of electric technologies in the case of a generic 50 passenger regional aircraft. Typical power requirements throughout the mission profile are considered for modelling the hybrid electric system. Two architectures are presented and discussed, a parallel hybrid electric architecture combining gas turbine and batteries and a parallel hybrid architecture combining gas turbines, fuel cells and batteries. Emphasis is placed on the modelling and integration of the different electric technologies along with their interdependencies and interactions. Considerations related to the number of electrical/energy sources and sinks are discussed along with the impact of distribution voltage on the various electric components and machines. For the purposes of the analysis generic electrified systems are modelled and simulated that are based on "off-the self" electronic and fuel cell components. Variations in operating points and efficiencies throughout the mission profile for the individual components, subsystems, overall propulsion system, and aircraft are considered and discussed.

Future aviation fuels and their role in the transition to climate neutral aviation

Dr. Valentin Batteiger (Bauhaus Luftfahrt)

The aviation industry intends to eliminate net CO2 emissions by the year 2050 [www.destination2050.eu]. This target requires a transition to renewable fuels over the next decades. Scalable and sustainable fuel production pathways are needed to meet future jet fuel demand. Furthermore, non-CO2 emissions contribute significantly to the full climate impact of aviation. Alongside with technological and operational measures, clean-burning synthetic fuels reduce the radiative forcing of aviation-induced ice clouds. This contribution will motivate the key role of future aviation fuels for the transition to climate-neutral aviation by reviewing fuel demand projections, feedstock potentials, fuel production pathways and the interplay of fuel composition, emissions, and climate impact. One focus will be a comparative assessment of synthetic fuels from solar and wind energy, advanced biofuel production pathways and first-generation aviation biofuels, mainly in terms of their production potential, production cost and environmental impact. By providing a brief but comprehensive overview about future aviation fuel options, this contribution introduces to a session that addresses important aspects of future aviation fuel production and use in more detail, namely:

- “Fast-Track to Climate Neutral Aviation with 100% SAF”, by Patrick LeClercq/Bastian Rauch, DLR Institute of Combustion Technology
- “Renewable Fuel Options for Aviation – a system-wide comparison of Drop-In and Non Drop-In Fuel Options”, by Gunnar Quante, aireg/Hamburg University of Technology
- “Estimating Power-to-Liquid Fuel Production Costs at International Prime Wind and Solar Power Locations”, by Benjamin Portner, Bauhaus Luftfahrt

Renewable Fuel Options for Aviation Development Scenarios for Drop-In and Non Drop-In Fuel Options

Mr. Gunnar Quante (TUHH), *Nils Bullerdiek, Ulf Neuling, Martin Kaltschmitt*

The CO2-emissions of the global air transport sector were approximately 1 Gt of in 2018. This corresponds to ca. 2.4 %/a of anthropogenic CO2-emissions, while the overall share of aviation in regard to global anthropogenic climate forcing is estimated at 4%/a. Assuming constant air traffic growth and future fuel efficiency improvements, aviation’s carbon emissions could double to more than 2 Gt of CO2 in 2050. A key lever for the mitigation of these emissions is the replacement of currently used fossil-based aviation fuels by specification compliant (“drop-in”) fuel options from renewable sources. However, their use presently accounts for less than 0.1 % of global aviation fuel consumption. Other fuel options, which do not comply with current aviation fuel specification, are accordingly called “non-drop in” fuel options. These (e.g. hydrogen or methanol) receive increasing interest in other sectors and within the overall energy system. Hence, they might become available in greater volumes compared to renewable drop-in aviation fuels based on kerosene. Some alcohols, in particular ethanol, are already being produced based on renewable feedstock. However, these fuel options cannot be used within existing aircraft fleet. The design of new or modification of existing aircraft and infrastructure would be necessary instead. Against this background, the goal of this study is to derive scenarios for the future development of drop-in and non-drop in aviation fuel options. All presently certified drop-in aviation fuel options based on kerosene are discussed. For non-drop in fuel options three alcohols (methanol, ethanol, butanol) as well as three gases (ammonia, methane, hydrogen) are assessed. The following points summarize central results: • The provision of drop-in options is mainly limited by lacking production capacities. Non drop-in options could be accessible at greater volumes, due to partly existing production infrastructure, but incur fuel infrastructure modifications, the need for modification of existing or development of new aircraft designs. • Currently, all renewably sourced fuel options in this study are more expensive than fossil fuel based kerosene. A renewable fuel demand from aviation alone will most likely not induce significant effects of technological learning and upscaling. Other sectors, such as the chemical industry, could enable faster cost degressions. • In order to achieve international climate agreements, immediate emissions reductions are necessary in aviation. Currently available drop-in fuel options play a key transitional role until more advanced technology, such as hydrogen, fuelled aircraft become available and replace the use of renewable drop-in kerosene in different air transportation segments.

Estimating Power-to-Liquid Fuel Production Costs at International Prime Wind and Solar Power Locations

Mr. Benjamin W. Portner (Bauhaus Luftfahrt)*, Valentin Batteiger*

The Power-to-Liquid (PtL) process offers the potential to produce large quantities of renewable fuel using abundantly available solar and wind energy resources. Our contribution presents a PtL fuel production cost assessment at various preferable wind and/or solar power locations worldwide. A Python tool was developed to estimate the fuel production costs and -volumes of generic PtL plants at the respective sites, taking into account the fluctuating nature of wind and solar energy with the help of hourly resolved generation profiles. The plant's key subsystems are sized to minimize the cost of fuel production. Our results show that a mix of wind and photovoltaic (PV) power achieves the lowest costs at most of the studied locations, indicating that both profile types show sufficient complementarity to generate cost advantages. In general, favorable wind sites achieve lower production costs than favorable solar sites under the current cost assumptions. Whereas the production costs of PV-powered plants are minimized by buffering diurnal cycles with the help of gas storage, wind-powered designs are more cost-effective without storage*, provided that both electrolysis and fuel synthesis can follow the generation profile flexibly.

**The cost-optimization algorithm sets the gas storage capacity to zero provided that the downstream processes are sufficiently flexible. This means that energy is not stored in the form of intermediate H2. However, it is expected that a minimum amount of gas storage is still necessary in PtL plants for operational reasons.*

Flame Propagation Enhancement of hydrogen/methane mixture by nanosecond plasma discharges

Dr. De Giorgi Maria Grazia (University of Salento), *Mehdi Ghazanfar, Cinieri Giacomo, Zubair Ali Shah, Bonuso Sara, Ficarella Antonio*

Combustion is playing the leading role in air transportation, however, the combustion efficiency of existing aero-engines is relatively low, and also the burning of fossil fuels is producing hazardous emissions which affect climate change. Therefore, to meet the strict emission regulations of CAEP

(Committee on the Aviation of Environmental Protection) and increase fuel efficiency, several international organizations are working on the concept of lean combustors. Currently, hydrogen is considered a carbon-free and alternative fuel. This study investigated the numerical and kinetic modeling of ignition and combustion enhancement of hydrogen/methane air flames using nanosecond plasma discharges (NSPD). Due to the lack of detailed literature on plasma kinetics of hydrogen/air mixture, it is difficult to understand, actually what kind of species played a role to enhance the combustion process. By motivating the exceeding discussions, in the present study, an extended version of the plasma kinetic model of H2/air was used for numerical analysis. ZDPlasKin and CHEMKIN were coupled together to investigate the thermal and kinetic effects of plasma discharge on the H2/air mixture. The experimental data of electrical characteristics such as reduced electric field (EN) and energy input (Ei) obtained through the non-reactive flow conditions were used for numerical analysis. Different plasma actuation conditions were considered particularly focusing on low inlet temperature and pressure and their effects on combustion enhancement. The key reaction pathway analysis is conducted to identify the key elementary reactions involved in the ignition enhancement using NSPD. The lean flammability limit was described as the minimum fuel-air mass ratio or lowest volume of fuel in the air that can result in hydrogen combustion using different plasma actuation conditions. Finally, the ignition characteristics have been investigated. The output product stream from ZDPlasKin for H2/air plasma discharges was inserted into the target initial equivalence ratio and temperature mixture of H2/air. The energy equation was considered to describe the thermal effects produced due to the temperature rise during the discharge process. The ignition timings are defined in terms of the time required for achieving the predicted flame temperature, sufficient for the combustion process. It has been noticed that NSPD produced a significant amount of H, O, and OH radicals that promote the lean flammability limits and ignition enhancement.

GREAT project session

Session Chair : Mr. Michael Finke (DLR, Germany)

The GreAT Project - Overview

Mr. Michael Finke (DLR)

This session will report the latest findings and results of the Horizon 2020 project 'Greener Air Traffic Operations' (GreAT). The work presented focusses on how air traffic management can contribute to a reduction of greenhouse gas emissions produced by the air traffic, as well as its impact on climate change. Presentations will provide detailed proposals for improved ground and approach control procedures, which will demonstrate the possibilities but also the limitations of optimizing air traffic control towards minimum environmental impact. Further, this session will give insights in the environmental impact assessment based on an analysis of current and modified aircraft trajectories. It closes with a review from an airline perspective, underlining again the importance of research in this area.

Efficient Conflict-Free Taxi Trajectories Using Genetic Algorithms

Mr. Lukas Tyburzy (German Aerospace Center), *Meilin Schaper, Lennard Nöhren, Kathleen Muth*

In order to reach the goals of the Paris Agreement, it has become evident that it is necessary to reduce the impact of the whole aviation sector on the environment. The Project GreAT (Greener Air Traffic Operations) aims to showcase how a combination of advanced air traffic management tools and procedures for departure, en-route, arrival and surface operations can support this reduction of aviation's environmental impact. For the surface operations of aircraft at the airport, the surface management system TraMICS+ (Traffic Management Intrusion and Compliance System Plus) has been developed to support ground controllers with a safety situation assessment and trajectory advisories for taxi operations. TraMICS+ uses a genetic algorithm to plan and adjust taxi-trajectories in real time to resolve conflicts between aircraft on the ground, with the aim to reduce holding time after engine startup as well as preventable braking and acceleration actions due to other traffic. This paper presents a case study at Hamburg Airport, comparing the fuel efficiency of regular taxi trajectories with the optimized conflict-free trajectories generated by TraMICS+.

Enabling green approaches by FMS-AMAN coordination

Mr. Nils Ahrenhold (German Aerospace Center), *Izabela Stasicka, Thorsten Mühlhausen, Marco-Michael Temme*

Growing political pressure and widespread social concern about climate change are triggering a paradigm shift in the aviation sector nowadays. To make aviation more sustainable, many projects are being launched to improve procedures and methods currently used. Targeting one of the major goals of reducing aviation's CO2 emissions and their impact on climate change. The development of innovative solutions towards an environmentally friendly carbon-neutral aviation sector and costeffective flight control are in the foreground today. In this paper, a new coordination between aircraft Flight Management Systems (FMS) and Arrival Managers (AMAN) is investigated to enable fuelefficient and more sustainable trajectories and approaches. For this purpose, all concept elements have been first developed and then implemented for evaluation in the real-time simulation environment at DLR Braunschweig. The coordination between aircraft FMS and AMAN poses two major challenges. Firstly, current AMANs are developed with regard to increase capacity and to support air traffic controllers at scheduling and sequencing inbounds. Thus, the planning process is not optimized towards fuel-efficient trajectories. Enabling greener approaches with less CO2 emissions, such as Continuous Decent Operations (CDO), depend upon a redesign of the airspace structure and the capacity centric AMAN calculation. Since these independent long-distance approach CDO procedures start at the top of decent and end on the final, aircrafts' speed profiles are unknown for air traffic controllers, which takes up more space for coordination with standard approaches. Therefore, a completely new terminal maneuvering area was designed for an independent parallel runway system and a trajectory negotiation process between the aircraft's FMS and the inhouse developed AMAN was established to enable CDOs. In this paper, approaching air traffic is divided into two types, which are distinguished by their technical functionality of the on-board FMS. Aircraft, equipped with conventional FMS are categorized as 3D-FMS aircraft. These aircraft are able to follow calculated trajectories. However, they are missing the ability to meet a target time within a range of less than twenty seconds reliability due to changing environmental conditions. Aircraft, equipped with advanced FMS and a broadband data link are referred as 4D-FMS aircraft. These aircraft have the capability to perform a flight along pre-calculated trajectories with negotiated target times within a range of plus-minus six seconds. In this context, the 4D-FMS equipped aircraft received all privileges to plan their fuel-efficient (low CO2 emission) trajectories and negotiate those with the AMAN. Furthermore, another result of the new airspace design is the splitting of the arrival streams for 3D-FMS and 4D-FMS equipped aircraft. Where the latter ones use a late merging point (LMP) to be integrated on the final only six miles before the thresholds, whereas 3D-FMS aircraft use the conventional path stretching areas. This leads to the second major challenge for air traffic controllers. The AMAN and the 4D-FMS plans the trajectories time-based, whereas air traffic controllers guide the traffic distance-based. To enable coordination and traffic guidance, the two tactical assisting systems Ghosting and TargetWindows have been implemented for air traffic controllers in a primary display, to provide more sophisticated support functionalities then today. The whole concept is further conducted in a first validation campaign with air traffic controllers from HungaroControl at DLR real-time simulation facilities in Braunschweig. The results from simulation data analysis indicate a reduction in fuel burn from 4D-FMS equipped aircraft and associated lower CO2 emissions, reducing the impact of aviation on global CO2 emissions. Moreover, an evaluation of the tactical assisting systems, to support air traffic controllers when combining time- and distancebased planned arrival streams, are carried out by them.

The environmental impact assessment of greener trajectories

Prof. Gustavo Alonso (Universidad Politecnica de Madrid), *Arturo Benito*

GreAT (Greener Air Traffic Operations) is a project funded by the European Commission under the H2020 frameowrk programme, that began in January 2020 and will be completed by June 2023. The overall objective of the cooperation of Chinese and European partners in GreAT is to reduce the fuel consumption and gas emissions during "gate-to-gate" flight phases through developing and assessing environment-friendly air traffic operational concept, adaptive airspace and green trajectory optimization technologies, and supporting avionic systems. Evaluation campaigns through cross evaluations are planned to validate the proposed concept and show a potential significant reduction of the aviation's impact on climate change. In order to accurately and scientifically describe the impact of aviation emissions on climate change, it is necessary to clarify the sources and types of aviation pollutants, as well as determine the causes and distribution laws of the aviation emissions, so as to analyse the impact on the atmosphere to obtain the impact on climate change. The climate change environmental impact of aviation is still in development phase, with different levels of scientific certitude. It is generally accepted that CO2, NOx and contrails are covering more than 95% of the total impact, if cloud formation is excluded due to the low scientific knowledge about its formation and effects. GreAT assessments consider those three elements. The comparative parameter is the radiative forcing of each one. As this is an instantaneous magnitude, the final impact indicator will be the Global Warming Potential (GWP) that takes into account not only the instantaneous effect but the average life of every emission. Based on the scientific description of the impact of aviation emissions on the climate, the work within GreaT is seeking the key factors of the impact about aviation emissions on climate change characteristics by using sensitivity analysis, such as greenhouse gases, pollutant gases and condensation, and then select these factors as environmental impact assessment indicators, including fuel consumption, aviation emissions, air quality and greenhouse effect, etc. establish a calculation model for evaluation indicators using the fuel consumption model, gas emission model and climate change model. System analysis methods are used to build an aviation emission environmental impact (EIA) assessment index system structure, use environmental impact assessment indicators, construct a general environmental impact assessment index system, and propose a comprehensive assessment method for aviation environmental impact. The following step in the project is the environmental impact assessment of air traffic operations to determine how green air traffic performs. According to the existing air traffic operation patterns, the flight characteristics and trajectory characteristics of the aircraft are pushed, and the environmental impact assessment index system is used to evaluate the environmental impact under the air traffic operation plan and the impact and improvement effect on climate change.

Operational assessment by an airspace user

*Tim ten Velde***, *Mr. Clim van der Weijden (KLM)***

GreAT (Greener Air Traffic Operations) is a project funded by the European Commission under the H2020 framework program. The project started in January 2020 and will be completed by June 2023 and consist of a partnership of several European and Chinese parties. The overall objective of the GreAT project is to reduce the fuel consumption and gas emissions during “gate-to-gate” flight operations. This is achieved by developing and assessing an environment-friendly air traffic operational concept, adaptive airspace and green trajectory optimization technologies including supporting (airborne) avionic systems. Evaluations are executed to validate the proposed concept and show a potential significant reduction of aviation’s impact on the environment. As an Airline we realise that today’s aviation is far from sustainable. That is why we work hard to improve every relevant aspect of our company to improve on our societal role and environmental impact. The aviation industry has the ambition to become net zero by 2050. To underline our commitment, we are developing our own pathway according to the Science Based Targets Initiative. This pathway consists of several measures, and each one contributes to reducing our CO2 emissions step by step. These include fleet renewal, operational improvements, carbon offsets and replacing fossil-based jet fuel with Sustainable Aviation Fuel (SAF). Within the GreAT context our main role is to bring in the operational experience as an airspace user. We focus on short-haul and long-haul working packages and support the development of improved flight paths on a vertical and lateral profile. Our goal is to improve operational efficiency by focusing on fuel planning and usage, route optimization, aircraft performance, weight reduction and ground operations. As an example; improvements can be achieved by an increase of predictability of the planned route to be flown at an optimal planned level and the most optimal descend path without delays. Most flights carry extra fuel for unforeseen circumstances. Carrying this extra fuel generates extra emissions. In this way predictability (taking less fuel) increases sustainability. The commercial benefit of predictability is a robust Network performance where connections are realised for transferring passengers. Another operational benefit is an optimised A-CDM model generating shorter taxi times also increasing sustainability. The next step in the project is the operational assessment of air traffic operations to determine how green air traffic performs. The new trajectories will be validated in our flight plan systems and assessed in our flight simulator to determine if they perform as designed and if additional training for flight crews is needed.

ACKNOWLEDGMENT

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Human-centred design of AI and digital assistants: Part I

Session Chair : Dr. Simone Pozzi (Deep Blue, Italy)

AI ER4 Projects common introduction

Mr. Carlo Abate (Deep Blue Srl)

Nowadays, as in our everyday life, automation is being more and more introduced to help the Air Traffic Controllers to reduce their stress and workload while performing their usual activities, so to meet the needed safety standards. In ATM, sometimes a simple answer is not enough: human lives are involved, therefore, an Air Traffic Controller could need an Artificial Intelligence able to try to explain why it took that specific decision to trust more an AI outcome. In ATM there are some tasks with a low need of explanation, or more complex tasks where an explanation is fundamental to trust properly the AI outcome. MAHALO, TAPAS and ARTIMATION tackled medium to high complexity Conflict Detection and Resolution tasks. These projects started from the assumption that in Conflict Detection and Resolution the explanation is fundamental. Each ATCO has his unique crossing resolution style and make their decisions based on sector capacity, the final destination and many other variables to be considered to develop an optimal solution in a limited amount of time. On the other hand, monitoring tasks can have low, medium or high need of explainability, since it depends on different factors such as the task itself, or the condition of the sector. Monitoring requires developing a shared situational awareness with all the other actors involved in the tasks: this is AISA project use case, that aimed at automating monitoring tasks, making the system aware of traffic situations and issues in that moment in time. SafeOPS tried to assess the need of explainability of the Go Arounds. Tower controllers are involved in approach operations that can require a lower need of explainability: what matters, sometimes, is just understanding if the pilot will ask for a Go Around, to be prepared and optimise the following operations. TAPAS and ARTIMATION, finally, developed a second use case within their projects to answer to the need of explainability of Demand Capacity Balancing tasks, such as the duties of flow and network managers. In this common session, representatives from the five XAI projects will present their preliminary and final results, illustrating all the use cases with their similarities and differences.

AISA project: AI Situational Awareness Foundation for Advancing Automation

Dr. Tomislav Radišić (University of Zagreb)

AISA (AI Situational Awareness Foundation for Advancing Automation) was a SESAR Exploratory Research project investigating how to increase automation in air traffic management. The project explored domain-specific application of transparent and generalizable artificial intelligence methods. The main objectives of the project were to explore the effects of human-machine distributed situational awareness and opportunities for automation of monitoring tasks in en-route operations. The Artificial Situational Awareness system developed by the Project collects high-integrity information (using aeronautical information exchange models) to create knowledge graph describing the traffic situation on a sector level. In addition to factual knowledge, a knowledge-based system manages and executes rule-based knowledge, defined and executed on top of the factual knowledge via reasoning engine. Knowledge-graph is integrated with multiple machine-learning (ML) modules which enable the assessment of probabilistic events (e.g. aircraft trajectory prediction or conflict detection). By combining reasoning engine with machine-learning, the system assesses complex interactions between objects, draws conclusions, explains the reasoning behind those conclusions, and predicts future system states.

Human-in-the-loop simulations were conducted in Zurich in the facilities of Skyguide with the involvement of air traffic controllers with two main goals. First, to compare the human and artificial situational awareness and, second, to assess the feasibility of integration of artificial situational awareness system into team situation awareness. The experiments showed that the artificial situational awareness system is comparable to human situational awareness and that a lot of work remains to be done to successfully integrate the two. The results of the project will be used to inform the future research directions in the context of human-machine shared situational awareness. Also, it lays foundation for research of integration of further machine learning based automation with knowledge graph systems.

TAPAS project: Towards and Automated and exPlainable ATM System

Mr. Jose Manuel Cordero (CRIDA A.I.E), *Rubén Rodríguez, George Vouros, Gennady Andrienko, Natalya Andrienko, Ian Crook, Antonio Gracia, Hugo Salinas, Natividad Valle, Maria Florencia Lema, Enrique Iglesias*

In a nutshell, TAPAS project has carried out is the systematic exploration of AI/ML solutions towards increasing levels of automation in specific ATM scenarios, through analysis and experimental activities, with the objective to deliver principles of transparency, enabling the application of AI/ML supported automation in ATM, in particular in two operational cases: Conflict Detection & Resolution applied to Air Traffic Control (ATC, tactical), and Air Traffic Flow Management (ATFM, pre-tactical).

In particular the project will present its findings in:

- The development eXplainable Artificial Intelligence (XAI) methods, addressing the requirements of both operational cases, which focus on the needs of operators (and potential other actors) concerning the quality and transparency of solutions generated by XAI methods.
- The application of Visual Analytics techniques to assess and enhance explainability of AI/ML systems in ATM.
- The results of the validation experiments involving skilled ATCOs that assess the applicability of XAI methods in the various levels of automation considered, exploring different ways of interaction and information exchange. The focus is on the understanding of how operators (and potential other actors) increase their trust to XAI methods.

The development of a general set of principles for addressing explainability and transparency in AI/ML applications in the ATM domain

ARTIMATION project: Transparent Artificial intelligence and Automation to Air Traffic Management Systems

Mr. Nicola Cavagnetto (Deep Blue Srl)

To further improve the reliability and functionality of AI, it is necessary that users become aware of "how" and "why" the Artificial Intelligence is making the decisions. Reliability and trust will come once humans understand how AI systems think and operate. ARTIMATION's main aim is to use Explainable Artificial Intelligence (XAI) and AI methods to address the challenges related to transparency of automated systems in the ATM domain. To meet this objective the project explored explainability through 2 different ATM use cases: Conflict Detection and Resolution and Delay Prediction and Propagation. Both proposed tools aim at improving explainability through AI algorithms based on data-driven storytelling and immersive analytics, assessing the effectiveness of different visualisation techniques. Two main validation activities were carried out in the project, a low fidelity simulation on Conflict detection and resolution task with 15 ATCOs and a workshop that explored Delay Prediction and Propagation for traffic flow management will be presented. The objectives guiding the validation activities were to measure the impact of different levels of explainability and different types of visualization on acceptance, human performance (i.e. trust, situation awareness, workload, usability) and on system performance. The methods used to collect information were interviews, questionnaires, log file analysis and neurometrics. Preliminary results indicate that high levels of explainability can negatively impact experienced ATCOs performance, especially in high workload situations or in time constrained tasks. Trust and reliability become critical aspects to consider in AI that supports short-term decision support tools. On the other hand, high levels of explainability seem to be potentially interesting for operational optimization, training and briefing purposes. XAI can play an important role in shaping the problem solving style of inexperience ATCOs, this can be both an opportunity and a drawback.

MAHALO project: Machine Learning for Air Traffic Management: Empirical Results of Human-in-the-Loop Simulation

Borst, C., ***Mr. Cocchioni, M (Deep Blue Srl****), Hilburn, B., Monteiro Nunes, T. & Westin, C.*

The SESAR-funded Modern ATM via Human / Automation Learning Optimisation (MAHALO) project recently completed two years of technical work exploring the human performance impacts of AI and Machine Learning (ML), as applied to enroute ATC conflict detection and resolution (CD&R). MAHALO started from a simple but profound question: Should we be building ML that matches the style and strategies of the air traffic controller (a construct the team termed conformance), or should we be building ML that is explainable / understandable to the controller (transparency)? MAHALO first developed a hybrid ML CD&R capability (using both Supervised- and Reinforcement Learning models), along with a realtime simulation platform and experimental User Interface (UI). After a series of development trials, the project culminated in a pair of field studies (i.e., human-in-the-loop trials) across two EU countries, with a total of 35 operational air traffic controllers. In each of these two field studies, controller behaviour was first captured in a pre-test phase, and used to train the ML system. Subsequent main experiment trials then experimentally manipulated within controllers both Conformance (as either a personalised-, group average-, or optimized model) and Transparency (as ether a baseline vector depiction, an enhanced graphical diagram, or a diagram-plus-text presentation). Dependent variables included both objective performance / behavioural measures (e.g. acceptance of advisories), and also self-report data (rated workload, survey responses). The proposed talk would focus on design of the ML system, the experimental user interface, and experimental trials, with particular emphasis on results of the recent field studies as they addressed the impacts of conformance and transparency on controller behaviour and survey responses. Finally, discussion would centre on lessons learnt, in terms of both designing and evaluating ML for air traffic control applications.

SafeOPS - Evaluating an AI based Decision Support for Go-around Handling in the Operational Context

Mr. Lukas Beller (Technical Universtiy of Munich), *Carlo Abate, Pablo Hernandez, Philipp Kurth*

The next generation of air traffic management systems is being driven more and more toward digitization. The process is driven by two goals that are difficult to reconcile. First, the demand for increased capacity and cost efficiency. Second, maintaining and optimally improving a high level of safety and resilience of the air traffic management system. SafeOPS, a SESAR Joint Undertaking funded, exploratory research project, is investigating whether and how AI solutions can enable safety applications that create a proactive, data-driven approach to safety and predict potential threats in real time. More specifically, SafeOPS developed a prototye AI solution, to provide air traffic controllers with timely warnings of the occurrence of go-arounds, to help them in their decision-making when handling go-arounds. SafeOPS exemplarily investigates the potential safety and resilience benefits, but also the potential risks of data-driven, predictive decision-support tools in air traffic management. With this contribution, we provide an overview of SafeOPS and explain the underlying user-centered development approach for go-around prediction as well as the evaluation approach to assess the impact of the SafeOPS concept on the safety and resilience of go-around and approach handling. Finally, we summarize the lessons learned during the project. SafeOPS is divided into three strands: an Operational Layer, a Predictive Layer, and a Risk Framework. Within the Operational Layer, a user-centered development process was established based on recurring workshops of researchers and stakeholders, primarily air traffic controllers and pilots. In these, after developing a common understanding of the goals, possible reference scenarios describing tower control processes of approach and missed approach handling were developed, focusing on currently available technologies and data and their use by controllers. In addition, solution scenarios, were defined that describe possible strategies for handling go-arounds, if go-around predictions were available. Based on the solution scenarios, an initial set of requirements were derived, which served as bases for the implementation of the AI-based, go-around prediction tool. The technical implementation of the go-around prediction, covered in the Predictive Layer, is not within the scope of this contribution and will be published in a contribution at DASC 2022 in September. Based on the implementation results, SafeOPS evaluates the impact of the tool on approach and go-around safety and resilience, again in recurring workshops with stakeholders. Semi-structured interviews were conducted to document the strategies for handling go-aroundss without and with the developed prototype, as defined in the reference and solution scenarios. Comparison the reference and solution scenarios, especially the necessary coordinative actions between controllers and pilots, allows to evaluate the adaptive and restorative resilience. Thereby, one can assess how the tower controller returns to normal operation, after an unforeseen event, like a go-around, has occurred and how his actions change, in case he is prepared for a go-around beforehand. Using the documented go-around handling strategies, SafeOPS also simulates the reference and solution scenarios, using generic aircraft models, developed in Simulink. From the simulation, measurements regarding separation of involved aircrafts will be generated, allowing a comparison of safety in the scenarios, w.r.t wake and separation problems. Finally, a risk model was developed to capture individual events occurring during the missed approach procedure, assess their associated risks and identify the contributing factors that may worsen or mitigate these risks. This includes in particular the provision of the probabilistic information generated by the AI-tool and how these information modify the risks involved in the go-around handling, including the issues of information reliability to end users (e.g. nuisance alerts, missed alerts, unclear meaning of visual feedback etc.).

The application of the SAFEMODE methodology to RPAS operations

***Ms. Anna Giulia Vicario (Deep Blue Srl)**, Matteo Cocchioni*

This paper describes the application of a new methodological approach developed within the SAFEMODE project to analyse accidents and incidents in a company operating with drones. The SAFEMODE project is the largest EU cooperation initiative between aviation and maritime that will have a worldwide impact on safety by involving partners worldwide from three continents. The project's main aim is to develop a novel Human Risk-Informed Design (HURID) framework to identify, collect, and assess Human Factors data that, based on the results, will provide better recommendations on design aspects and operations. The need to develop this framework stems from the lack of a systematic approach in the maritime and aviation (including Remotely Piloted Aircraft System operations- RPAS) domains to collect and assess Human Factors information, either in normal or emergency conditions. The study of human factors in safety is a complex subject as it involves different levels and areas of an organisation, which are not always directly observable. Human Factors specialists, in fact, do not limit themselves to a simple reconstruction of the facts (e.g. what happened, who did what, what happened next) but delve into the reasons why an accident occurred, taking into account aspects related to human performance, organisational culture and work organisation. The specialist reconstructs the personnel's actions (how) and the cognitive, contextual and organisational factors involved (why). The main question is: "Why, at that moment, did it make sense for the person concerned to do that particular thing he or she did that caused the accident?" The expected result of this analysis is to provide the organisation with more helpful information to prevent the event from happening again by acting on the intrinsic causes and not on their manifestation (the symptoms). In this regard, the two tools used to analyse the Incident Reports were the Safety Occurrence Analysis Methodology (SOAM) and the SAFEMODE methodology, or more precisely, the taxonomy defined by SAFEMODE to catalogue the HF factors identified in the incidents, a taxonomy called SHIELD. SOAM, developed by Eurocontrol, allows the investigator not only to focus on identifying human errors, to identify a 'culprit' but to analyse the whole range of factors that contributed to the occurrence of an accident so that similar events can be prevented. The SHIELD (Safety Human Incident & Error Learning Database) taxonomy, developed by SAFEMODE, is used to catalogue HF factors identified in incidents. It is a human error framework consisting of four main layers: Acts, Precondition, Supervision, Organisation, each of which determines a level of human failure. A framework that provides a snapshot of areas relevant to human performance management at the organisational level was used to categorise the results obtained. This framework, called Human Performance Capability Profiling (HPCP), highlighted the organisation's strengths and areas needing improvement; it identified the maturity level of each area and the next steps the organisation could take for optimal human performance management. The results showed the effectiveness of the SAFEMODE methodology to the RPAS operations. Furthermore, the results gave the basis for developed operations and methodological recommendations for both short- and long-term interventions.

Human-centred design of AI and digital assistants: Part II

Session Chair : Dr. Simone Pozzi (Deep Blue, Italy)

HAIKU project presentation

Dr. Ricardo Jose Nunes Dos Reis (EMBRAER)

HAIKU (Human AI Teaming Knowledge and Understanding for aviation safety) is a three-year research project funded by the European Commission. The project aims to pave the way for **human-centric-AI** by developing new **AI 'Digital Assistants'**, and associated **Human-AI Teaming** practices and guidance, for **aviation**. It also explores and define strategies for **XAI** and **human-in-the-loop learning**, and deliver **Human Factors design guidance and methods** to develop safe, effective and trustworthy Digital Assistants for Aviation. HAIKU looks also at **organizational aspects**, aiming to determine how human role will evolve with the introduction of AI in terms of roles, skill-set and safety culture. More specifically, HAIKU will deliver prototypes of AI Digital Assistants for **six use cases**, positioned between TRL2 and TRL6. Two use cases are intended for flight crew (cockpit). The first one aims to **support crew during unanticipated and confusing events** by to minimizing the consequences of a startling and surprising events. The second use case has the goal to **reduce pilots' mental workload** by alleviating cognitive resources involved in secondary tasks and, thus, enable them to focus on critical decision-making. In this cases, explainability, acceptability and bi-directional communication are key challenges that HAIKU will explore and tackle. The third use case is focused on **Urban Air Mobility**, the new air transportation system of cargo and passengers expected to go live on a broader scale in cities already in 2025. HAIKU will develop an AI Digital Assistant to help humans oversee the increasing air traffic over cities, alerting them to potential conflicts with other airspace users or with city activities on the ground. This use case, beside facing the challenge of air traffic management in complex cities, will also consider and address social aspects which are key for acceptability. A **Digital Assistant for Tower** (and **Remote Tower**) is the forth use case. It will assist controllers with routine and repetitive tasks with the aim to reduce their workload, improve situational awareness and increase efficiency, implying also a significant increase of capacity and provision of new safety nets. The last two use cases are intended for airports. One is named **"Airport Safety Watch"** and consists in an AI solution capable to help learn from data collected across the airport, understand where future hotspots or safety 'pinch-points' might arise, with a view to staying one step ahead on airport safety. Lastly, the sixth use case aims to provide support to airports operators in **forecasting and monitoring the risk of the spread of airborne and touch-transmitted pathogens**, due to overcrowding in specific areas.

Towards Human-Centered Design in complex systems development: a toolkit to plan, develop and execute Low-Fidelity Simulations

Mr. Gianmaria Mallozzi (Deep Blue Srl), *Ana Ferreira, Ana Lidia De Almeida Castro, Ricardo Jose Nunes Dos Reis, Jose Ricardo Parizi Negrao*

One of the biggest challenges in complex and safety-critical systems development is to uncover final users' needs and evaluate design requirements at the early stages of the system life cycle. The Human-Centered Design approach proposes dozens of activities and best practices to enhance systems' effectiveness and efficiency involving the final users iteratively during the development process, to uncover user needs and evaluate design solutions. However, this approach is not widely adopted by the complex systems design teams, especially when they are very technology-driven. There, the focus is usually in the technical issues of the technologies or system solution and users are usually involved using modeling and simulation activities at later stages, nearing completion. A possible perception is that meaningful human simulations are complex to plan, develop and execute. The SAFEMODE project addressed this problem by proposing a Toolkit to plan, develop and execute Low-Fidelity Simulations (LFS). The toolkit proposes an approach to combine Human-Centered Design methods to develop simulation activities that are effective and easy to execute, in order to uncover design requirements during the early stages of the system development process, contributing to make a step further in the design of systems that are truly able to meet human needs, limitations, and performance.

Probabilistic and Statistical Analysis of Aviation Accidents

Yanne Amaral, Ana Barqueira, Luis Santo, ***Prof. Rui Melicio (University of Lisbon),*** *Duarte Valério*

This study presents a probabilistic and statistical analysis using ARIMA model to study the distribution of aircraft accidents in Europe and present a future trend. Since its creation, the main goals of aviation revolved around the safety operation of aircrafts, and as being an industry operated by humans it's only natural that characteristics of human development and evolution are present in it such as learning from previous errors and lessons, a key principle in aviation safety. Trough the analysis and understanding of accidents and its associated causes and variables, either human or not, makes it possible to adopt a proactive attitude in order to improve safety levels and void accidents.

Is it possible to evaluate the event-based task load of an atco using an atc simulator?

María Zamarreño Suárez, Rosa M Arnaldo Valdés, Francisco Pérez Moreno, Raquel Delgado-Aguilera Jurado, Patricia María López de Frutos, Víctor Fernando Gómez Comendador

Task load is a measure of human performance that refers to the difficulty an individual encounters when executing a task. In the field of human factors applied to ATM and, specifically, to air traffic controllers, the variable of interest to study is the event-driven task load. If it is possible to establish a series of relationships between ATC events and the task load of air traffic controllers (ATCOs), a number of conclusions of great interest can be drawn. These conclusions should be considered in the design of future scenarios to limit the workload of ATCOs. In the study presented, an attempt has been made to establish this task load based on a series of controlled events, which have been included in several real-time ATC simulation exercises, using the en-route flight simulator SkySim. Throughout this process, a number of challenges have been identified and, in later stages, solved. The first results indicate a promising methodology that would allow approaching the idea of establishing the event-based task load applied to air traffic controllers. As a starting point for the study, a simulation platform configured ad hoc for the project was ready. In addition, an estimated task load profile was available for each of the exercises, considering the events that were designed to occur during the simulations. To evaluate the occupancy level of the ATCO performing the simulations, the ISA method was implemented on the platform to evaluate, on a scale of 1 to 5, the perceived workload of the participant at regular intervals. The analysis of these results led to two interesting conclusions. Firstly, it was identified that the task load distribution perceived by the participant was out of phase with respect to the estimated level (which was considered when designing the simulation exercises). In relation to the above, it was found that participants did not evaluate their workload at the time the question was asked, but rather by taking into account the events they had experienced in the interval before the question appeared.

Therefore, certain areas for improvement were identified, focusing on two objectives: to be able to disregard the subjective evaluation, using reaction time instead, and, on the other hand, to be able to establish a more realistic task load profile, not only based on the events foreseen during the design of the exercises, but also considering the actions performed by the controller during the simulations. After implementing these improvements, the first results are promising. By combining the data obtained from the controller's reaction time and the event-related information obtained from the simulation platform, it has been possible to move towards the definition of the real occupancy profile and a more realistic measurement of the ATCO's task load.

Hybrid Electric aircraft roadmaps (joint session of FutPrint50, IMOTHEP and EASIER)

Session Chairs : Dr. Ricardo Reis (EMBRAER, Portugal) & Prof. Timoleon Kipouros (University of Cranfield, UK)

IMOTHEP European project: toward a roadmap for the development of hybrid electric propulsion

Dr. Philippe Novelli (ONERA), *Sébastien Defoort, Nicolas Tantot, Dirk Zimmer, Dario Varchetta, Christophe Viguier, Pia Iodice*

Facing the challenge to drastically reduce and even cancel its greenhouse gas emissions, aviation is exploring a large panel of technologies, amongst which introducing some electrification in the main propulsion is seen as a disruptive way to reduce fuel consumption. If full electrification of commercial aircraft appears hardly possible beyond short-range regional aircraft with limited payload, hybridization with thermal engines opens a large design space and offers a broad scope of possible configurations to look for lower emissions. Many architectures have been proposed to date. Parallel hybrid power chains, thanks to energy storage in batteries and electric assistance to thermal engines, provide the opportunity to substitute some decarbonized electricity to fossil fuel in the energy used by the aircraft, as well as some possibilities to better optimise the global propulsion system. On the contrary, series hybrid, or turboelectric, produces all the electricity on board from thermal machines but offers some perspective for optimising the efficiency of the whole propulsion system, in particular through distributed propulsion. Combination of parallel and series are also explored. Obviously, this implies introducing in aviation electric technologies that represent a disruptive step compared to the level of power of the current electric systems on board aircraft. These technologies raise challenges in terms of energy and power density of electric systems, power bus voltage, protection against partial discharges and electromagnetic interference or thermal management. A first objective of the IMOTHEP project is to get a better view of the potential of hybridization for reducing fuel consumption and CO2 emissions of aircraft. For this, IMOTHEP is assessing the benefit of hybridization on four different configurations of hybrid aircraft covering regional and SMR missions and representing different levels of disruption in aircraft design. This assessment is performed in close connection with the investigation of the electric components and the architecture of the hybrid power train, the specifications of which are derived from the configuration studies. In return, the performances obtained from the component studies feed the performance assessment of the aircraft. Together with sensitivity studies, the comparison of the components' performances with the initial technology assumptions derived from the existing body of literature and experts' judgement, provide the inputs for a gap analysis that informs about the required research for the development of hybrid electric propulsion (HEP). This gap analysis, together with an investigation of the tools and facilities required for the maturation of HEP, forms the basis of the elaboration of a development roadmap that constitutes the ultimate goal of IMOTHEP. The paper will present a first vision of this gap analysis and a preliminary roadmap established at mid-term of the project, based on interim results.

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Development of the Initial Certification and Technology Roadmap for the FUTPRINT50 Framework

Dr. Nicolas Moebs (University of Stuttgart), *Ricardo Reis, Evert Windels, Timoleon Kipouros, Michelle Westin, Andreas Strohmayer*

The main goal of the research project FUTPRINT50 is the acceleration of the introduction of a hybrid-electric regional aircraft. One essential part of this project is to develop a roadmap which couples the technological development with its associated research infrastructure and regulatory aspects. This aims at maximizing the likelihood of a successful hybrid-electric 50-seat regional aircraft with a projected entry-into-service by 2035/40. This presentation shows the first version of the FUTPRINT50 roadmap, with the findings of the consortium about key enabling technologies and testing infrastructures necessary to achieve the final integrated demonstrators that provide evidence for lowering risk of adoption (TRL 6/7) and for bridging mapped regulatory gaps in regard to hybrid-electric propulsion. Links to other complementary roadmaps are highlighted. All those results have been elaborated by the FUTPRINT50 consortium with comprehensive involvement of the project's advisory board comprised of official regulators and industry experts.

A roadmap for engineering development practices for the electrification of aircraft

Prof. Ola Isaksson (Chalmers University of Technology), *Christoffer Levandowski, Timos Kiporous, Massimo Panarotto*

Electrification has entered the aircraft business, where hybrid, and even electric, propulsion is under development. A roadmap will be presented that outlines the necessary activities to enable realisation of electrification in aircraft focusing on its implications on competence, practice, and support tools rather than the technology as such, addressing questions such as what can be learnt from automotive – and what needs to be developed based on the aerospace business context. Furthermore, one of the key issues associated with a disruptive product architecture like this is regulation and assurance. We understand how to regulate, test, and assure a conventional kerosene powered aircraft, but we don't have the decades of knowledge for electrical propulsion systems. And the existing regulatory/assurance framework is either inappropriate or over-constraining. Unless we consider regulation and assurance within the overall design process transformation, we shan't see these products in widespread operation. The roadmap seeks to present a view for discussion on how electrification impact competences and practices for engineering development. The experiences have been drawn from previous and current national and European projects, as well as from workshops organised through Special Interests Groups within the Design Society.

Session Chair : Prof. Andreas Strohmayer (University of Stuttgart, Germany)

Influence of Distributed Propulsion on the Sizing of the Vertical Stabilizer and Rudder in Preliminary Aircraft Design

Mr. Alexander Albrecht (Fraunhofer - Institute for Chemical Technologie), *Andreas Bender, Andreas Strohmayer*

During preliminary aircraft design the rudder sizing is done by the use of volume coefficients. These represent a statistic approach using existing configurations correlating parameters such as wing span and lever arm to size the vertical surfaces. For a more detailed analysis with regard to control performance, the rudder size strongly depends on the critical loss of thrust assessment. This consideration increases in complexity for the design of aircraft using distributed propulsion systems. Within this study the position of the engine integration shall be assessed with regard to the tradeoff in weight and the possibility to reduce the necessary vertical stabilizer size and hence the correlating aerodynamic drag. Two different configurations of a hybrid-electric 19-seater aircraft, based on the existing Beechcraft 1900D, are compared. The configurations were developed within the GNOSIS project, a consortium of seven Universities and the Bauhaus Luftfahrt e.V., aiming for a holistic assessment of the feasibility of electrified propulsion. The first configuration keeps the initial engine position of the Beechcraft and complements it with two wing tip propellers (WTP). Since research done by the GNOSIS consortium suggests, that a further outboard integration brings an aerodynamic advantage, the second configuration has the inner propulsors placed further towards the wing tips. For both configurations, the critical loss of thrust is defined. Afterwards the vertical stabilizer and rudder are sized using class 1 methods, which are extended to consider the effects of distributed propulsion. Thereafter the preliminary sizing tool MICADO is used to calculate the OME, as well as the required mission energy. The results are compared to the original configurations without the optimized vertical stabilizer. The wiring of the electric engines has a significant effect on resulting momentum and the behavior of the aircraft in case of a failure of the internal combustion engine, as well as on the empty mass. Therefore, two different wiring options are assessed and compared for both configurations.

Assessment of (hybrid)-electric drive-train architectures for future aircraft applications

Dr. Paul König (Brandenburg University of Technology Cottbus-Senftenberg), *Phillip Müller, Klaus Höschler*

Future regional aircraft and propulsion systems will have to address both a growing market and stricter environmental constraints. Besides the increase of component efficiencies, the technological transformation from conventional to (hybrid)-electric propulsion systems represents a paradigm shift with great potential for the aviation industry. In this context, economic, market-relevant as well as technological boundary conditions for the electrical and mechanical components are developed in this paper for a reference regional aircraft and are based on current research results from different institutions. The propulsion performance analysis of a conventional turboprop is compared and evaluated with a serial-hybrid and a fully-electric configuration (both battery-electric), status today as well as status ~2035, as an example, whereby the presented process can also be applied to other hybrid configurations too. An energy-optimised propulsion and operating concept is derived with regard to minimum resulting system weight. The results of this analysis help to define necessary boundary

conditions for future subsystem investigations and identify key research items, especially in the field of the battery.

Modelling of a battery supported fuel cell electric powertrain topology for a regional aircraft

Dr. Martin Staggat (German Aerospace Center (DLR)), *Jonas Ludowicy, Victor Bahrs, Antje Link*

Electrification of aircraft propulsion may offer a way towards CO2 neutral air travel. Here, the electric aircraft demonstrators already flying mostly rely on the use of batteries as energy source. While battery electric concepts may be suitable solutions for short range applications, such as urban air vehicles (UAV), the energy density of state-of-the-art batteries is not yet sufficient to power regional aircraft with a typical range of 1000 nm and 80 passengers. One possible topology option of a propulsion concept for a regional aircraft may be a hybrid composed by a fuel cell system and a battery. On the one hand, this concept uses hydrogen (H2) as the primary energy carrier resulting in a significant reduction of the required battery mass. On the other hand, a battery support of flight phases with high power demand, such as take-off or climb, allows a smaller dimensioning of the fuel cell system and the corresponding thermal management system (TMS) for cruise flight and therefore additional overall system mass benefits. The present paper describes the sizing of a battery supported fuel cell electric power train topology for a regional aircraft based on an analytical approach. The modeling includes the sizing of the fuel cell stack, other mechanical and electric components, such as gearboxes, electric motors and power electronics and the corresponding TMS with respect to the operating point performance requirements. In a second step, the sizing of the liquid hydrogen (LH2) tank, the required amount of hydrogen, the sizing of the battery stack and the prediction of the aircraft empty mass without propulsion system is predicted based on a mission performance analysis. Finally the potentials that arise from a future increase in battery power density as well as the choice of the hybridization factor are discussed by a parametric study.

A rule-based energy management strategy for hybrid-powered eVTOL

Mr. Taher Marzougui (Capgemini Engineering)

In recent years, as the levels of air pollution reach alarming levels, new energy aerial vehicles like electric vertical take-off and landing (eVTOL) aircraft have become the development trend of future aviation industry. This paper presents a rule-based energy management strategy (EMS) for a multi-source aircraft. The hybrid power system (HPS) is composed of a proton exchange membrane fuel cells (PEMFC) as the main energy source and lithium-ion batteries (Li-ion) as auxiliary one. The onboard sources deliver power to the DC bus through two DC-DC converters. The main objective is to optimally split the power demand between the different sources while respecting their limits and extending their lifetime. The adopted control strategy is described as a set of rules based on some predefined conditions and thresholds over the control variables. It is chosen due its simplicity of implementation, its reliability, and a low computation time. The relevance of this strategy is evaluated and implemented on a set of simulations for an eVTOL mission corresponding to a search and rescue flight. Results on power distribution, fuel cell dynamics and battery parameters are analysed and confirm the effectiveness of the proposed strategy.

AI approaches for Battery Management of Future Electric Propulsion System

Ms. Tahmineh Raoofi (University of Kyrenia), *Melih Yildiz, Suleyman Tolun*

The battery-powered propulsion system is introduced in the literature as a suitable solution for the CO2 emission challenge induced by aviation. However, because of design and manufacturing factors, during or after abused operational and environmental situations, Lithium-Ion battery safety, and reliability cannot be easily guaranteed. Thus, an effective Battery Management System (BMS), is an essential unit in Electric Propulsion System (EPS) of Electric and Hybrid Electric Aircraft. Battery state estimation and prediction are essential to provide required safety strategies through acquiring battery data such as current, voltage, and temperature. There are various methods of state estimation including physics-based, model-based, and data-driven approaches which are well analyzed in the literature. Among them, the recent data-driven method seems to be a novel solution for conquering the current experimental difficulties and inaccuracies in battery management. In a data-driven method, the battery is considered as a black box while a large volume of data is applied to learn the internal dynamics of the battery, using Artificial Intelligence (AI) and Machine Learning (ML) approaches. However, there are still major uncertainties and hurdles in application and using AI in EPS due to data source scarcity, complexity of computation, and airworthiness certification process. The goal of this study is to provide a comprehensive review of BMS strategies in different applications supported by intelligent algorithms to propose appropriate solutions for battery management of EPS. Moreover, assessing the current regulations reveals that the inadequacy of initial airworthiness requirements is one of the critical safety issues for employing AI technology in the battery management of future electric and hybrid electric aircraft.

Hybrid-electric flight: Part II

Session Chair : Prof. Andreas Strohmayer (University of Stuttgart, Germany)

Application of Model-Based Systems Engineering for the Integration of Electric Engines in Electrified Aircraft

Mr. Abhishek Kiran Malayappan Kamalanathan (Cranfield Univeristy), *Bahareh Zaghari, Timoleon Kipouros, Ricardo Jose Nunes Dos Reis*

The objective of green, carbon-neutral flights is propelling the innovation of newer propulsion systems. With this increased development of an interdisciplinary form of propulsion for aircraft, the integration burdens and efforts intensify. In literature, it is estimated that it takes 4-10 years to design and develop an aircraft. Any innovation and effort to cut this time by any degree should be explored and analysed. One of the techniques that has the potential to help fast-track the research and development of interdisciplinary systems is MBSE (Model-based System Engineering). Various studies have shown the benefit of employing a model-based design strategy. This study encompasses the electric machine and the propeller, along with any system used for their integration. For a Hybrid Electric Propulsion, the electric machine and propeller need to be integrated and their interaction to be analysed. MBSE is proposed as a methodology that would help streamline the process of design and integration of the two systems. This study documents the exploration of connecting MBSE with current simulation and modelling of subs-systems in order to ensure the fulfilment of stakeholder needs and full system effectiveness. The study is evaluated using certain criteria that would attempt to quantify the efforts.

Towards Zero Net Emissions: Evaluation of Electrified Aircraft Performance Using CHARM - Cranfield Hybrid electric Aircraft Research Model

Dr. Evangelia Pontika (Cranfield University), *Hossein Balaghi Enalou, Tianzhi Zhou, Bahareh Zaghari, Timos Kipouros, Panagiotis Laskaridis*

The paper presents the development and implementation of CHARM: Cranfield's Hybrid electric Aircraft Research Model. The framework presented integrates the various elements of electrified propulsion along with the impact of electrification on the overall performance of the aircraft throughout the mission profile. Various energy sources including SAF, batteries and hydrogen are combined and integrated with gas turbines, fuel cells, power electronic and electric machine components to assess the performance of future electrified aircraft that will contribute towards Zero Net CO2 Emissions. In this context, various hybrid architectures are modelled and examined. A 50-passenger regional aircraft is considered. The impact of the various hybrid architectures on the performance of different mission profiles varying from 300nm to 800nm is assessed. Component, subsystem, system and aircraft performance parameters are defined and analysed along with the overall performance of the aircraft during the different phases of the mission profile. Combinations of different energy and power sources that include both gas turbines and batteries as well as gas turbines and fuel cells are considered. The impact of varying power requirements on the matching, performance and efficiency of the various components is presented. The evaluation accounts for overall energy, emission and gas turbine lifing considerations.

Assessing improvements to enable the feasibility of using fuel cell in a small aircraft

Mrs. Ana Lídia de Almeida Castro (EMBRAER), *Carlos Henrique Belloni Mourão, Pedro Teixeira Lacava*

With the expectation that greenhouse gas emissions of the aviation sector increase in 70% by 2050 with the fossil fuel matrix unchanged, international organizations have been determining aggressive targets for reduction of emissions in the sector. A key candidate for accomplish these reductions is the electrification of the propulsion using green hydrogen to power fuel cell (FC) systems. In this way, a FC powered Hybrid-Electric Propulsion System (HEPS), with proton-exchange membrane FC (PEMFC) and batteries, was integrated in an existing small airplane model, using H2 tanks at 700 bar and 350 bar, to evaluate the behavior of the hybridization at aircraft level, but without losing focus on the propulsion. In previous study, it was identified that this HEPS is feasible for small electric airplanes, increasing the range of battery-only version, but they have to improve to offer performance advantages in relation to a standard propulsion with internal combustion engine (ICE). Therefore, this study aims to assess these improvements required by the HEPS to be feasible, when compared to the baseline ICE propulsion. The aircraft aerodynamics, weight, sizing parameters and other aspects were modeled and simulated in a virtual environment (SUAVE), and the aircraft performance was assessed using Energy Specific Air Range (ESAR) indicator and total aircraft mass. Firstly, the hybridization schedule analysis evidenced that a better performance was achieved when 60% of takeoff and climb power (and 100% of cruise, descent, and landing power) is provided by FC system, and 40% is supplied by battery. Secondly, the variation of four propulsion parameters (FC system specific power, H2 storage specific energy, battery specific energy, and H2 tank ratio) were assessed, with the increase in FC specific power having the greatest influence in performance. However, this advance was not sufficient to achieve the ESAR of the ICE version, so improvement scenarios, joining increase in FC specific power and in H2 storage specific energy, evidenced that an extreme effort (raise of about five times) in these parameters would be required to make the hybrid versions viable in relation to the original combustion propulsion. Therefore, further improvements in different aspects of HEPS are required to close the gap to conventional ICE system. Despite that, the environmental concerns require the industry to keep pushing for the evolution of low-carbon propulsion technologies, and systems with H2 and FC systems have a great potential in this approach.

Functional and Safety Challenges of Hydrogen Fuel Cell Systems for Application in Electrified Regional Aircraft

Dr. Stefan Kazula (German Aerospace Center (DLR)), *Martin Staggat, Stefanie de Graaf*

This paper presents and evaluates potential design adaptations or new developments on component level, which are necessary to enable electrified regional aircraft for commercial aviation. Powertrain topologies for electrified regional aircraft and according to components are presented. Requirements, which result from the application of these components in aviation, are introduced. Based on these requirements, potential adaptations of existing solutions as well as necessary new developments are identified and evaluated on component level and compared with the current focus of research. These investigations highlight the necessity of further research concerning means of heat transfer, preheating solutions, weight reduction and electromagnetic compatibility. Due to the climate change, a high demand for sustainable transport technologies arises in our modern world. This demand is supported by the political goals from the Paris Agreement for a limitation of the climate change and especially for aviation by the Flightpath 2050 goals published by the European Commission. One goal of the Flightpath

2050 is reduction of CO2 emissions per passenger kilometre by 75% compared to a new reference aircraft from the year 2000. A way to achieve this goal is increasing the efficiency of existing aero engines, which consume fossil fuels to provide thrust. Another way is presented by the utilisation of sustainable and regenerative energy sources instead. These sources can be sustainable aviation fuels, hydrogen or stored electric energy. As a consequence, the topology of the powertrain evolves. Numerous topologies for the powertrain of electrified aircraft have been identified for different passenger numbers and flight ranges. These topologies comprise different respective components, which have not been applied generally or within this range of power in aviation yet. Therefore, existing technologies have to be adapted to meet the high requirements in aviation or entirely new aviation specific components have to be developed. This paper presents potential design adaptations or new developments on component level, which are necessary to enable electrified regional aircraft for commercial aviation. Powertrain topologies for electrified aviation and according components are presented. Requirements, which result from the application of these components in aviation, are introduced. Potential adaptations of existing solutions and necessary new developments are identified and evaluated on component level, highlighting necessary investigations for different means to comply with the requirements in aviation. Components, which shall comply with the demanding requirements for safety, require electromagnetic compatibility (EMC) on ground and during flight. Reliable operation during all potentially occurring operation conditions, e. g. ambient pressures and temperatures, as well as moisture, must be ensured. This implies necessary means to preheat components or to transfer excessive heat from components. As the aero engine and thus the traditional source of bleed air could be omitted, new options for the prevention of inflight icing on relevant aircraft surfaces or for providing conditioned air to the cabin have to be investigated. Finally, the power to weight ratio of all relevant components have to be maximised. This way, sustainable flight with electrified regional aircraft could be enabled and hence contribute to limiting the climate change.

IMOTHEP Hybrid-electric Regional Aircraft

Session Chair : Dr. Arne Seitz (Bauhaus Luftfahrt e. V., Germany)

Possible technology roadmap about future Regional Platforms from 50PAX up to 100PAX with E.I.S. beyond 2035

Mrs. Pia Iodice (LDO), *Giovanni Cerino*

In the last few years the aviation industry is going through a period of extraordinarily rapid evolution: Hybrid-Electric propulsion (HEP) has moved into the focus of aviation research. The Hybrid-Electrical Aircraft is a concept aircraft that uses different energy sources to fly, a traditional thermal source, common to conventional airplanes, and an electrical one supplied by batteries or hydrogen fuel cells and then distributed to the propulsion system and to the on-board sub-systems. Concerning the hydrogen capability as alternative power and electrical propulsion option, it is worth to note the thermal engine may also burn H2 if properly sized and designed. An important technological improvement oriented to fuel/pollution reduction is the sustainable aviation fuel (SAF) adoption. This option, already at a good maturation level, will bring on the next future, at a first big step in terms of CO2 reduction.

Are batteries fit for hybrid-electric regional aircraft?

Dr. Helmut Kühnelt (AIT), *Francesco Mastropierro, Ningxin Zhang, Somayeh Toghyani, Ulrike Krewer*

"Hybrid electric propulsion is likely to play a more prominent role for regional aircraft with 40+ passengers in the future air transport system with reduced climatic impact. In IMOTHEP, two hybrid-electric regional (HER) aircraft concepts, a conservative and a radical, are developed. Energy dense battery technologies are needed to enable hybrid-electric propulsion of regional aircraft. Furthermore, these batteries need to become commercially available within in the planned development time of the new aircraft, i.e. until 2030. This paper will discuss general requirements for the HER battery and aims at providing an overview on the most promising industrial approaches for energy dense battery cell technologies – from advanced Li-ion to all-solid-state – with view of their application in air transport and forecasted availability on the market. Furthermore, results will be presented from the study preformed in IMOTHEP on hybrid polymer-ceramic all-solid-state battery electrochemistry that combines lab trials with electrochemical numerical simulation.

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Study of a regional turboprop aircraft with hybrid-electric turboshaft assistance

Ms. Anais Habermann (BHL), *Fabian Peter, Philipp Maas, Carsten Rischmüller, Hagen Kellermann, Arne Seitz*

Due to the apparent need to reduce the impact of aviation on climate change, the electrification of aircraft as an enabler for low emission air transportation has been increasingly studied in recent years. For regional air transportation with typical mission ranges < 300 nmi, hybrid-electric propulsion (HEP) is a promising technology. Here, the usage of electric energy can contribute to an overall emission reduction if the aircraft configuration addresses the challenges of HEP adequately. HEP poses two major challenges: Flight performance degradation on aircraft level due to cascade effects, which are primarily caused by the additional weight of batteries and electrical components (especially due to the disadvantageous gravimetric energy density of the batteries), and handling of significant excessive waste heat attributed to the same components. The aircraft concept presented in this study combines technologies, which shall offer a solution to these challenges for a hybrid-electric regional turboprop aircraft with an entry into service (EIS) in 2030+. It combines a flexible utilization of electric energy in an advanced parallel-hybrid power plant architecture (Maas 2022, Rischmüller 2022) with a propeller slipstream enhanced electrical waste heat rejection through wing surface heat exchangers (Kellermann 2020, Habermann 2022). The studied configuration is based on a twin-turboshaft propulsion architecture with two propellers (similar to the existing ATR 42-600), which features electric assistance from batteries to the turboshaft engines (a visualization of the concept is presented in Fig. 1). It aims at increasing the efficiency of the engines and thus a block fuel reduction on aircraft level. The electric assistance is two-fold: cycle-integrated parallel hybrid electric assistance – CIPH (Vratny 2017), i.e. an electric drive of the gas turbine compressor, and mechanically-integrated parallel hybrid – MIPH (Seitz 2018), i.e. electric assistance to the power shaft. The required electric energy is sourced from an on-board battery. This hybrid-electric aircraft configuration is investigated as part of the European Union-funded Horizon 2020 IMOTHEP project (Investigation and Maturation of Technologies for Hybrid Electric Propulsion) following a holistic aircraft design approach. The study presents integrated aircraft level results of the second conceptual aircraft design loop in IMOTHEP. To gain a thorough understanding of the impact of such a HEP configuration, all required components and disciplines are represented by detailed models and methods. A special focus is placed here on the modelling of the electrically assisted turbo generator (see also Maas 2022) and the hybrid-electric power train (see also Rischmüller 2022). To contrast the energy demand of the proposed aircraft configuration against a conventionally evolved configuration with the same EIS, aircraft level results for a typical mission of the hybrid-electric aircraft are compared against the performance of a reference aircraft with similar top-level aircraft requirements. The reference aircraft is derived from the ATR 42-600 using an evolutionary projection for the advances of conventional structural, aerodynamic and propulsive technologies to the year 2030. In addition, sensitivity study results are analyzed to improve the understanding of the impact of key technology performance parameters on the potential of HEP for the regional turboprop configuration. It is shown, that the potential to save emissions caused by fuel combustion is small for the proposed configuration using the current technology projections for 2030+. This is mainly due to cascade effects on aircraft level caused by the estimated heavy specific weight of the batteries. Thus, the study thoroughly explores a variation of hybridization strategies detailed for each flight phase to arrive at a best and balanced compromise between electrical assistance and overall aircraft mission performance.

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Performance investigations of a cycle - & mechanically - integrated parallel hybrid-electric turboshaft

Mr. Philipp Maas (BHL), *Arne Seitz, Dominik Wirth, Peter Geiger, Mirko Hornung*

With rising global temperatures during the past decades, the aviation industry is looking for new solutions to reduce its environmental footprint. One step in achieving this goal could be the use of hybrid-electric power train architectures, whose benefits and challenges have been broadly investigated in recent years [Seitz, 2013], [Schmitz, 2016], [Vratny et al., 2017], [Seitz et al., 2018]. At aircraft level, hybrid-electric configurations are limited by the specific weight of the electrical components. At power plant performance level, overall propulsion system efficiency can be significantly increased using a parallel hybrid approach, in which electric power is added as a substitute for the gas turbine power. However, this approach can lead to operational constraints within the turbo components, e.g. in case of electrical system failure. To overcome this challenge, the present study analyzes the particular concept of a parallel hybrid-electric propulsion system, in which electric power from conventional batteries is added in two ways: The first electrical assistance directly drives the engine power shaft - also known as Mechanically-Integrated Parallel Hybrid (MIPH) propulsion system [Seitz et al., 2018]. The second electrical assistance is added to the core cycle by compressor electric drive – also known as Cycle-Integrated Parallel Hybrid (CIPH) propulsion system [Vratny et al., 2017]. This propulsion system concept (schematically depicted in Figure 1) was chosen for the regional conservative ("REG-CON") aircraft configuration [Habermann et al., 2022] that is currently investigated as part of the European Union-funded Horizon 2020 IMOTHEP project (Investigation and Maturation of Technologies for Hybrid Electric Propulsion) with a possible entry-into-service (EIS) in 2030+. In order to analyze the proposed propulsion system concept, a thermodynamic model using the BHL in-house framework Aircraft Propulsion System Simulation (APSS) has been created (cf. Figure 2) and the underlying design methodology is presented. An initial propulsion system sizing is performed, taking into consideration key thermodynamic cycle parameters. Since the hybrid-electric propulsion system design strongly depends on the amount of electrical energy added, feasible degrees of power hybridization as well as pre-specified abnormal (failure) conditions are integrated into the sizing study and its effect on the overall engine performance are shown. The study will also provide a deeper understanding on the combined use of cycle-integrated and mechanically integrated electrification during turboshaft operation. It is shown from previous studies [Seitz et al., 2018], [van Holsteijn et al., 2020], that the electrical assistance can pose operational constraints due to aerodynamic limitations within the turbo components. To mitigate these limitations, a parametric study considering the overall degree of hybridization as well as the power ratio between the CIPH and MIPH system is conducted. Based on this, conclusions on feasible degrees of CIPH and MIPH hybridization are drawn and recommendations on the best and balanced propulsion system design are given, ensuring efficient turboshaft operation within the aerodynamic boundaries of the turbo components for key relevant mission points. Finally, to provide a preview on aircraft integrated sizing and performance implications, basic sensitivities of aircraft fuel consumption versus key limiting factors such as the battery specific energy and the impact of propulsion system sizing for important abnormal operation cases will be shared.

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IMOTHEP Plug-In Hybrid-Electric Aircraft Concept: REG-RAD

Mr. Georgi Atanasov (DLR)

A 40 seater plug-in hybrid-electric aircraft concept was modelled for the HORIZON 2020 project IMOTHEP, which will be described in the conference presentation. The concept was concieved as a solutions to the targets set by the project plan for a radical regional aircraft design - REG-RAD. The reference aircraft for the regional aircraft class in IMOTHEP is the ATR42, which is used as a base to provide the TLARs (Top-Level Aircraft Requirements) of the hybrid-electric aircraft studied in the project. The design range is set to 600nm with a Mach number of 0.4 and an operational ceiling of 25000ft. An evaluation mission of 200nm, which is the typical operational distance for this class of aircraft, is used for comparing the energy efficiency of the different regional aircraft concepts. This distance is within the capabilities of battery-driven aircraft, which can be the most efficient means of transporting payload with a self-propelled aircraft, due to electric motor efficiency levels of over 95% and battery charge discharge cycle efficiency of around 90%. For comparison, fuel cells reach around 40-50% efficiency, whereas state-of-the art gas-turbines of the regional aircraft class achieve around 25-30%. Hence, to optimize energy efficiency at the evaluation mission, an all-electric range of 200nm was set as a design target for the radical regional concept. However, in order to comply with the design mission requirement of 600nm, a kerosene-fueled range extender was needed. The range extender was chosen to be a gas turbine driving a generator to power the electric motors, which supports the batteries for missions longer than 200nm. The range extender is also used for the reserves of the aircraft, which allows sizing the battery only for the main mission and allocating the much lighter kerosene for reserves. Thus, up to 200nm, the aircraft can be flown completely electrically, using kerosene only in the rare occasion of a diversion after a denied landing. Furthermore, the electric propulsion allowed for using distributed propellers, which can improve the overall efficiency of the aircraft by about 5-10%. The resulting concept, despite being significantly heavier due to the battery, is about 60% more energy efficient at the evaluation range than a conventional turboprop with the same level of technology. The conference presentation will provide a detailed overview of the concept, including operational and safety aspects, sizing results of the overall aircraft design modelling and a detailed comparison with a conventional turboprop of the same technology level and TLARs.

Aerodynamic Investigation of the High-Lift Performance of a Propeller-Driven Regional Transport Aircraft with Distributed Propulsion

Dr. Dennis Keller (DLR)

Increased high-lift capabilities due to propeller slipstream, i.e. slipstream deflection, is seen to be one of the main benefits of distributed propulsion, as it may lead to a reduction in the main wing size and thus to reduced drag in cruise flight and/or reduced system weight and complexity. The presented work assesses the potential of distributed propulsion on the high-lift capabilities of a novel transport aircraft design from an aerodynamic point of view. The assessment is based on a regional propeller-driven transport aircraft designed within the European IMOTHEP project. A key feature of this aircraft design is the hybrid-electric approach allowing for fully electric flights on short range missions while extending the range with an integrated gas-turbine for longer range missions. Several aspects of the high-lift behavior such as low thrust demand -- and thus limited lift augmentation potential -- under approach/landing conditions, large propulsor nacelles, and trade-off considerations between cruise efficiency and high-lift performance are discussed. For the assessment, a high-lift design has been carried out in a first step. Based on the initial design, a sensitivity study on the number of propellers and propeller positions with regards to the maximum lift coefficient under take-off conditions has been performed. Moreover, wing modifications, nacelle design adjustments, and thrust redistribution have been investigated. The study was performed with the DLR TAU code using a RANS approach with actuator disk model based on the blade element momentum theory. The results generally confirm the potential of significant increases in the maximum lift coefficient. However, they also indicate that the maximum lift gains may come at a cost.

Leveraging cross-sectional industries to enable BVLOS drone services

Session Chairs : Dr. Ricardo Reis (EMBRAER, Portugal) & Dr. Morten Larsen (AnyWi Technologies, The Netherlands)

A Drone Secure Handover Architecture validated in a Software in the Loop Environment

Mr. Enio Vasconcelos Filho (ISEP), *Filipe Gomes, Stéphane Monteiro, Ricardo Severino, Sergio Penna, Anis Koubaa, Eduardo Tovar*

The flight and control capabilities of uncrewed aerial vehicles (UAVs) have increased significantly with recent research for civilian and commercial applications. As a result, these devices are becoming capable of flying ever greater distances, accomplishing flights beyond line of sight (BVLOS). However, given the need for safety guarantees, these flights are increasingly subject to regulations. Handover operations between controllers and the security of the exchanged data are a challenge for implementing these devices in various applications. This paper presents a secure handover architecture between control stations, using a Software in the Loop (SIL) model to validate the adopted strategies and mitigate the time between simulation and real systems implementations. This architecture is developed in two separate modules that perform the security and handover processes. Finally, we validate the proposed architecture with several drone flights on a virtual testbed.

The air mobility journey and beyond: advanced deterministic networks combining best-in-class solutions from the automotive and aerospace worlds

Dr. Anna Ryabokon (TTTech Computertechnik AG), *Jean Paul Barreto Guerra, Jasmin Jessich, Wolfgang Forster, Jochen Koszescha, Enrico Orietti, Axel von Blomberg, Mario Brotz*

The ADACORSA demonstrator introduced in this presentation represents a drone avionics architecture proof-of-concept deploying best-in-class COTS elements from two exciting worlds. Automotive and aerospace-grade components are the main building blocks of this solution. TTTech's high-speed Deterministic Ethernet backbone is a key element of the demonstrator. It ensures Deterministic Ethernet-based data communication according to a pre-defined schedule with very high reliability, making it suitable for certifiable avionics in aeronautics and space. Infineon's TÜV-certified automotive AURIX safety microcontroller, extended for multicore processing tasks and equipped with an innovative powered management IC, is deployed to guarantee functional safety up to the highest needs. In addition, the highly security- and safety-certified real-time operating system PikeOS by SYSGO has been integrated to support up to DAL A aerospace applications. Are you curious to find out how cross-domain technologies can be employed to reliably support BVLOS drone services? Find out more in this presentation!

Development of a Multi-Link Communication Gateway Enabling UAV BVLOS Scenarios

Mr. Patrick Purucker (University of Applied Sciences Amberg-Weiden), *Morten Larsen, Christian Reil, Alfred Höß*

As the general interest and possible fields of operation for commercial unmanned aviation are increasing, there is a rising demand for stable wide area communication in order to support Beyond Visual Line of Sight (BVLOS) scenarios. One approach to attempt this challenge is provided by a multi-link interface gateway utilizing several standardized and commercially available wireless technologies to ensure redundant and reliable End-to-End (E2E) connection between the Unmanned Aerial Vehicle

(UAV) and the ground station. The developed gateway supports the current mobile network standards such as the Long-Term Evolution (LTE) as well as the 5th Generation (5G) technology. Additionally, an interface integrating the WiFi-p standard is being integrated on the gateway covering the use cases required during the landing phase of the UAV as well as BVLOS flight due to the high coverage and availability of the mobile network. To control the data transmission over multiple links the gateway provides a scheduler, selecting the transmission path packet by packet and a link manager fed by a Quality of Service (QoS) prediction model to calculate the link quality for the scheduler. Thus, cell handovers of the mobile network, which are usually leading to spikes in latency, can be recognized before they occur and mitigated switching to a secondary link ensuring reliable low latency connection applicable for Command and Control (C2) data.

Multisensor architecture for BVLOS drone services

Mrs. Jessica Giovagnola (Infineon Technologies AG, University of Granada), *Miguel Molina Fernández, Roman Beneder, Patrick Schmitt, Manuel Pegalajar Cuéllar, Diego Pedro Morales Santos*

This ADACORSA demonstrator focuses on the implementation of a fail-operational avionics architecture combining Commercial Off-The-Shelf (COTS) elements from the automotive, the aerospace and the artificial intelligence world. A collaborative sensor setup (time-of-flight camera and FMCW radar from Infineon Technologies, stereo camera, LiDAR, IMU and GPS) allows to test diverse sensor fusion solutions. An AURIX microcontroller with its Tricore Architecture supports the execution of safety supervision tasks as well as data fusion. A powerful embedded computer platform (NVIDIA Jetson Nano) allows to deploy AI algorithms and data processing. Furthermore, an FPGA enables power optimization of Artificial Neural Networks. Finally, a Pixhawk open-source flight controller ensures stabilization during normal flight operation and provides computer vision software modules allowing further processing of the captured, filtered and optimized environmental data. This presentation shows various hardware and software implementations highlighting their emerging applications within BVLOS drone services.

ADACORSA: leveraging cross industry results for a competitive European drone industry

Dr. Ricardo Reis (EMBRAER), *Morten Larsen, Ulrike Glock, Walter Decker*

ADACORSA is a Key Digital Technologies JU (former ECSEL) project addressing key technologies for Beyond Visual Line of Sight (BVLOS) drone operations. Its diverse consortium ambition is to carry technologies from adjacent industries (mobility, communication, computing) over to unmanned aviation to lower the effort required to develop components and systems for drones aimed at BVLOS operation. For instance, the integration of automotive sensors and AI algorithms or communication solutions from the telecoms industry. The presentation will give an overall overview of the project, achieved results and outlook regarding the final demonstration activities.

The newcomer challenge: contributing to lower barriers to entering the aviation domain

Mr. Morten Larsen (AnyWi Technologies), *Ricardo Reis, Ricardo Parizi, Mahathi T Bhargavapuri, Ozren Cecelja, Elena Politi*

Aviation is a tightly regulated space. In that regard, drone operations – an emergent industry – is quite attractive for newcomers due to the perception of a lower barrier to entry, certification wise. On the other hand, the need to make drone operations regular and seamless, integrated into the future airspace with manned aviation and other entrants (think Urban Air Mobility), will lead to more formalized and mature processes regarding regulatory practices. Supply Chain 10, within the ADACORSA project, aims to support new entrants – mainly SMEs but also larger companies without previous aviation presence – with guidelines and methods that allow understanding the regulatory context and translate them in a practical manner into requirements for development. SC10 aims to develop these guidelines by exploiting a BVLOS logistics use case and the Specific Operations Risk Assessment (SORA) methodology. The presentation will highlight SC10 goals, current achievements, and remaining work to develop the guideline.

Data-driven uncertainty quantification and propagation for probabilistic trajectory planning

Mr. Andrés Muñoz Hernández (Boeing Research & Technology Europe), *Manuel Polaina, Alejandro Güemes, Jordi Pons, Xavier Prats, Emre Koyuncu, Daniel Delahaye, Raimund Zoop, Alex Kuenz, Manuel Soler*

One of the main objectives of Trajectory-Based Operations (TBO) is to increase the predictability of the aircraft behavior within the Air Traffic Management (ATM) system. However, most systems involved in TBO (such as flight planning systems) focus on proposing deterministic trajectories in the strategic phase, not taking into account the uncertainty factors that affect the trajectory prediction process in the tactical phase. Consequently, there is an increased frequency of updates and modifications to trajectories in later planning phases, which leads to degraded stability, resulting in an overall decrease of the performance of the ATM network. In this presentation, a data-driven methodology will be introduced for characterizing the uncertainties affecting the development of an aircraft trajectory, together with their integration into a stochastic trajectory predictor for obtaining robust sets of probabilistic trajectories from an initial flight plan. Additionally, this methodology employs data assimilation models that capture updated information from the air traffic system to reduce the present uncertainty. First, the main sources of uncertainty for aircraft trajectories will be identified and quantified using historical flight instances for a full year of pan-European air traffic. After quantifying these sources of uncertainty, it will be possible to evaluate the potential variations for a flight plan given the probability distributions for uncertain factors affecting the flight. Instead of applying computationally demanding methods, such as Monte Carlo simulations, for calculating all possible trajectories, a stochastic trajectory predictor is proposed that makes use of the characterization of trajectory uncertainty to compute probabilistic trajectories given an initial flight plan. The stochastic trajectory predictor uses arbitrary Polynomial Chaos Expansion (PCE) theory and the point collocation method to find polynomials describing the aircraft trajectory for the initial flight plan as a function of the identified uncertain factors. Therefore, the quantified uncertainty sources can be fitted in the polynomials to find a reduced set of probabilistic trajectories that are robust and resilient to potential variations in the tactical phase. Complementing this, a set of advanced data-assimilation models based on machine learning techniques are integrated to provide accurate estimations for some of the uncertain factors based on the last available status of the air traffic system. These estimates reduce the uncertainty spectrum for important variables in the trajectory prediction process and help adapting the resulting probabilistic trajectories to the current system status. Finally, a study case is introduced in which the proposed methodology is implemented. This study includes the results of analyzing the probabilistic trajectories for one city-pair and supports the idea of integrating probabilistic trajectories as a key enabler for envisioned TBO concepts and modern airline operations planning.

ATM network modelling, uncertainty propagation with thunderstorm disruptions

Dr. Emre Koyuncu (Instambul Technical University), *Muhammet Aksoy, Andrés Muñoz, Jordi Pons, Daniel Delahaye, Raimund Zoop, Alex Kuenz, Manuel Soler*

In this work, as a part of START, we have developed an ATM network macro-model, allowing us to model the propagation of flight trajectory uncertainties and further assess the impact of disruptive events, i.e., thunderstorms. We utilized data-driven analytics models mimicking the dynamics of epidemic spreading, which is analogous to delay or uncertainty propagation over transport networks. The connections between the operational aspects of the air traffic flow management and the developed meta-model are given as the airports' traffic densities correlated with the infection rates among the individuals; and the capability to absorb the uncertainties of the airports associated with recovery rates. Uncertainties over individual flight trajectories, which are the functions of flight times, have been defined through probabilistic distributions where superposed on the arrival times. Deep learning models have been integrated to capture the nonlinear relationship between the recovery rates, uncertainty accumulation, and disruptive events' attributes. The model allowed us to simulate and analyze the behavior of the network under uncertainty accumulations coming from trajectory uncertainty. Finally, we have used Reinforcement Learning to explore the best actions to enhance the network resiliency, defined through stability theory. From the operational perspective, resiliency is associated with the managing balance between the intervention rate (depending on "the time for washing away the effect of the transition period) and costs. The problem, at this point, transformed into an optimization-based control problem to guarantee convergence over time, meaning the effect of disruptive events dies out eventually. Quick recovery is typically preferred, but it applies significant intervention measures impacting many flights in this case. RL provided us with pinpointing the OD pairs, and the flights require regulatory action such as flight cancelation and aircraft grounding. The case studies are analyzed for the selected time windows chosen in the interval of 1-10 June 2018, where thunderstorms affected large areas of North-West Europe with intense local convective activities.

Network-wide robust and resilient metaheuristic trajectory optimization under thunderstorm disruptions

Mr. Julien Lavandier (ENAC), *Daniel Delahaye, Daniel González-Arribas, Javier García, Manuel Soler, Emre Koyuncu Aksoy, Andrés Muñoz, Jordi Pons, Xavier Prats, Daniel Delahaye, Raimund Zoop, Alex Kuenz*

Network-wide robust and resilient trajectory planning is realized after the uncertainty propagations at trajectory and ATM levels. The inputs are the 4D trajectories with uncertainty and the delays applied to trajectories for network resiliency. The delays only shift the trajectories in time. The output is a set of algorithmic solutions for optimal trajectory selection under high complexity situations. According to the START concept, a proposed rerouting and/or rescheduling solution of the user-preferred flight plan is proposed to improve the resiliency and robustness of overall planning. The optimization process is realized using the simulated annealing metaheuristic to find the optimal rerouting and delays for each flight. The objective function of this optimization problem is a complexity metric function, based on Linear Dynamical System. This metric can consider uncertainty in the 4D trajectories. However, the computation of such metric requires extensive computation time. We proposed GPU-based concept to speed up the metric computation. We have found that the proposed GPU-based concept can potentially provide the desired performance and prove the computational viability of the START project.

Nevertheless, our findings are not uniformly positive, as the reliance on single-precision arithmetic (on which current GPUs provide substantially higher throughput) seems to have proved more problematic than our previous expectation. The global air traffic complexity is reduced by a factor of six hundred from around 120 to 0.2. It corresponds to a better organization of the traffic. In fact, the complexity is mainly due to very few flights. The complexity reduction decreases the potential number of conflicts, because there are less converging air traffic situations.

Simulation Exercises for robust Flight dispatching solution under thunderstorm disruptions

Mr. Alex Kuenz (DLR), *Emre Koyuncu, Muhammet Aksoy, Andrés Muñoz, Manuel Polaina, Alejandro Güemes, Jordi Pons, Xavier Prats, Julien Lavandier, Daniel Delahaye, Raimund Zoop, Alejandra Frías, Daniel González-Arribas, Javier García, Manuel Soler*

The development, implementation and validation of optimisation algorithms for robust airline operations that result in stable and resilient Air Traffic Management (ATM) performance even in disturbed scenarios are the overall goals of START. This presentation focuses on the validation part. The validation of the START robust airline operations is performed by comparing the performance of a reference and a resilient scenario under disturbed and undisturbed conditions. The reference scenario is derived from the traffic demand for two days in 2018, June 7th and June 10th with strong convective weather phenomena. The resilient scenario is built on the reference scenario but is prepared for more frequent planning updates due to changing forecasts of capacity shortfalls mainly caused by weather impacts. Resiliency refers to the intrinsic ability of a system to adjust its functioning prior to, during, or following changes and disturbances. Within the validation trials performed, disturbances are included by means of convective weather areas which are handled as No-Fly-Zones (NFZ). Validation of the START results is performed threefold. First, reference and resilient scenarios are compared, mainly focussing on expected duration of overall conflict hours of aircraft with other aircraft and convective weather zones. Second, real life departure uncertainties are added by means of Monte-Carlo simulations with different distributions. Finally, scenarios are resolved with conflict resolution algorithms above FL150 as far as possible. The presentation gives an overview of the validation results, showing an overall low but stable benefit for the adapted aircraft fleet (Star Alliance) of the resilient scenario, with no negative effects for the global scenario.

Artificial Intelligence and Weather Forecasting

Aniel Jardines (UC3M), *Iván Martínez, Javier García, Manuel Soler*

Robust Climate Optimal Aircraft Trajectory Planning within Structured Airspace

Mr. Abolfazl Simorgh (UC3M), *Manuel Soler*

The climate impact of the non-CO_2 emissions, being responsible for two-thirds of aviation radiative forcing, highly depends on the chemical and meteorological background conditions. Hence, there is a potential to reduce their associated climate effects by rerouting aircraft trajectories around climate-sensitive regions (Simorgh et al. 2022). Determination of aircraft trajectory and quantification of the climate impacts associated with non-CO_2 emissions require meteorological variables. The presence of uncertainties due to the inevitably uncertain weather forecast, if not accounted for within aircraft trajectory planning, can lead to inefficient trajectories. In this study, we propose robust climate optimal aircraft trajectory planning within the currently structured airspace considering uncertainties in the standard weather forecast. The ensemble prediction system (EPS) is employed to characterize the uncertainty in the weather forecast, and climate-sensitive regions are quantified using algorithmic climate change functions. Uncertainty analysis shows that variability in relative humidity within EPS weather forecast is high, leading to considerable uncertainty in the determination of persistent contrails formation areas (PCFA) and, consequently, the climate impact of contrails. As the contrails have dominant climate effects compared to other species, including CO2 and NOx emissions, the net climate impact will be uncertain as well. To integrate and manage such uncertainties in determining climate optimal trajectories, an objective function is defined, including the mean and variance of climate impacts. A heuristic algorithm based on the augmented random search is employed and implemented on graphics processing units to solve the robust optimization computationally fast. Some scenarios support the effectiveness of our proposed strategy in planning robust climate optimal trajectories within the structured airspace. For the considered case study, employing the climate optimal routing option during nighttime reduces both the mean and uncertainty range of climate impact as the aircraft avoids forming warming contrails. In contrast, during the daytime, as contrails can have cooling climate effects, aircraft with climate optimal routing option tends to fly through uncertain PCFA to benefit from the cooling impacts. Although the climate impact is mitigated, the uncertainty is still considerable in this case. By penalizing variance of climate impact in the objective function, the ability to control and reduce the effects of uncertainty associated with the weather forecast for the daytime scenario is provided.

Complexity Assessment of Adopting Climate Optimal Aircraft Trajectories at Network Scale

Mr. Fateme Baneshi (UC3M), *Manuel Soler*

Aviation contributes to anthropogenic climate change through carbon dioxide (CO2) and non-CO2 emissions. Due to the direct dependency on atmospheric location and time of emissions, the non-CO2 climate impact can be mitigated using operational measures such as aircraft trajectory optimization (Simorgh et al. 2022). However, adopting independently optimized trajectories may not be operationally feasible for the Air Traffic Management (ATM) system because of the associated impact at the network scale on the safety, demand, and complexity of air traffic. Hence, the mitigation potential of climate impact needs to be analyzed at the network level to assess how the adoption of independently climate optimized trajectories affects the air traffic performance and then propose resolution strategies to compensate for the arisen negative impacts. Previous studies have analyzed the climate impact mitigation potential at the trajectory scale (see Simorgh et al. (2022) for a recent, comprehensive survey on climate optimal aircraft trajectory planning). In this study, we aim to explore the effects of employing climate-optimized trajectories on air traffic complexity. To this end, a network-scale scenario with 1005 flights is considered over Spain and Portugal’s airspace. The 4D trajectory optimization is performed for all flights independently in the free-route airspace. The algorithmic climate change functions are employed to quantify the climate impact of each species, including contrails, and emissions of nitrogen oxides, CO2, and water vapor, in terms of average temperature response over the next 20 years. The optimized trajectories are determined in a probabilistic fashion in order to consider the effects of uncertainties in the atmospheric variables, characterized using the Ensemble Prediction System, on both the aircraft trajectories and the quantified climate impacts. A probabilistic complexity metric based on traffic density is employed to generate a complexity map to evaluate the traffic performance and detect congested areas. For the considered scenario, the results indicate that by adopting trajectories with less climate impact, the complexity is increased around climate hotspots mainly due to the tendency to avoid climate-sensitive regions. In order to mitigate such an increase in complexity, a resolution strategy needs to be employed to find the optimal mechanisms to manage ATM from a climatic perspective.

Identification and critical assessment of circular ecosystems for aerospace composite components based on a novel R6-strategy

Mr. Philipp Johst (Leipzig University of Applied Sciences), *Paul Schulz, Alexander Knorr, Robert Kupfer, Robert Böhm*

The demand for composites in the aerospace industry significantly increased over the last decades. This is due to the excellent properties of composites, especially low weight, design flexibility, reduced maintenance effort, corrosion resistance, and improved fatigue life. However, aircrafts with a high percentage of composite components provide new obstacles for the recycling sector. In order to contest the way that is given by the Green Deal of the European Commission, new pathways are required to ensure an effective and economic multiple use of end-of-life components. We introduce a strategic approach for returning decommissioned parts of aerospace composites back into the material chain with a particular focus on waste reduction, consequent energy, and emission savings. This approach aims for sustainable methods in order to exploit numerous circular possibilities, consisting of: reuse, repair, refurbish, remanufacture, repurpose, and recycling (R6 strategy). Based on the proposed concept, circular ecosystems (eco-settings) with minimal entropy are identified and qualitatively described. These eco-settings comprise closed loops, starting with sorting and dismantling of used aircraft composites which helps to realize a cascade use of the composite products. For that reason, extended regional value chains across sectors and borders are described. Additionally, an assessment for the various eco-settings is presented based on scientific and economic criteria.

ECO-CLIP: From CF/ LMPAEK factory waste to recycled material for aerospace structural parts manufacturing

Dr. Rocio Pena (AIMEN Technology Center), Dr. Elena Rodríguez-Senín (AIMEN Technology Center), *Celia Martín-Pérez, Daniel Rodriguez-Del Rosario, Noelia González-Castro*

The introduction of composites in aerospace industry can be understood due to the continuous evolution looking for lighter materials with good performance, first moving forward metal materials to thermoset composites (TSCs), and nowadays with a transition to thermoplastic composites (TPCs) due to a new era of ecological concern, since TPCs can be recycled. ECO-CLIP project is based on a combination of innovation activities oriented to achieve lighter structural parts from TPCs factory waste for the next generation of MFFD fuselage demonstrator, which is undertaken as part of the Clean Sky 2. The recycling steps comprise factory waste shredding, melting, and blending with virgin LMPAEK material using a twin-screw extruder. The shredding process was studied to obtain a satisfactory fiber distribution length (FDL) in the final part. For this aim, sieving of the shredded material was performed obtaining 3 different fractions according to their fiber length. The smaller one to be used for 3D printing proposes (0-2 mm), the middle one for injection moulding (0-18 mm) and the longest one to be reprocessed (>20mm). Different mixtures were obtained by a twin-screw extruder by blending virgin polymer (%LMPAEK) with short carbon fibre recycled fraction (%rLMPAEK) resulting in different final carbon fiber content (wt%CF) from 30 to 66 wt%. Melt-state mixing parameters were optimized for each formulation and FDL distribution, fiber content, thermal properties, torque measurements and rheology properties were also studied to select the final formulation.Subsequently each mixture was processed

by injection moulding and mechanical properties were tested to correlate the effect of the short fiber in the mechanical performance of the novel composites to select the final material. Mold filling simulation was performance to ensure final part fulfilling. In this sense, the relationship between carbon fiber percentage, fiber breakage and mechanical properties was stablished after injection moulding and 3Dpriting. This study contributes to the development of new recycling route for CF-LMPAEK and the chance to tune the performance on final parts for the next aerospace structural demonstrators, also enables to add value to TPs scrap factory materials contributing to LCA+.

Potential of polymer recycling in aeronautics. ECOCLIP project

Dr. Celia Martín Rocío Pena (AIMEN Technology Center), *Santiago G. Cuervo, Raquel Travieso, Elena Rodríguez*

The ECO-CLIP project, which is carried out as part of Clean Sky 2, is based on a combination of innovative efforts aimed at producing lighter structural elements from TPCs industry waste, for the next generation of aviation fuselage demonstrator. In the context of Clean Sky 2, Large Passenger Aircraft – Platform 2, ECO-CLIP focuses on the development of short fiber reinforced thermoplastic composites using recycled CF/LMPAEK from factory waste to produce structural parts like frame clips and system brackets to be installed in the Next Generation Multi-Functional Fuselage Demonstrator (MFFD). This project is an alternative recycling method that uses continuous CF/LMPAEK industrial waste to recycle polymers and fibers to develop a new short CF/LMPAEK material. Factory scraps were crushed to flakes as part of the recycling process. Then, flakes were melted and blended with virgin material using a twin-screw extruder. Different mixtures were done by blending virgin polymer with the short carbon fiber recycled flakes in a rage of 30 up to 66 wt% CF. Based on material properties for the different formulations, and their processability by injection molding and FGF, 40%CF material was selected. In order to demonstrate environmental benefits a comparative LCA was carried out following ILCD handbook and ISO14040 methodology. Cradle to door scope was considered in order to evaluate manufacture and raw materials impact. But also, a cradle to grave analysis was contemplated to evaluate weight reduction during the use of the airplane in the case of aluminium substitution Results from cradle to door analysis showed, if developed from raw and recycled LMPAEK-CF were compared, it could be possible a 5% reduction in environmental impact (Pt in ILCD endpoint methodology) and 20% carbon footprint reduction comparing results for injection moulding manufacturing. In the cradle to grave analysis, it is possible to validate that environmental impact is minor due to component weight reduction, when raw material is changed from metal to polymer. In conclusion, the project demonstrates improvement in using recycled CF-thermoplastics in aeronautics. Moreover, weight reductions for material change (CF-thermoplastic vs metal) compensate for the higher impacts in the manufacturing phase, due to during the use phase is expected less fuel consumption and consequently combustion gases emissions.

Investigation of induction heating capacity of nanocomposite materials for on-demand debonding/re-bonding applications

Mr. Konstantinos Zafeiris (National Technical University of Athens), *C. Yasirogiannis, T. Kosanovic, S. Anagnou, C.A. Charitidis*

Induction heating is a fast, selective, and flexible method to deliver high-strength magnetic fields to ferromagnetic nanoparticles, which act as susceptors, generating heat in nanocomposite materials by hysteresis. Through the induction heating mechanism, nanocomposite materials embedded with magnetic nanoparticles (MNPs) constitute promising materials for induction-based repair of composites, adhesive joining systems, enabling reversible joining procedures, providing easy-to-disassembly operations. Herein an investigation of the heating capacity of nanocomposite materials by employing induction heating technology is presented. Thermoplastic (TP) matrices of poly-ether-ketone-ketone (PEKK) were compounded with 2.5-10.0% wt. iron oxide-based (Fe3O4, NiFe2O4 and CoFe2O4) MNPs using a twin-screw extruder. Samples for induction heating evaluation were prepared by injection moulding and their heating capacity was examined as a function of time, and frequency of electromagnetic filed applied by RF generator with two different inductor coil geometries. All nanocomposite samples presented temperature increase proportional to the MNPs concentration with regards to their exposure time in the applied magnetic field. Specimens with higher concentrations of MNPs presented a more rapid temperature increase, resulting in a polymer matrix melted state in most experiments. RF generator working parameters have proved to significantly affect the heating capacity of investigated configurations. Taking advantage of the induction heating mechanism, nanocomposite materials functionalized with MNPs constitute promising materials for composite systems, providing easy-to-disassembly operations by induction heating. Two approaches were proposed to boost the heating ability and optimize the disassembly processing window; i.e., improving the MNPs composition /concentration, and fine-tuning the frequency excitation after optimization of the inductor design.

Research on ThermoPlastic Composite (TPC) repairs. RETPAIR Project

Ms. Noelia González-Castro (AIMEN Technology Center), *Francisco Ansedes, Ivette Coto, Adrián Rodríguez, Ricardo Losada, Elena Rodríguez- Senín*

The future of aeronautic factories is oriented to manufacture lighter and cost-effective components using greener materials like thermoplastic composites (TPCs). In this sense, given their increasing use, providing with costefficient repair methods for their complete integration in production is needed. The ain objective of RETPAIR is the development of new high performance, flexible and cost-effective, automated and robotized net-shape technologies to rework and repair TPC parts to be integrated in the manufacturing line. The proposed solutions assure one-side accessibility and are supported by a digital-based methodology to assist the patch design and manufacturing. An induction welding solution for structural damages repair based on pre-manufactured patches will be developed, and two in-situ consolidation solutions for structural and non-structural applications based on automated and robotized layer-by-layer patch in-situ creation: an automated laying (AL) solution based on ATL/AFP technologies (automated tape laying/automated fibre placement) will be investigated for structural and large size repairs, and a 3D printing FFF-based (Fused Filament Fabrication) solution, using both continuous carbon fibre filaments and short fibre filaments will allow to tune patches' strength for different requirements (structural and cosmetic) to assure the thermal and mechanical quality of the repair, the critical process parameters (temperature, pressure, times/ rates) will be monitored and controlled. RETPAIR will contribute to European aeronautical industry competitiveness by developing digital environments in aircraft manufacturing plants, which will allow for higher integration, shorter production cycles, energy efficiency improvement and environmental friendliness. Highly flexible automated and robotized processes will be possible in such digital framework, and such solutions will be extended to in-service MRO operations, contributing to develop the future aircraft smart and customized maintenance solutions for the benefit of European airlines and MROs.

Multi-material design and function integration of composites: Part I

Session Chair : Dr. Angelos Filippatos (Technical University of Dresden, Germany)

Integration of high-performance hybrid metal-composite-structures into the mechanical simulation model of a jet engine using the superelement method

Mr. Friedrich Töpfer (Technical University of Dresden), *Alrik Dargel, Sebastian Spitzer, Christoph Klaus, Maik Gude*

FLIGHTPATH 2050 aims to reduce the resource consumption of aviation systems. Therefore, composite materials with its high specific strength and stiffness offer the possibility of saving emissions and at the same time fulfilling the functions due to a large number of adjustable design parameters. In a complex system of a jet engine (cf. Figure 1), materials must be used in alignment with the requirements to the component itself. The intermediate case (IMC) contains complex structural and functional components. A hybrid design allows the structure to be tailored to its function, which leads to a lighter and thus more efficient jet engine. Fibre reinforced polymers are predestined for load path optimized structures whereas metallic parts are used to introduce loads and handle complex three dimensional stress conditions. To analyse the structural behaviour, the hybrid IMC demands design and modelling of each component as well as assembly modelling to connect the parts at their interfaces. To reduce the size and complexity of the assembly part, the superelement method is introduced in this paper.As a first step, the interfaces and their functions are analysed. It is followed by the modelling of the component and definition of the boundary conditions, before the superelement reduction is performed. The superelement is then integrated into the assembly part at the defined interfaces. The superelement method allows the reduction of calculation time and increases the overall handling of large models. Furthermore, it simplifies the transition between different CAE programs and allows e.g. the use of unsupported element types in a specific solver environment. The post-processing of the superelement and its structural analysis requires additional methods which will be presented in this paper.

In-situ identification of ice accumulation profile and vibration response at composite blades under various icing conditions

Dr. Angelos Filippatos (Technical University of Dresden), *Simon Schwab, Georgios Tzortzinis, Evgenia Madia and Maik Gude*

Ice accumulation on wind turbine blades still stands a major operational issue for wind energy plants. Especially under cold climatic conditions, icing can occur on the rotor blades drastically affecting their safe and smooth operating conditions. Ice growth can greatly reduce the energy yield, increase critical stresses on turbine components such as blades and gearbox, and at the same time pose a high safety risk from falling or hurled ice chunks. Therefore, a better understanding of the icing behavior and the resulting change at the structural vibration behavior of blades can contribute to predicative measures during ice accumulation, and to prevent critical loads that can potentially lead to damage initiation. To address these challenges, this study experimentally investigates the vibration behavior of downscaled composite blades under icing conditions in an in-house developed rotor test rig. The rotor test rig is positioned inside a climate chamber for experiencing temperatures down to -20°C. An ice-generation subsystem of three nozzles and a mounted sensor system for the measurement of the ice accumulation at the rotating blades, are also installed. Downscaled composite blades of a 200 mm length and 50 mm width of a symmetrical NACA-0018 profile were designed, manufactured and tested. The blades have an integrated sensor-actuator system for experimental modal analysis under different rotational velocities. A highlight is the application of a laser profiler, which collects displacement data across the rotating blades, enabling an in-situ full-field measurement of the ice accumulation on the blades during their rotation. A series of approximately eight scenarios describing unique ice distribution profiles are experimentally examined between -10°C and -20°C, at 40 different time steps. The obtained frequency response spectra are plotted as waterfall diagram, to identify qualitative and quantitative changes under increasing ice mass. The results demonstrate that the direction and magnitude of the changes in the frequency response spectra are subject to manifold, partly conflicting influences by the ice mass and distribution as well as the contributing stiffness of the ice layer. Finally, the collected measurement data from various sensors are organized into a database to serve as a starting point to correlate the response of blades with the type, distribution and mass of the accumulated ice.

Function integration at multi-material composite fuel storage tanks using structural topology optimization

Mr. Kaushik Abhyankar (Technical University of Dresden), *Georgios Tzortzinis, Angelos Filippatos*

European Green Deal Strategy seeks for a 90% reduction in greenhouse gas emissions by 2050 through introduction of sustainable, affordable, and cleaner alternatives to conventional fossil fuels. Such an alternative is ammonia (NH3), a clean fuel with no carbon content, which comes with a number of advantages regarding handling, existing infrastructure and sustainability. Specifically, it is conveniently stored and transported at ambient temperatures, is an already established commercial product in the fertilizer industry, and is a renewable fuel which can be produced from green electrical energy. However, ammonia is also inherently toxic and has low energy density. The European project titled "NH3CRAFT" focusses on safe and efficient storage of ammonia within ships. The aim is to design high-fidelity, scalable and adaptable composite fuel storage tanks for safe and efficient storage of large quantities of ammonia. To address these challenges, the ammonia fuel storage tanks have to fulfill two functions: structural integrity and leakage-monitoring. The structural integrity function secures the tank for operational loading conditions, whereas the leakage-monitoring function ensures that the tank is leakage-free during its course of operation. A contradiction that can be observed in the purpose of the abovementioned functions is as follows: Although subcomponents such as embedded micro-electronics and pressure, strain and level-measurement sensors [1–3], integrated in composite tanks help monitor the leakage-free operation, they may also disrupt it's structural integrity [4–6]. Disrupted structural integrity due to local defects and stiffness discontinuities may lead to catastrophic failure of the structure. A possible preventive measure in the long run is to locally reinforce the structure using suitable materials. We utilize the novel spiral design approach to find the optimal reinforcement configuration in terms of spatial distribution, quantity and materials. In the framework of applying spiral design approach, finding the topology of such an optimal reinforcement that ensures dynamic stability and minimal efforts under certain loading conditions can be formulated into a structural topology optimization problem [7]. To solve this optimization problem, we computationally investigate the performance of cylindrical fuel storage tanks made from glass fibre reinforced plastic with representative imperfections due to the existence of a subcomponent. For searching large optimization space of unique reinforcements, a multi-choice Genetic Algorithm (GA) [8] is used to identify potential optimal configurations in terms of structural performance and reinforcement requirements. The GA is coupled with finite element solver to obtain the optimal configuration for given specific technical requirements. This design approach although applied for ammonia storage tanks, can be further utilized for generic fuel storage systems e.g., liquefied Hydrogen storage.

Integration of sensors in sandwich composites for the detection of structural damage

Mr. Florian Lehmann (Technical University of Dresden), *Tim Bätzel, Anja Winkler, Niels Modler, Matthias Woog, Lorenzo Matassini, Sebastian Sauer, Teiwen Fehse, Philip Johannes Steinbild*

A decisive factor in achieving the climate targets of the German government is the reduction of CO2 through the gradual electrification of transport. In battery-electric vehicles, the energy storage system is typically positioned close to the ground under the passenger cell. Thus, the crossing of obstacles or typical load scenarios affecting the underbody play a crucial role for vehicle safety. Currently, such battery protection structures usually consist of thick-walled aluminum, steel or titanium constructions, which are associated with increased weight and manufacturing costs. Larger moving masses in battery electric vehicles lead to high resource consumption during the usage cycle. Therefore, the battery protection structure represents a lightweight structure, that. This paper addresses the development of a functionally integrative lightweight battery protection structure made of glass fiber reinforced plastic (GRP). In addition to the purely mechanical protection of the energy storage unit, this structure should be able to detect and classify any damage occurring to the battery module above it during operation. A structure-integrated sensor system can also be used to automatically determine the extent of damage, which means that service activities or component replacements will only be carried out when demonstrably necessary and not within defined maintenance intervals or on suspicion. Based on a detailed requirement profile for the structure, a comparison of selected sensor concepts is carried out. For further investigations, three sensor types (pressure sensor, strain sensor, inductive sensors) are examined in more detail and analysed with regard to their positioning in the composite and their suitability for detecting different load cases. A further issue is the clarification of possible integration options in terms of production technology. For this purpose, the so-called e-preforming technology is used, which enables an automated application of functional elements. In this context, different types of conductor track manufacturing and contacting of electronic components within the sandwich structure will be demonstrated. The results of this paper can be transferred to the field of aviation and influence approaches for the development of structural health monitoring components.

In-Situ Computed Tomography — Analysis of a Single-Lap Shear Test with Composite-Metal Pin Joints

Mr. Daniel Köhler (Technical University of Dresden), *Julian Popp, Robert Kupfer, Juliane Troschitz, Dietmar Drummer, Maik Gude*

Lightweight design in the form of intelligent multi-material structures that combine the advantages of high strength steel and continuous fiber reinforced thermoplastics (CFRTs) gain increasing relevance. In this context, the joining operation is the primary challenge as it has to be time and cost efficient and the resulting joint has to exhibit a high mechanically durability. One possible approach is the use of cold formed pin structures, which can be inserted into the CFRT to create a form fitting joint under avoidance of fiber damage as it is commonly the case for bolted or riveted joints. The deformation phenomena of pin joints are usually investigated by microsectioning or (ex-situ) computed tomography. However, due to resetting elastic deformations and cracks that close after unloading an inaccurate state of the inner joint structure is measured. Furthermore, an investigation of different stages with increasing load and progressing failure is very time consuming, because multiple samples have to be tested and

investigated. Alternatively, in-situ computed tomography (in-situ CT) can be used to investigate the testing of pin joints. In this paper, a method for in-situ CT analysis of a single-lap shear test with composite-metal pin joints is presented. The pins are plastically extruded to a height of approx. 1.8 mm from the metal sheet (1.5 mm thick) and are pressed into the locally heated glass fiber reinforced plastic (GFRP) sheet (approx. 2 mm thick) creating a form fit. Specimens with quasi-unidirectional fiber reinforcement in 0°- and 90° direction as well as biaxial samples 0°/90° are tested. With this procedure, the three-dimensional deformation of the joint can be observed and failure modes can be identified for each reinforcement direction respectively. Thus, this method can also be used for validating numerical simulations.

Changes in electric resistance of cracked copper-coated, pitch-based carbon fibres for structural health monitoring in a glider wing

Mr. Philip Johannes Steinbild (Technical University of Dresden*), Jan Condé-Wolter; Anja Winkler; Tom Ehrig; Pawel Kostka; Niels Modler*

Structural health monitoring based on detecting strain enables further exploitation of the lightweight potential of aircraft structures. Since carbon fibres (CF) can be easily integrated into aircraft structures made of fibre-reinforced plastics (FRP), their use in sensor applications has become subject of research. One of many novel approaches is the use of cracked CF for strain detection. During loading and unloading, the fibre cracks are opening and closing respectively, resulting in substantial changes in the electrical resistance. The high dependence of the electrical resistance on the mechanical strain enables spatially resolved strain sensing along the transmission line based on the electric time domain reflectometry (ETDR) principle. However, due to high inhomogeneity of the used pitch-based CF and the resulting electric properties, the ETDR-signal is degraded largely by impedance mismatch along the transmission line, which limits the measuring length of a spatially resolved sensor. In this contribution, a concept for the use of a spatially resolved CF-based strain sensor in a glider wing is described, outlining the challenges that need to be addressed. One approach for the extension of the measuring length is lowering the base resistivity of the used CF, which is discussed in detail. In order to achieve a low base resistivity while maintaining the characteristic of opening and closing fibre cracks, copper-coated CF are investigated. The copper-coated pitch-based CF are integrated into test specimens consisting of a composite material and are subjected to tensile loading. Simultaneously to the deflection, the electrical resistance is measured. Consequently, the sensitivity as well as the respective gauge factors are determined and discussed.

Numerical Investigation of the Magnetic Alignment of Fe-Co-Coated Single Reinforcement Fibers

Anja Winkler, Mr. Yun Xu (Technical University of Dresden*), Martin Helwig, Niels Modler, Maik Gude, Axel Dittes, Dominik Höhlich, Thomas Lampke*

Fiber-reinforced composites are progressively more used in a variety of industrial applications. In recent years, carbon fiber-reinforced plastics have become increasingly popular, particularly in the aerospace sector because they offer outstanding mechanical properties combined with low weight. However, the orientation and distribution of the fibers have a significant effect on the mechanical and physical properties of the composite materials. Using conventional manufacturing technologies, it is not always technologically possible to adjust the fiber orientation to the load. This applies, e.g. to complex geometries or ribs, which often show areas with insufficiently oriented fibers. This means that the full lightweight potential cannot be exploited. A possible approach for a targeted orientation of fibers is the

combination of classical manufacturing processes with a superimposed magnetic alignment process so that the fibers can be oriented according to the load during component manufacturing. In this context, the study of the alignment of reinforcing fibers is receiving more and more attention. The orientation and distribution of short fibers through an external magnetic field seem to be well suited to be integrated into the conventional manufacturing process of fiber-reinforced composites. Therefore, the generally non-magnetic reinforcement fibers, e.g. carbon or glass fibers, need to be modified or coated by magnetic materials. In this paper, Fe-Co-coated carbon fibers are prepared by electrodeposition for the validation of simulation models developed in previous studies and the magnetic properties of Fe-Co-coated carbon fibers are described. Furthermore, experimental and numerical studies are presented in regard to the orientation of such fibers in polymeric matrices. Thus, the orientability of coated carbon fibers in polymeric materials is shown and the works provide an important reference for future studies of fiber orientation and alignment using magnetic fields.

Multi-material design and function integration of composites: Part II

Session Chair : Dr. Angelos Filippatos (Technical University of Dresden, Germany)

Modelling the structural energy dissipation of interface-modified textile-reinforced composite materials

***Mr. Moritz Kuhtz** (**Technical University of Dresden**), Jonas Richter, Jens Wiegand, Albert Langkamp, Andreas Hornig, Maik Gude*

Carbon fibre-reinforced plastics (CFRP) are predestined for use in high performance components due to their high specific mechanical property. In addition, these materials have the advantage that the material properties and in particular the failure behaviour can be adjusted, for example, via the angle of the fibre orientation. In contrast to the brittle failure behaviour in the fibre direction, delamination as a specific inter-fibre failure mode represents a good-natured failure case, since on the one hand a lot of energy is dissipated by the large-area crack formation and on the other hand the structural integrity is often remained. Previous investigations have shown that interface modifications can be used to selectively adjust the interlaminar properties, which decisively influences the delamination behaviour [1] and the associated failure behaviour of structures [2]. However, a systematic analysis of the influence of positioning and characteristics of the interface modifications on the structural failure behaviour is still missing [3]. Based on existing experimental investigations on the energy dissipation of CFRP impact-loaded beams [4], the failure behaviour of these beams is described in this study with the help of a simulation model. Based on calibrated material models describing both the in-plane and out-of-plane failure behaviour of the interface-modified CFRP, the structural failure behaviour and the energy dissipation are represented in a three-dimensional, parameterised finite element model. The large number of model input parameters requires a metamodel-based description of the correlation between the positioning and characteristics of the interface modification and the energy dissipation. Within the scope of the present work, a procedure is therefore developed which, on the one hand, enables an efficient design of interface-modified CFRP under highly dynamic loads. On the other hand, generic design recommendations are derived with regard to the positioning and characteristics of the interface modification.

Investigating the structure-property-function (SPF) relations of cnt-doped adhesive composites

***Dr. Angelos Filippatos (Technical University of Dresden)**, Georgios Tzortzinis, Evgenia Madia*

In composite materials, the structure-property-process (SPP) relations are widely understood through fundamental principles in materials design and development of composite structures. Specifically, it is thoroughly investigated how the microscopic structure (internal topology) of a fiber-reinforced composite structure, its layup and the fiber architecture provide a set of macroscopic mechanical properties and the associated processes regarding textile architecture and manufacturing. In parallel, present day's increased needs for reduced weight and installation space have enhanced the function-integration design approach. Function-integrated composites can be realized by incorporating new functional materials into the structure, enabling new properties to fulfill multiple functions, leading to new type of relations, the structure-property-function relations (SPF). Although SPF relations are state of the art in other scientific fields such as biology, chemistry, and physics, only few investigations exist for different composite materials and topologies and the vast majority of these investigations are mostly experimental. Ideally, a direct mapping between functions of a system and internal structure through the required properties could open a new avenue of understanding and selecting specific materials for specific applications. However, due to the lack of direct mapping, we often face the contradiction of having new materials with specific properties without being able to implement them for a specific function. To investigate this challenge, we study a typical set of composites. We select cnt-doped adhesives with well-established SPP-relations of coupling between their structure and the generated mechanical and electrical properties. These properties enable the ability of the composite to fulfill multiple functions; adhesion, signal transmission and electromagnetic shielding (EMI). Specifically, we investigate the means by which the internal structure, cnt-size, dispersion, orientation and volume fraction affect the mechanical and electrical properties of the composite. Therefore, we perform a first mapping of the SPF-relations for two different group of materials, namely adhesives and cnts under different topologies. Through this scope, we explore the terms structure, property and function and the possibility of a targeted balance between structural and electrical properties leading to the aforementioned functions.

Joining of Composites with Metals using Graded Metal Fabric Interfaces

Mr. Richard Grothe (Technical University of Dresden)*, Daniel Weck, Cornelia Sennewald, Juliane Troschitz, Maik Gude, Chokri Cherif*

Due to their excellent mechanical properties' composites are becoming increasingly important for aerospace and automotive applications. However, the inclusion of composites into common structures is often leading to several additionally needed developments within the manufacturing process. A purposeful combination of different material characteristics also results using metal and composite parts simultaneously as hybrid composites. These are essential for intelligent lightweight constructions, since material and component properties can be adapted for the different component regions, which leads to a profitable combination of the specific material characteristics. Such innovative approaches of hybrid components are almost predestined for highly loaded structures of aeroplanes, cars, components of the process industry like fans, but also for jet engines and even in new approaches of electrical engines. Within this paper, joining solutions based on established production methods and devices are presented which facilitate an efficient manufacturing process of hybrid components. Due to the implementation of metal tapes in a fabric structure, a novel development approach was pursued which, as a result of the combination of two basic materials, produces a hybrid semi-finished fabric. After the consolidation process the structure becomes a composite with a one-sided metallic interface (metal-composite-structure (MCS)) which allows novel approaches to join the MCS with e.g. metal sheets. Various approaches, like laser welding, laser soldering, induction welding, resistance spot welding and adhesive bonding to join the MCS with metals were investigated and compared with regard to their attachment and the transmittable forces perpendicular and parallel to the joining surface. This new type of hybrid fabric structure makes it possible to generate a form-fit and adhesive bond connection between the metal tapes and the composite material. The possibility of joining the parts through one-sided accessibility, as well as the good force transmission within the joining zone, can be highlighted as advantages.

By utilizing the metallic interface, the MCSs - as novel hybrid structures - were joined to metallic components with different joining technologies and all joints were prepared at coupon level. Due to the very good results, the joints made with laser welding were analysed in detail, examined microscopically and tested with destructive testing methods. The research conclusions reveal a high potential of the developed technology showing the high performance under in-plane-shear and out-of-plane-tensile loading conditions as well as additional benign failure behaviour. The feasibility of the technology has thus been demonstrated and can be transferred to a wide range of material combinations.

Generative Hybridization of Thermoplastic Composites with Thermoplastic Elastomers - increasing the bonding strength by physical surface pretreatments

*Johanna Maier, **Mr. Christian Vogel (Technical University of Dresden)**, Niels Modler, Maik Gude, Thomas Behnisch, Tobias Kastner*

For the sustainable fabrication of lightweight structures in multi-material design, generative hybridization has proven to be very efficient by combining classical composite manufacturing processes with additive manufacturing technologies. Thereby, components with high geometric complexity and high mechanical properties are generated in small series without the need for additional molding tools. In this study, hybrid specimens were fabricated by additively depositing TPE (thermoplastic elastomer) via fused layer modeling (FLM) onto continuous woven fiber GF/PA6 (glass fiber/polyamide 6) flat preforms. In particular, the effects of surface pretreatment and process-related surface interactions were investigated. Optical microscopy for contact angle measurements as well as laser profilometry and thermal analysis were used. The adhesion characteristics at the interface were evaluated by quasi-static tensile pull-off tests, and adapted test specimens were developed for this investigation. The results show that especially the adhesion strength, but also the corresponding failure mode vary with the pretreatment settings and process parameters during generative hybridization. It is found that especially the base substrate temperature has a significant influence on the adhesive tensile strength. In particular, it is shown that surface activation by plasma can significantly increase the specific adhesion during generative hybridization.

Hybrid Strategies for the Improvement of the Flame Retardancy of in-situ Silica-Epoxy Nanocomposites cured with Aliphatic Hardener

***Mr. Aurelio Bifulco (Università degli Studi di Napoli Federico II)**, Claudio Imparato, Sabyasachi Gaan, Giulio Malucelli, Antonio Aronne*

Epoxy resins show a combination of thermal stability, good mechanical performance, and durability, which make these materials suitable for many applications in the Aerospace industry. Different types of curing agents can be utilized for curing epoxy systems. The use of aliphatic amines as curing agent is preferable over the toxic aromatic ones, though their incorporation increases the flammability of the resin. Recently, we have developed different hybrid strategies, where the sol-gel technique has been exploited in combination with two DOPO-based flame retardants and other synergists or the use of humic acid and ammonium polyphosphate to achieve non-dripping V-0 classification in UL 94 vertical flame spread tests, with low phosphorous loadings (e.g., 1-2 wt%). These strategies improved the flame retardancy of the epoxy matrix, without any detrimental impact on the mechanical and thermal properties of the composites. Finally, the formation of a hybrid silica-epoxy network accounted for the establishment of tailored interphases, due to a better dispersion of more polar additives in the hydrophobic resin.

Optimization of Mechanical Performance of Continuous-Discontinuous Tape Thermoplastic Composites

***Ms. Deniz Ezgi Gulmez (Delft University of Technology),** Sergio Turteltaub, Jos Sinke, Clemens Dransfeld*

Continuous-Discontinuous hybrid fiber architectures are an innovative solution for minimizing manufacturing cut-offs of thermoplastic composites used in the industry. This study analyzes distinct hybrid tape architectures at the coupon level in order to optimize their mechanical performance. Various stacking sequences and ratios between discontinuous and continuous tapes are considered and their stiffness and strength are established through lamination theory and finite element simulations. Detailed sub-ply configurations are generated by using the Set Voronoi tessellation, which accounts for mesoscopic stochastic variability. The strength of the hybrid configuration is established based on the first ply failure in the finite element simulations. The relative performance of each configuration is used to find an optimum compromise between mechanical performance and hybridization ratio.

Construction Technologies of APU Exhaust Muffler Thermal Barriers and Air Intakes

Mr. Rafał Żurawski (Łukasiewicz Research Network - Institute of Aviation), *Marek Tabor, Paweł Guła, Marcin Praski*

The main objective of CHRZASZCZ (acronym) Project is design, development and manufacturing the technology demonstrators of Air Intake and Muffler for APU of Large Passenger Aircraft. Consortium consist of four members: Łukasiewicz Reaserch Network – Institute of Aviation (coordinator, Poland), Politecnico di Milano (Italy), Petroceramics (Italy), LA COMPOSITE, s.r.o. (Czech Republic). Main project objectives are weight reduction, acoustic attenuation improvement, implementation of innovative materials, environmental impact reduction, manufacturing cost and time reduction. Results of the project, according to stated objectives, will be presented in final paper. The Air intake is composed of duct (with interface to NACA inlet), elbow (with interface to APU inlet) and two guide vanes inside elbow, that are securing proper air flow inside Air Intake. Design approach to new construction will be presented. Test campaign will be described alongside final evaluation of project result. Main goal is to secure as high acoustic performance, as possible and this will be the main topic of final paper for air intake topic. The Muffler is composed of inner liner (to which rest of parts are attached), frames/baffles (supports outer surface) with outer skin and thermal blanket. Description of new design with requirements will be presented. Necessary tests and obtained results will be described alongside with comparison of final project results. Due to high operational temperature, final paper will focus on high temperature materials used for demonstrator production and their influence on acoustic attenuation of final design.

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Nanomaterial-based Devices for Green and Efficient Aviation and Space Applications

Session Chair: Prof. Patrizia Lamberti & Dr. Monica La Mura (University of Salerno, Italy)

Impact of design parameters uncertainty on the performance of graphene-based ambipolar electronics

Dr. Monica La Mura (University of Salerno, Italy), *P. Lamberti, V. Tucci*

The interest for graphene-based materials and devices rises from the particular properties of the planar allotropic form of Carbon. The focus on graphene-based electronics is an important matter of research due to the great carrier mobility, atomic thickness, resistance to radiation, tolerance to extreme temperatures of the so-called "wonder material". In fact, these characteristics allow the development of devices and circuits with high performance, good thermal efficiency, high tolerance to cosmic radiation, and most of all small footprint and low weight. For these many reasons, the research on graphene-based electronics is still strongly directed towards the development of devices and circuits that find application in the aeronautics and aerospace fields. Due to the relatively new technology required for the fabrication of devices including graphene in single-layer configuration or in a few layers, the process for the growth, deposition, transfer, and processing of graphene is not yet optimized, and therefore still influencing strongly the quality of the produced devices. More precisely, the uncontrollable factors involved in the fabrication process determine an impairment of the resulting devices' performance. It is therefore of interest to understand which are the most influential process-related parameters that impact on certain figures of merit used to assess the quality of the manufactured component. The basic component of graphene electronics is the Graphene Field-Effect Transistor (GFET). We have previously investigated the impact of the design parameters' tolerance on the GFET amplification capabilities (in the 10th EASN Virtual International Conference, 2020) and high-frequency performance (in the 11th EASN Virtual International Conference, 2021). In this work, we consider the impact of the design parameters' uncertainty on the performance of a GFET-based frequency multiplier by using a factorial design of experiments. GFET-based frequency multipliers take advantage of the ambipolar conduction of GFETs to generate harmonics of the input signal's frequency. The circuit behavior is simulated by means of a charge-based compact model of the GFET in the Advanced Design System® (Keysight Technologies, Inc.) commercial suite for the design and simulation of RF electronics. The frequency multiplier performance indicators are computed in correspondence of designed combinations of the geometric parameters, varying between their minimum and maximum value according to the design parameters' tolerance range, following an extreme-value analysis approach. In this way, the relative contributions of the individual factors to the performance variability are assessed.

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Electromagnetic Shielding with Graphene Nanoplatelets Coatings for Aeronautical Applications

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Airborne electronics requirements for Electromagnetic Compatibility (EMC) are so tight [1], that an EMC-aware design poses severe challenges, such as those related to the need of limiting the EM emission to the required levels. This goal is usually achieved with a proper design of EM shields, usually made by aluminum casings, a choice that guarantees EM shielding, together with satisfactory thermal and mechanical behavior. However, with the new design trends, the electronic systems are distributed over the aircraft, thus suggesting the use of housings with shapes optimized to the space, with the lowest possible weight, so pushing towards new solutions that involve lighter materials with better printability. In this paper, the electronic cases are realized in 3D printing by using ULTEM® 9085, a lightweight and certified thermoplastic material [2], but with no EM shielding capability. It is well known that graphene-based composite materials can provide outstanding mechanical, thermal and electrical behavior [3]. Due to its costs, attention is nowadays paid to the so-called commercial graphene (such as the Graphene Nanoplatelets, GNPs), that realizes a satisfactory compromise between performance and cost [4]. In this paper, we have used coatings based on GNPs, industrially synthesized from a low-cost graphitic precursor. The composite materials for the coatings have been realized by mixing GNPs and a binder (epoxy) in different percentage. These materials have been integrated on the samples by spray coating and film adhesion. A study of the performance of the case in real operating conditions has been carried out with reference to the EMC emission test imposed by the norm DO-160-G. Specifically, a controller board (EUT) is chosen, whose emission is exceeding the limit mask Cat-H ([1], Section 21.5), by about 15 dB in the range 100-200 MHz. Tests in an anechoic chamber have demonstrated that when the EUT is placed inside the fabricated case the emissions are strongly reduced and the EMC compliance is guaranteed.

Robust design of graphene-enhanced absorbing metasurfaces for THz applications

Dr. Monica La Mura (University of Salerno, Italy),*, P. Lamberti, V. Tucci, P. Kuzhir, et al.*

The electromagnetic response of 2D materials in the THz frequency range make graphene-based materials and metamaterials interesting for the development of new devices and components for several applications. Recently, interesting absorbing properties have been proven for graphene-enhanced metamaterials based on patterned substrates [1], [2]. If combined with the radiation tolerance of polymer-supported graphene [3], it is possible to develop high-performing THz passive devices for space applications, such as detectors, bolometers, and different types of sensors. In the development of THz passive devices based on graphene-enhanced metamaterials, it is important to understand how the properties of the metamaterial depend on the geometry, and how they can be effectively tuned by operating on the design parameters. Recently, we presented the fabrication, modeling, and characterization of a metasurface made by a SiO2 grating covered with a gold reflector, coupled to a PMMA/graphene/PMMA multilayer [4], [5]. In this work, the impact of the grating vertical geometry change on the electromagnetic performance of the metamaterial is assessed by characterizing samples fabricated according to a factorial 32 design of experiments. The sensitivity of the power reflection, transmission, and absorption spectra in the frequency range spanning from 0.1 THz to 1 THz is investigated by taking into account the concurrent variation of the grating height and of the gold reflector thickness across three levels. The grating height ranges from 11 nm to 21 nm, as constrained by the laser micromachining equipment capabilities. The gold thickness spans from 0 to 100 nm. The considered levels for the input factors are h = (11 nm, 15 nm, 21 nm), for the grating height and dg = (0 nm, 70 nm, 100 nm), for the gold thickness, and the input settings located in the factor space can be seen in Fig. 1. The most influential factor between the two is assessed for the three considered performance of interest. The linearity of the dependence is assessed by computing the interaction effects between the two factors. The electromagnetic performance of the fabricated samples is evaluated in two different operating conditions, i.e. by applying the electric field o

NEMESIS project H2020 and C12A7:e- material analysis

Session Chair: Dr. Angel Post (AT Devices, Spain)

NEMESIS achievements: new cathode technology using C12A7:e- as electron emitter

Dr. Angel Post (AT Devices), *J. F. Plaza, J. Toledo, D. Zschätzsch, M. Reitemeyer, A. Guglielmi, A. Gurciullo, A. Siegel, P. J. Klar, P. Lascombes, and B. Seifert*

This work is summarising some of the results from the H2020 NEMESIS project activities on electride-based new cathode technology compatible with all kinds of electric propulsion (EP) systems requiring neutralization or electron emission. The project challenge is to fully transfer the theoretically ideal materials properties of the C12A7:e- electride material to neutralizer and any other kind of electron emitting devices, in order to fully make use of its potential for application to achieve the best performance and reliability and to become a disruptive force in the cost-driven satellite market. Different cathode architectures and several emitter configurations with traditional and with alternative propellants are being developed and tested within the project, all of them using C12A7:e- electride material as thermionic electron source. The anticipated advantages of this new cathode technology are being confirmed in terms of lower operational temperatures, lower power consumptions, and compatibility with more propellants, including iodine, versus the existing cathode technologies based on traditional thermionic materials like LaB6 or BaO. Several performance analyses will be described in this work for some of the different cathode devices developed by the project consortium members, including first endurance tests results. Also performance analysis will be provided comparing the same electron emitting devices when based on C12A7:e- or based on other alternative thermionic materials.

NH3 fuelled space EP systems using C12A7:e- as electron emitter

J.F. Plaza, J. Toledo, ***Dr. Angel Post (AT Devices)***

Given the significant changes taking place in the geopolitical global situation, and the derived supply chain issues for some traditional EP propellants like Xe, alternative propellants issue is perceived as a strategic topic to tackle, and NH3 is becoming one serious candidate. NH3 is increasingly being investigated to extend Green Hydrogen use by overcoming the storage and transportation issues of H2. NH3 characteristics like its high energy density and low temperature and/or pressure needs for storage (10 bar at 20ºC liquid ammonia), make it very valuable for simplified unexpensive energy storage and transportation, and these characteristics makes it also especially suitable for on-board spacecrafts EP purposes. Based on the research activities performed at ATD on NH3 generation and dissociation processes with C12A7:e- as catalyst, this work will describe the ammonia more relevant characteristics and properties associated to the advantages of using the cheap and abundant NH3 aa a very appropriate alternative propellant for EP systems, and will also present and discuss the results of the first successful tests performed with ammonia as fuel for a C12A7:e- based neutralizer, including relevant endurance tests in operation conditions. Additionally, the dual application as propellant and on-board energy generation system of NH3 will also be discussed.

Measurement of the C12A7:e- thermionic emission enhancement due to photon exposure

*J. Toledo, **Dr. Angel Post (AT Devices)**, J.F. Plaza*

Thermionic emission is the release of electrons from an electrode by virtue of its temperature when the thermal energy given to the charge carrier overcomes the work function of the material. Photon-enhanced thermionic emission (PETE) is a concept firstly introduced by the Stanford University consisting in combining the quantum effect of the large energy of solar radiation photons to excite electrons, as in photovoltaic cells, with the thermal mechanism of thermionic emission. In this way, the PETE process is based on the thermionic emission of electrons excited by solar photons within a semiconductor at high temperature. C12A7:e- is a increasingly known thermionic material with a very low work function (2.4 eV) but up to now there were not available data on its capability to enhance its thermionic emission through the quantum effect of incident photons. In this work, a test set-up device is designed, developed and manufactured to perform a direct measurement of the emission enhancement that the photon absorption can bring to the thermionic emission of C12A7:e- electride material. This result will provide an indication whether the electride material could be a valid material for building a PETE device where the C12A7:e- is the semiconductor used as cathode. The development steps. as well as the performed measurements, will be described and results will be presented and discussed.

Tailoring effective work function. C12A7:e- effective work function variations via thin film depositions of different materials

*J. Toledo, **Dr. Angel Post (AT Devices)**, J.F. Plaza*

C12A7:e- “electride” is a well know low work function material (2.4 eV). The effect in lowering the effective work function of some high work function materials via thin film depositions of certain special materials has been studied and analysed, and is well known in some cases like Thoriated Tungsten, or BaO. Dipole effect and electronic band bending are the most frequently formulated hypothesis for explaining this phenomenon. On its side, C12A7:e- is a low work function material but some authors have observed similar effective work function lowering behaviour that could not agree with the most consistent hypothesis. We have been carrying out at ATD an exhaustive analysis of this topic and a number of experiments using several different materials for thin film depositions over C12A7:e- samples, combining materials with high and with low work function, with different bandgaps, different vacuum and conduction bands positions versus Fermi level, different conductivities and other variables in order to validate the most common hypothesis or to reach new ones that could explain better this behaviour. New models that show which variables could significantly influence in the effective work function, could be a valuable tool for tailoring the effective work function for certain applications. In this work we will describe the experimental results of the effective work function variations observed for the different thin films depositions and we will discuss the rational found for such variations and the hypothesis we can formulate to explain them.

Unbreakable, flexible and multipurpose cathode based on ceramic C12A7:e material deposited on special substrates

*J.F. Plaza, **Dr. Angel Post (AT Devices)**, J. Toledo*

The NEMESIS project covers a long series of experiments with the aim of improving electron emission using C12A7:e- as active material in cathodes. Likewise, since the material is a ceramic, it is necessary to reduce the probability of fracture or cracking in space conditions due to vibrations and shocks. For achieving this goal, improvements have been introduced with the insertion of nanoparticles of materials such as Y2O3 that evidences a greater resistance to fractures. Among the most disruptive solutions, the use of flexible substrates as carbon fiber on which the C12A7 material is deposited has revealed as a definitive solution for avoiding ceramics lacks occurring when using bulk samples. Several deposition techniques were developed, tested and analyzed. Sputtering, even Pulsed-DC and HiPIMs techniques, specially indicated for ceramics materials, had some important issues due to selective sputtering behavior that slightly changes the material composition in the substrate, but enough to have a poorer electron emission. PLD (pulsed Laser Deposition) guarantees a perfect and stoichiometric translation from C12A7:e target to substrate but it is relatively impractical method for any cathode shape. Finally, electrospray techniques have resulted a success method for large substrates coverage keeping the material stoichiometry, even with a fine doses control. On the other hand, a new solute product based on C12A7:e- and new post processes have to been developed for recovering the original material emission properties. An unbreakable, flexible and resistant material is made using carbon fiber, treated for conductivity increasing, containing C12A7:e electride that keeps its original electron emission properties. The material would then support thermal shocks, vibrations, pressures, tensions and it is inert for a lot of chemical interactions keeping the emission properties comparable to bulk samples.

New Challenges for next Generation Aircraft

Session Chair: Mr. Jeronimo Medina Gonzalez (AIRBUS, Spain)

Unleashing the potentials of digital twinning in the production of composite aircraft components

Dr. Erik H. Baalbergen (Royal Netherlands Aerospace Centre NLR), *Julian A. de Marchi, Remco Klerx*

The aircraft industry, like other industries, is continuously challenged to do "more with less". The industry must deliver more complex products meeting increasingly stricter regulations and growing specific customer demands, provide better quality products in larger quantities, and pay more attention to reusability and circularity issues. However, the industry needs to achieve these "mores" with lower costs, shorter lead and production times, and less waste, delay, energy consumption, emissions, and raw non-renewable materials. To keep up with these challenges, the aircraft industry automates and continuously innovates as much as possible. The increasing use of composites in aircraft and aircraft components adds the extra challenge of rapidly bringing innovative composites manufacturing processes to the factory floor. An obvious step towards facing the challenges is smarter use of available resources (including materials and production facilities) thereby exploiting automation and digitization. Modern operational information technologies provide broad support for automation and digitization, and have stimulated the rise of notions like Smart Industry, Factories of the Future, Industry 4.0, and even Industry 5.0. With these developments, aircraft product design, analysis, testing, and production are increasingly digitized and automated, and consequently involve and produce more and more data. Data is considered the modern gold. Digital twinning is an important enabler for digging and exploiting this gold. A digital twin is a digital replica of a physical product or process. The digital replica mimics the behavior and properties of the physical twin, based on data about – and collected (preferably real-time) from – the physical twin and its context. A digital twin commonly comprises a tailored and integrated combination of applicable information technologies, including modelling and simulation, machine learning, data science, and visualization (e.g. augmented reality), to master the large quantities of data available from and about the physical twin, and to facilitate easy-to-use and insightful human-machine interaction. Digital Twins aim to help their stakeholders to master and exploit this ever growing plethora of data.

Lifing and performance methods for operational analysis of advanced "smart" engines implementing novel control strategies

Dr. Evangelia Pontika (Cranfield University), *Panagiotis Laskaridis*

Modern aero engines have increasingly sophisticated control systems and future aero engines and fleets have the potential to offer even more operational flexibility. Some of the most promising control variables that can "handle" the trade-off between fuel burn, lifing and emissions over the flight mission are the cooling flows, active tip clearance and climb derate policy. This paper presents a physics-based framework for the performance, emissions and lifing analysis of future "smart" engines with advanced variable settings. The presented framework enables performance and lifing analysis over the flight mission but can also zoom into operating point level and flight phase level. The captured parameters include operational severity in terms of creep, fatigue and oxidation, Exhaust Gas Temperature (EGT) which is an important indicator in engine health diagnostics, fuel burn, emissions, climb time and mission time. The present analysis examines the effect of variable settings on the operation of a high-bypass turbofan engine for long-range, wide-body aircraft. Modelling the behaviour of smart engines will inform operational decisions at individual engine level or fleet level in response to externally imposed scenarios. Such scenarios could be prolonging time-on-wing because it is peak travel season, trading off some engine life for improved fuel consumption during a period of fuel price rise, reducing airport NOx at the expense of engine efficiency and others. Finally, different trade-offs may become beneficial during different flight phases, for example, take-off is more critical to life consumption while cruise is critical for overall fuel burn, especially in long-range applications.

Development of an innovative experimental test bench for advanced metallic and thermoplastic aircraft stiffened panels

Dr. Jose Polo (APPLUS), *Ignacio Arrufat, Alfonso Carpio, Panagiotis Kordas, Konstantinos T. Fotopoulos, George N. Lampeas, E. Carelas, Jan Halm, Senne Sterk*

To simulate, under laboratory conditions, axial, bending, shear, torsional and differential pressure loads on airframe structures, a complex test rig system is required. Existing test bench concepts have certain limitations in terms of adapting to different panel dimensions. This paper presents an alternative test bench design that is completely modular and can be adapted to any level of loading and panel geometry, while being capable of accurately introduce the fuselage barrel representative load combinations and the representative fuselage boundary conditions on the tested panels. The different elements of the test bench that can be combined to achieve realistic boundary conditions while allowing flexibility of the test setup are presented. The adaptation of two completely different panels is presented to demonstrate the flexibility of this concept; on the one hand a metal panel and on the other hand a panel made of thermoplastic. In both cases the dimensions and the stiffening system of the panel are completely different and require a flexible test bench as the one proposed here.

Acknowledgement: This research has received funding from the Clean Sky 2 Joint Undertaking under the European Union's Horizon 2020 research and innovation programme under grant agreement No 101007881 (under the call H2020-CS2-CFP11-2020-01): DEMONSTRATE 'Demonstration of Novel Fuselage Structural Integrity'

Novel aerodynamic propulsion concepts
Part I: Configurations & Conceptual Design
Part II: Novel analysis methods

Session Chair: Dr. Drewan Sanders (Cranfield University, UK) & Dr. Tomas Sinnige (TU Delft)

Part A: "Configurations and Conceptual Design

Performance Estimations for Guiding the Design of Rear-Fuselage Boundary Layer Ingestion Wind Tunnel Tests

***Dr. Drewan Sanders (Cranfield University)**, N Mutangara, N Moirou, P Laskaridis and J Alderman*

Supporting Understanding of Boundary Layer Ingestion Model Experiment (SUBLIME) is part of the Clean Sky 2 Joint Undertaking aimed at improving the understanding of Boundary Layer Ingestion propulsion physics, towards assessing the technology's potential contributions in helping meet the goals set out by ACARE for 2035. The project has focused its activities on an extensive wind-tunnel test campaign, supported by corresponding Computational Fluid Dynamics studies. SUBLIME will conduct tests on two Boundary Layer Ingesting Configurations installed on a conventional tube-and-wing configuration. The first (referred to as BLI360) is a thrust-split configuration which retains two podded underwing turbofan engines with the additional requirement of powering an additional electrically driven, ducted fan, positioned concentrically around the fuselage's tail-cone. The second configuration (referred to as BLI180) considers installing two turbofan engines on the either side of the tail-cone, similar to the NOVA concept. In the early stages of the project, it was necessary to obtain performance estimates to help guide the design of the subscale wind tunnel test models. This work describes the preliminary design exploration study that was conducted on the BLI360 configuration used to set the ranges of the performance parameters defining the subscale model design.

This paper first contains a description of the overarching performance accounting approach that will be adopted in the project. Secondly, a preliminary 0D thermodynamic model of a free-stream ingesting propulsor is presented, which is used to provide an estimation of the Power Saving Coefficient (PSC). This has two purposes, the first to represent a purely free-stream ingesting configuration, and the second a thrust-split BLI configuration, where a portion of the thrust is produced by underwing podded engines, and the remainder via the BLI propulsor. The third aspect presents work conducted on a 2D axisymmetric BLI propulsor + fuselage assembly using RANS CFD computations. The BLI propulsor is positioned at the rear of the fuselage and is concentric to it, thereby ingesting 360 degrees of the fuselage boundary layer. These studies are performed at full scale operating at realistic flight altitude and Mach number, representative of an A321. The radius of boundary layer ingested is varied parametrically by altering the throat height of the propulsor, whilst sweeps of the fan pressure ratio are also conducted to achieve different levels of net assembly force. An iterative solution model is used to maintain a constant average Mach number at the fan face as well as a constant fan polytropic efficiency, with the purposes of representing a common fan technology level. The test matrix provides efficiency curves for the fuselage-fan assembly and are combined with the free-stream underwing propulsors to produce curves of power saving coefficient. Power savings in the region of 2-5% are observed for a wide range of designs.

To translate the data to the scale models for wind tunnel testing, some preliminary transformations are given, along with recommendations on certain performance parameters. These include what mass flow rate to ingest (related to the amount of BL ingested), propulsor areas, the thrust-split to target as well as the required mechanical energy rise across the propulsor. Issues surrounding Reynolds number scaling in the context of Boundary Layer Ingestion are discussed briefly.

Towards greener aviation through propulsive fuselage aircraft: a hybrid momentum- and energy-based approach for assessing the power saving coefficient

Dr. Nicolas G. M. Moirou (Cranfield University), *Ngonidzashe E. Mutangara, Drewan S. Sanders, Panagiotis Laskaridis*

A potentially promising solution for improving the next generation commercial aircraft's performance hinges upon boundary-layer ingestion (BLI), alleviating the engines' fuel consumption, and consequently emissions. The technology implies an astute positioning of a propulsion system to ingest part of the boundary-layer flow forming around the airframe. Amongst conceptual architectures, a propulsive fuselage aircraft is composed of a conventional tube-and-wing partially propelled by under-wing engines that also drive a turbo-electric rear-mounted BLI propulsor. The performance of such thrust-splitting configuration is often quantified with a power saving coefficient (PSC), a surrogate for fuel burn, accounting for both propulsion systems and their efficiencies relative to a reference aircraft. Nonetheless, important divergences (7-15\%) are reported which give prominence to the modelling of the powered reference and its BLI-derived concept. This work, therefore, intends to quantify the sensitivity of the metric of interest, i.e. PSC, through variations in both under-wing power plants and BLI propulsors. To that end, on-board engine candidates are modelled with various sizes, operating conditions and components efficiencies coupled to CFD-based aft-mounted BLI fans. By means of a hybrid momentum- and energy-based approach, a performance assessment is enabled on the design space explored giving further opportunities to develop aerodynamic analyses. Lastly, the down-selected modelling for the SUBLIME (Supporting Understanding of Boundary-Layer Ingestion Model Experiment) project, funded by the European Commission and Clean Sky 2 (GA-864803), is compared with existing conceptual propulsive fuselage aircraft such as the NASA STARC-ABL and EU-funded CENTRELINE.

Part B: “Novel Analysis Method

Horizon 2030-2050 - Towards Ultra High Efficiency: Wake Energy Management, Mitigation and Utilisation through Integrated Airframe-Propulsion Concepts

Dr. Drewan Sanders (Cranfield University)*, I Lamprakis, N Moirou, N Mutangara, P Laskaridis*

In the endeavour to reduce aircraft emissions, it is necessary to consider unconventional airframe-propulsion integration architectures that can potentially improve the external aerodynamic performance of aircraft in a holistic manner. Examples of these include Distributed Propulsion (DP), Boundary Layer Ingestion (BLI), Wing Tip Propellers (WTPs) and Aerodynamic Surface Skin Heat Exchangers, to name a few. As Drela [1] highlights, attempts to accurately quantify, and understand the physical benefits behind such novel concepts, has brought into question the validity of long-standing performance definitions such as thrust, drag, and lift. Aircraft aerodynamic performance has been traditionally based on the decomposition of net forces into components associated with either the engine or airframe (i.e. thrust versus drag) or different supposed physical mechanisms/concepts (profile, wave and induced drag for example). However, there remains ambiguity in both defining and determining these components because several different formulations and treatments exist, each with their own definitions and physical interpretations. For conventional architectures, these ambiguities have had limited implications, but as future aviation turns to more novel architectures and operation, the uncertainties in both quantifying and understanding performance, becomes significant. In response to this challenge, various far-field methods are under development to take advantage of the rich, high-fidelity, flow-field information provided by advancements in CFD and experimental measurements.

These methods were initially based on momentum conservation control volume approaches, with Destarac and Van Der Vooren [2] as a prime example, and have been a staple for industry. However, such methods have not been successfully applied to novel architectures utilising integrated propulsion systems, for example. More recent approaches have been centred around the mechanical energy relations Drela [3] and later exergy destruction Arntz, et al. [4]. These energy based methods adopt an alternative approach to aircraft performance which, rather than simply relying on divisions of net force, consider holistically the power supplied to achieving the required net force and how this power is consumed aerodynamically. This has shown to provide useful insights in tracing the potential performance benefits of new architectures, with BLI as a prime example. However, one critical aspect not addressed by momentum and energy-based methods, is in calculating lift which is only indirectly achievable via assumptions made in defining induced drag. The principle of vortex force and Lamb vector methods does offer a unique way of directly calculating lift from the far-field flow, and has the potential to fill the gap that energy-based approaches are missing. This work provides a review of the various far-field methods currently emerging and under development, in the context of the different integrated airframe-propulsion system concepts that are being considered. The aim is to demonstrate how such methods are enabling an improved and rigorous understanding of the physics underlying such concepts, and the potential benefits which may be achieved through them. In doing so, this work will provide some evidence from numerical simulations provided in literature, or in some cases produced directly for this paper. The concepts that will be covered, include BLI, WTPs and skin heat exchangers.

Aerodynamic energy recovery mapping and force decomposition for future ultra-efficient aircraft applied to a finite wing

Mr. Ngonidzashe Enock Mutangara *(**Cranfield University**), Nicolas Moirou, Drewan Sanders, Panagiotis Laskaridis*

In a bid to reduce aviation's ecological impact, a large effort has been undertaken into the design of novel fuel-efficient aircraft. Accurately quantifying and identifying the aerodynamic forces acting over these configurations becomes of crucial importance in reporting performance benefits. Conventionally, aerodynamic force is evaluated by integrating pressure and friction forces acting on the body surface, commonly referred to as the nearfield method. This, however, only provides a binary decomposition of drag into pressure and skin friction with these components not being able to be attributed to physical mechanisms such as viscous, lift-induced, and wave contributions. As a result, much effort has been taken to develop more physics-based decomposition methods that are able to identify the phenomenological source of these forces. Notable from these are thermodynamic methods which, although limited to the analysis of entropy generating phenomena, allow for the evaluation of viscous and wave drag contributions. The induced drag can only be obtained indirectly through subtraction from the nearfield force. This ambiguous definition of induced drag is easily resolved through another state-of-the-art method, the vortex force method. This method is able to quantify both the irreversible and reversible parts of the aerodynamic force i.e., lift and lift-induced drag. Other methods such as mechanical energy/exergy-based methods offer an alternative means of performance assessment by tracking the evolution of mechanical energy and accumulation of viscous dissipation within the flow field. This work will focus on the numerical implementation of these methods in commercial CFD code Ansys Fluent©, as well as investigate the insight obtained from applying these state-of-the-art methods in tandem on a NACA 0012 finite wing. The motivation for the development of such a method is three-fold: firstly it contributes toward the computation and decomposition of aerodynamic and propulsive forces in the case of highly integrated propulsion and airframe concepts. Such concepts could present challenges in differentiating between drag, lift and thrust. Secondly, it offers the opportunity to better understand the available energy in the wake of the wing that can potentially be recovered through the implementation of distributed and/or wing tip propulsors. Thirdly implementation of such methods can be a very valuable tool for the aerodynamic assessment of novel aircraft-propulsion configurations when tested in wind tunnels. In this context the method developed can be used to compute the net vehicle forces by analysing the wake of the airframe and the lifting surfaces in particular. Such an analysis can combine a fusion of experimental wake measurements and numerical flow field analysis of the configurations tested, as in the case of the SUBLIME (Supporting understanding of boundary layer ingestion model experiments) project to compute the net vehicle force. The work presented contributes towards this and a case of a finite wing is presented to test, validate and benchmark the method developed. The framework of this investigation falls under the SUBLIME project, part of Clean Sky 2 and funded by the European Union’s Horizon 2020 research and innovation program.

Optimizing Design for Inspection

Session Chair: Prof. E. Jasiuniene (Kaunas University of Technology, Lithuania) & Prof. R. Pullin (Cardiff University, UK)

Health monitoring of the shaft bearings in a micro turbojet based on vibration analysis

Dr. Radoslaw Przysowa (Instytut Techniczny Wojsk Lotniczych), *Pawel Majewski*

In a recently implemented aerial target, the propulsion system consists of two JetCat P140 RXi-B micro turbojet engines. Due to the limited durability of the rotor support bearings, the engine operation time has been limited to 2 hours and the number of flights to two. In addition, after each flight, an engine bench test with vibration measurement is required. The adopted maintenance system is also labor intensive and costly due to obligatory shaft bearing inspections performed frequently in the repair shop. These problems result from the limitations of the available high-speed bearing technology and from the high rotor loads related to aircraft maneuvers in the air. OBJECTIVES: The goal of the work is to develop a method for assessing the health of the main shaft bearings in the micro turbojet based on vibration signals. METHODS: Methods known from full-scale jet engines were used to monitor the health of the main shaft bearings. The rotor dynamics model was developed, the vibration and rotational speed sensors were mounted on the engine, the vibration and other parameters of the engine were measured and analyzed, and then symptoms of damage were sought. RESULTS: The vibrations of seven JetCat engines were analyzed, selecting the one for further destructive testing. In all three axes X, Y and Z, the vibration components related to the rotational frequency and its harmonics, especially 2x and 3x related to rotor dynamics, are dominant. CONCLUSIONS: It is difficult and costly to directly increase the durability, efficiency and safety of micro turbojets through redesigning. Conducting continuous engine vibration monitoring is a promising way of extending engine life and avoiding the deficiencies of microturbines related to their size and low-cost technology. The obtained results indicate that the tested JetCat engines have a life reserve, which has so far been used to a small extent.

Evaluation of quality of adhesive joints using non-destructive testing techniques and image fusion

Mr. Gawher Ahmad Bhat (Kaunas University of Technology), *Bengisu Yilmaz, Damira Smagulova, Vaidotas Cicėnas, Egidijus Žukauskas, Elena Jasiuniene*

Non-destructive testing is mainly responsible for detecting the inhomogeneities in the material and characterizing the material properties without effecting the sample under investigation. It is not always feasible to extract all the reliable information needed to evaluate the presence of flaw in a component using a single non-destructive evaluation technique. To have a higher probability of detection , two or more nondestructive evaluation techniques could be needed to estimate the size and location of the defect. This paper presents the integration of two non-destructive testing techniques: air-coupled ultrasonic testing and radiographic testing for evaluating multiple defects in aluminum and CFRP single-lap adhesive joint. Multiple images are acquired from air-coupled ultrasonic testing and X-ray radiography with different modalities. The data extracted from these non-destructive testing techniques are integrated into fused image by employing saliency analysis and multi-scale image decomposition. The results of the data fusion show an improvement in defect visualization with high resolution and improved edge extraction.

Mode-I Fracture Toughness Evaluation of a 20-ply Composite Panel

Dr. Ömer Necati CORA (Karadeniz Technical University), *Muhammed Latif Bekci, Marwan Naaman, Rhys Pullin, Matthew Pearson*

Composite structures have been extensively applied in various fileds including aerospace, marine, and civil industries due to their several advantages including high strength and stiffness to weight ratio. To meet specific needs requires an integrated approach to design composite structures including material selection, manufacturing method, and appropriate testing prior to final use. Regarding the testing, fracture toughness in an important property that dictates the service life of composites. Composites do not exhibit fatigue failure like metals yet they are more prone to failure by delamination. This can be due to several factors including but not limited to manufacturing defects such as voids, machining induced stress-concentrated zones, insufficient wetting of fibres, or service conditions such as humidity, moisture absorption, cyclic loadings, impact, wear etc. In addition, interlaminar stresses are generated due to significant differences in moduli values of resin and fibre which leads to a excessive straining in the resin. Delamination is possible in such cases where through-thickness reinforcement is insufficient. Fracture is divided into three pure failure modes, opening (Mode I), sliding (Mode II), and tearing (Mode III) and the Mode I is the most commonly conducted fracture toughness testing. The so-called Double Cantilever Beam (DCB) test method, standardized as ASTM D 5528 in 1994. Standards are also available for mode-II end notched flexure (ENF) and mixed-mode bending (MMB) tests on unidirectional (UD) laminates. However, most of the laminate designs of composite structures involve multidirectional (MD) laminates, and delamination usually occurs at the interfaces between differently oriented plies. Service conditions most of the time, does not involve single mode of fracture but a combination of those. Therefore, MMB test have been increasingly implemented in fracture studies. Even though there are considerable literature on the experimental aspects of MMB, numerical modeling studies are quite limited. This study, therefore, first aims to experimentally investigate the mixed-mode fracture behaviour of 18 plies of USN150B laminated composite structure used in a representative wing structure built in Cardiff University under the context of a COST Action CA 18203 Optimising Design for Inspection. Experiments will be conducted by means of a MMB fracture toughness test fixture (ASTM D 6671). Then, numerical models will be established to reflect the experimental response of the composite panel. To this goal, different techniques including virtual crack closure technique (VCCT), cohesive zone modeling (CZM), extended finite element method (X-FEM) will be employed and their results will be compared.

Piezoresistive sensors of carbon nanotube fibres for structural health monitoring of next generation composite airframe parts

Mrs. Anastasiia Mikhalchan (IMDEA Materials), *Moisés Zarzoso, Celia Martín-Pérez, Pablo Romero Rodríguez, Meir Hefetz, Carlos González, Juan J. Vilatela*

The works introduces the novel concept for the multi-stage manufacturing of multifunctional composite airframe parts with Structural Health Monitoring capabilities through incorporation of carbon nanotube (CNT) fibres realized in the frame of DOMMINIO project [1]. The concept offers the cost-effective and efficient methodology of incorporation of novel piezoresistive sensors via robotized technologies as FFF printing and ATL consolidation into structural composite panels. The key sensoring capabilities are provided by high-performance fibres made of continuous ensembles of CNTs synthesized by Floating Catalyst CVD process in gas phase reaction with general control over molecular composition and properties. Such CNT fibres demonstrate superb electrical and thermal conductivity and the specific tensile strength above 2 GPa/SG [2], already over-performing Kevlar and some conventional carbon fibres. The work will highlight the structural aspects of CNT fibres that make them ideal candidates for the development of novel pirzoresistive sensors for aerospace-grade composite laminates. The results demonstrate the relationship between the alignment and stress-transfer between the CNT bundles and the piesoresistive properties of continuous CNT fibres, which may lead to gauge factors of 5-10 in the dry-state (as-made), outperforming some commercial strain gauges as constantan alloy metal foil (Cu/Ni) and others. The examples of piesoresistive properties of 3D-printed CNT fibre-based sensors and those incorporated into composite laminate coupons in the wide strain range will be presented.

Preliminary validation results of a novel concept of operations for RPAS Integration in TMA and at airports

Mr. Gunnar Schwoch (German Aerospace Center (DLR)), *Gabriella Duca, Vera Ferraiuolo, Edoardo Filippone, Paola Lanzi, Co Petersen, Riccardo Rocchio, Vittorio Sangermano, Jürgen Teutsch*

The paper describes the results of recent research activities carried out to investigate the safe integration of Remotely Piloted Aircraft System (RPAS) into ATC controlled airspace with a focus on Terminal Manoeuvring Areas (TMAs) and airports. Until today, RPAS missions require segregated airspace configurations, largely restricting their operational capabilities and economic viability. In consideration of the predicted market growth for RPAS the relevant European air traffic transport masterplans target the full integration of RPAS (and other UAS) by 2035 in both controlled and uncontrolled airspace. However, in recent years European airspace has reached its capacity limits, especially in TMAs and airports, making this resource the bottleneck of the industry. Consequently, the integration of RPAS in such kinds of airspace becomes one of the most relevant issues to be dealt with to achieve the seamless full integration of RPAS in the civil air transport system. The research activities presented in this paper started with the definition of RPAS-specific use cases, the development of a preliminary novel Concept of Operations and the technical and operational requirements related to this integration. They proceeded with the definition and the execution of a simulation test plan for the validation of this new operational concept. The validation campaign has been carried out involving aerospace research centres in the Netherlands, Germany, and Italy, respectively at NLR, DLR, and CIRA. Different aspects of RPAS integration in the TMA were considered, such as latency of command & control link and voice communication link, Automatic Take-off and Landing (ATOL) operations, contingency procedures, and handover of control between two different remote pilot stations. Technical, safety-related, and human factors validation objectives were identified and then assessed through simulation experiments. Several of the previously defined use cases were selected for validation, considering a combination of both nominal and contingency situations. The validation exercises were conducted using real-time human-in-the-loop simulation facilities consisting of remote pilot station simulators, traffic simulators, and ATC simulators including tower and approach controller working positions. These facilities were used to assess the human performance of both air traffic controllers and remote pilots. Moreover, variations of equity between manned and unmanned vehicles, and runway throughput were assessed. The proposed paper describes the selection of relevant use cases, the high-level architecture of all simulation campaigns and a summary of the achieved validation results. These results are presented per validation objective and per Key Performance Area (KPA). Finally, the impact of the achieved results on the refined Concept of Operations and operational and technical requirements is discussed. The activities discussed in the paper were carried out in the context of the project INVIRCAT, co-funded by SESAR Joint Undertaking under European Union's Horizon 2020 research and innovation programme, by a Consortium led by DLR and involving members of CIRA, Deep Blue, EUROCONTROL, ISDEFE, ISSNOVA, and Royal NLR.

Simulation campaign results for a Remain Well Clear system for IFR-RPAS integration in Airspace classes D-G in Europe

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For full integration of Remote Piloted Aircraft Systems (RPAS) with General Air Traffic (GAT), a capability that performs Detect and Avoid (DAA) is required. The most challenging environment for the design of this DAA system is operations in Class D-G airspaces. The specific content of this paper is the identification of a validation plan, based on simulation test campaigns, for the assessment of the requirements and capabilities for the Remain Well Clear (RWC) function of DAA systems to be integrated into unmanned air vehicles flying Instrument Flight Rules (IFR) into airspace classes D-G, and the presentation of relevant results. The validation of the RWC functional, interoperability and human requirements is a complex task. For that reason, a multi-phase validation approach employing two different simulation techniques: Fast-time and Real-time simulations, will be discussed. More specifically, the Fast Time simulations are carried out to prove compliance with functional and interoperation requirements and to statistically validate and tune the RWC volume definitions, alert timings, etc. Further, a fine-tuning of the encounter scenarios selected for real-time validation was made. The real-time simulations aimed to operationally validate the complete RWC concept with a special focus on the human-machine interfaces for the pilot and the interactions with the Air Traffic Controllers. The real-time simulation (RTS) aims to collect data that can only be assessed in interaction with human participants. Therefore, a combination of qualitative and quantitative research methods was chosen to investigate the different areas of the human performance assessment. Three RTS campaigns have been carried out involving different types of RPAS, namely a tactical UAV, a MALE type of RPAS and different classes of rotary-wing RPAS, each with different performance levels. Moreover, several different test conditions have been considered in all the RTS campaigns, differentiating the runs by airspace classes among D-E-G classes as per the scope of the project, different levels of latency of the C" link, type and numbers of intruders, and also nominal and off-nominal conditions. Preliminary considerations deriving from the simulation runs, which will be described in the final paper, allow outlining that the RWC provides a good situational awareness coherent with the actual traffic dynamical evolution. The general evaluation from the validation campaign provides a good understanding of the properties attained with the various WC protection volumes being investigated. Overall, it will be shown that RWC can increase flight safety and help avoid traffic disruptions due to collision avoidance activation, not only in class G, but also in class D and E where VFR aircraft without transponders can be present. The final paper will discuss in detail the RWC system functional and operational requirements, the simulation plan and infrastructures utilized for the test campaigns, and a resume of the attained simulation results, describing the key conclusions arising from those tests.

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CORUS-XUAM project overview

Dr. Riccardi Giovanni (ENAV)

Over the last century, the development of the aviation industry has fundamentally changed the way we live, work, and travel, and aviation has not stopped innovating during this time. In the last few years, new types of aircraft have started to be developed, including Unmanned Aircraft Systems (UAS or drones) and Urban Air Mobility (UAM) aircraft. With the development of these new aircraft types, aviation is once again taking a significant step forward. UAM refers to an ecosystem that enables on-demand, highly automated, passenger or cargo-carrying air transport services, with particular reference to the urban and sub-urban environments, where aviation is often highly regulated today. The UAM industry's vision involves new vehicle designs, new system technologies, the development of new airspace management constructs, new operational procedures and shared services to enable an innovative type of transport network. The CORUS-XUAM research project demonstrates how U-space services and solutions could support integrated UAM flight operations, allowing air taxis, drones and other airspace users (unmanned and manned) to operate safely, securely, sustainably and efficiently in a controlled and fully integrated airspace, without undue impact on operations currently managed by air traffic management (ATM). The project is undertaken by the consortium that delivered the SESAR JU-funded CORUS U-space Concept of Operations (ConOps) in 2019, extended by the addition of UAM expertise. CORUS-XUAM activities started with updating of the U-space ConOps, addressing the integration of UAM and drone operations into the airspace, as well as identifying new U-space-phase U3 and U4 services. The project's activities than continue with the preparation and execution of six challenging Very Large Scale Demonstration (VLD) campaigns in Belgium, France, Germany/UK, Italy, Spain, and Sweden. These VLD activities are the core of the CORUS-XUAM project. They demonstrate integrated UAM, drone and manned aircraft operations, through advanced forms of interaction using digital data exchange, supported by integrated and advanced U-space services in urban, sub-urban, and inter-city scenarios, as well as in and near ATM-controlled airspaces and airports. The VLDs focus on different types of mission, such as passenger transport, logistics, delivery, emergency response and surveillance, using different U-space deployment architectures and state-of-the-art technologies. They consider coordination between ATC and U-space, including interaction with air-traffic controllers and pilots. The VLDs combine flights by air taxis with other traffic and operations in the control zones (CTR) of major airports. Vertiport procedures, separation, and data services are also demonstrated. The main results of CORUS-XUAM are used to further consolidate the ConOps at the end of the project. The project also involves extensive consultation and communication initiatives involving authorities, U-space stakeholders and end-users. Innovative ATM/U-space services and the development of smart, automated, interoperable, and sustainable traffic management solutions are the key enablers for achieving the high level of integration needed to make urban air mobility a reality. These challenging objectives can only be achieved through an evolutionary development process ensuring the definition and timely deployment of appropriate, advanced and interoperable ATM/U-space infrastructure, technology, and traffic management capabilities, providing advanced services that fit with expected types of operation and levels of demand.

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Special focus on demonstration activities

Dr. Riccardi Giovanni (ENAV)

The WP8 Italian demonstration, focused on guidelines for safe depot-to-depot operations between two logistics centres within a suburban area. Flight tests, with involvement of a fast UAM vehicle and other drones for specific operations, took place at Grottaglie-Taranto civil experimental airport, allowing the involvement of an ATM component and the demonstration of coordination and interoperability between ATM and U-space for the management of UAM cargo traffic. This VLD addressed the UAM-tailored performance framework developed in CORUS-XUAM, including safety, access and equity, cyber security and human performance, measured through human-in-the-loop assessment, such as ATCOs and pilots and analysis of data collected during the demonstration. In detail the scenario, was composed by three different macro area located in Apulia Region (South-East of Italy):

- Grottaglie-Taranto Civil Airport
- Manduria Airfield
- Urban Area: Hospital

The type of operation was identified as a medical cargo transportation. The demonstration saw the participation and involvement of different actors, vehicles, systems and facilities and was composed by the following phases:

- Phase 1: UAM medical cargo operation in U-space with other UAS
- Phase 2: BVLOS small cargo operation from suburban to urban area
- Phase 3: Management of emergency from ATM in U-space: HEMS flight with high priority

In detail the demo was composed by the following steps:

- A cargo (e.g. medical goods) arrives at Taranto Grottaglie Civil airport.
- The medical content was loaded on a Pipistrel (PVS) Large Fixed Wing Cargo UAS/RPAS placed in an area close to the airport.
- The PVS/RPAS started the mission and fly in U-space through a dedicated UAM corridor in VLL which ends in an area (logistic center) close to Manduria.
- During the flight other drones specific operations (photogrammetry, precision agriculture) where performed and managed in the U-space.
- Once the PVS/RPAS has landed in the airfield, the medical load was divided into several smaller loads.
- One of these, was loaded on a Techno Sky UAS and transported to final destination (Manduria city area near hospital) through a specific BVLOS operation.
- Before the return flight to Grottaglie of the PVS/RPAS (before take-off), an emergency occurred (an HEMS flight started in controlled airspace and executed operation in U-space). The emergency was managed at all levels.

SESAR PJ13 ERICA ""Enable RPAS Insertion in controlled airspace"" Validation experiment for the long-term integration of RPAS in an Italian air traffic scenario

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Recent technological advances in Remotely Piloted Aircraft Systems (RPAS) and their related business models have brought new possibilities of their utilization in various commercial markets. However, accepting an increase of RPAS into the ATM system (ATMS) poses many challenges and the need to address operational, performance and safety concerns related to RPAS integration into the non-segregated airspace, since the Remotely Piloted Aircraft (RPA) operations differ in several aspects from those of manned aircraft. RPA speed, manoeuvrability, climb rate, other performance characteristics, together with their avionic system equipage, may differ substantially from conventional aircraft. Experience of RPAS operations and their interaction with the ATMS to date indicates that currently, while seamless integration is the eventual aim, they are unable to comply with many standards, routine ATM procedures. This has not prevented RPAS operations but has limited their integration. RPAS are classified as 'aircraft' and ultimately should comply with all the rules established for flying, certifying, and equipping aircraft. International regulations and standards require that any new system, procedure or operation that has an impact on the safety of ATM operations shall be subject to a risk assessment and mitigation process to support its safe introduction and operation. The goal of safely integrating RPAS seamlessly into the ATMS with other airspace users is subject to standard Safety Management System (SMS) principles. Manned aviation has been recognized as safe due to the contributions of many factors, such as safety nets, the ATC system etc. These factors are now challenged by the introduction of a new airspace user. The challenge lies in the quantification of those RPAS attributes that can potentially degrade the current level of flight safety, such as latency related to voice communication and C2 link (in particular for BRLOS) and the feasibility of pre-programmed flight plan in order to comply with well-known contingency procedures. The integration of IFR RPAS is targeted at European level by the "European ATM Master Plan: Roadmap for the safe integration of drones into all classes of airspace" that identifies a stepped approach. The scope of this solution is the long- term integration of IFR RPAS into the airspaces A to C. This is where the SESAR project ERICA comes in. Funded from the SESAR Joint Undertaking under European Union's Horizon 2020 research and innovation programme under grant agreement No 874474.PJ13, ERICA aims to define the operational and technical capabilities that allow remote piloted aircraft systems (RPAS) to operate in controlled airspace safely, during nominal and emergency conditions. The ERICA Solution 117 aims to provide the long-term operational, procedurals and technical capabilities to allow certified RPAS to be integrated into Airspace Class A to C without any negative impact on safety and capacity compared to the current situation. Solution 117 targets an operational environment that comprises TMA (terminal manoeuvring area) and En-route airspaces with low/medium complexity/density. This paper describes a specific Real Time Simulation (RTS) campaign executed in the frame of this SESAR solution. The validation exercise (jointly executed by the partnership made up of ENAV, Leonardo, CIRA, TELESPAZIO) assessed the feasibility of integrating civil RPAS ('certified' category) in a low/medium density non-segregated Italian TMA. The operations were carried out in a mixed mode considering both RPAS and manned traffic.

In particular, the RTS investigated the RPAS ability to fly Standard Initial Departure and Standard Arrival Route procedures SID/STAR and respond to ATCOs clearances and instructions (vectoring included). The simulated operations were executed over the Brindisi ACC area, considering both nominal and contingency situations (e.g. loss of RPAS C2 link during vectoring, loss of Voice Comm. Link, ATC surveillance failure), to assess: the impact of latency in SATCOM used to relay C2 data and voice communication the contingency management means (procedures or technical means) designed for RPAS in case of C2 link loss or degradation of CNS performance during SID and STAR execution; the performance of Remain Well Clear (RWC) alerting function against one or more potential intruders in non-nominal situations (e.g. ATC surveillance failure, traffic transponder failure). The validation was executed by using the CARTAGO (Capua-Roma-Torino Air Ground Operation) distributed simulation framework, whose simulators are interconnected through a Virtual Private Network, based on the High-Level Architecture (HLA) standard protocol with a customized Federated Object Model (FOM) for ATM RT simulations and a MAK RTI component. The customization allows exchanging all the relevant information usually transmitted by aeronautical transponders from simple Mode A up to Mode S-ES configurations. In addition, the standard HLA data protocol has been integrated with a “time-stamps” aimed to keep under control the synchronization among the simulators CARTAGO consists of a Leonardo RPAS (Remote Piloted Aircraft + Remote Pilot Station) full simulator based in Turin, a Leonardo real ATC platform and a Telespazio SATCOM simulator in Rome, a CIRA simulation facility in Capua, made up of a fixed wing tactical RPAS and a General aviation manned aircraft with dedicated pilot. ENAV ATCOs personnel and RPs participated in the simulation working in a realistic operational environment. Specific assessments were performed for Safety and HP involving dedicated operational staff and specific data collecting methodologies. The simulation campaign results demonstrate that the integration of RPAS flying IFR in medium complexity terminal area environments is feasible even if it may come at the expense of additional workload for the ATCOs (with a consequent impact on airspace capacity) in specific contingency situations. Those situations are managed through the execution of well-established and published (in aeronautical publication) procedures activated through automatic functions of the RPAS. Latency in communications as well as performances of RPAS are key aspects to be considered when managing such kind of non-nominal situation. As a general outcome, the C2 link loss and ATC Communication loss management means validated in this exercise proved a satisfactory level of maturity and readiness to be validated at a higher TRL level. Lost separation scenarios were also explored with the application of a DAA (Detect and Avoid) system for RPAS, which also provides the remote pilot with situation awareness and alerting of potential condition of loss of separation minima. The general conclusion was that the RWC warnings, in non-nominal condition, can be considered safe and appropriate, both from RP and ATCO perspective, as well as from a technical point of view, considering that, in any case in A to C airspaces, RPA actions cannot be executed without authorisation from ATC.

Simulation and experimental validation of aircraft structures: Part I

Session Chair: Prof. George Lampeas (University of Patras, Greece)

Application of simulation for the design of experimental validation of new V-tail for tilt-rotor plane

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The aim of the contribution is the present proposal of experimental validation of a new composite tailplane for the newly developed tilt-rotor plane. The FE model of the rear fuselage and more detailed modelling of test rig parts were proposed for validation of test design and optimisation of the interface area and design and verified loading system. The different loading systems simulating real aerodynamic load were compared and verified by the analytical and numerical model. The article also discusses the design of a dummy model of the second tail surface for the implementation of a test with one test specimen. The results will be used on application on progressive damage model (PDM) for developing system of crack stoppers in laminate structures.

Simulation and experimental validation of crack arresting features in composite joints

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Composite structural elements have been widely used in primary and secondary aerospace structures due to their high strength-to-weight ratio and advanced durability. The joint areas of these components are typically the weakest links of these composite structures. For this reason, special design elements known as crack stopping or delamination arresting features have been developed and presented in the literature to prevent delamination or debonding crack initiation, or to maintain the evolution of crack growth within an acceptable pre-defined critical size, ensuring the reliable load bearing capacity of the composite structure.

Co-consolidated butt-joints is a viable and innovative option for joining of composite components and their application in a stiffened structural element is examined in the present work. Since the 'weak link' in this type of structures is the butt-joint itself, the design of appropriate structural configurations that serve as delamination arrest features is required.

In the present work, a modelling methodology developed for the investigation of the mechanical behavior of butt-joint structural elements incorporating embedded delamination arresting features is presented. Finite element progressive damage modelling and cohesive zone modelling methodologies for the determination of the intralaminar and interlaminar failure modes of laminate composite materials, respectively, are presented. For validation purposes, the developed numerical models are utilized for the simulation of experimental cases of relative works of the open literature in coupon-scale. Subsequently, the experimental investigation and the modelling of the mechanical response of the butt-joint structural element is presented. Linear and nonlinear finite element models are developed to simulate the mechanical behavior of the butt-joint element under static loading conditions.

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Multipurpose test rig of an innovative rotorcraft vertical tail – development and validation

Dr. Roman Růžek (VZLU), *Radek Doubrava, Martin Oberthor and George Lampeas*

Composite structures are more and more applied to the primary structures of advanced aircrafts. Moreover, composites with thermoplastic matrix allow to use technologies that enable to short manufacture cycle and improve cost efficiency of the structure. Between these procedures can be classify thermoforming, welding, repairability, joining, etc. The EU TAILTEST (Development of a multipurpose test rig and validation of an innovative rotorcraft vertical tail) project deals with the two main directions. The first one is scoped to investigation relating to joining and manufacturing process with regards to better understanding of composite structure behaviour and delamination propagation and arresting in different joints (for example butt-join and stringer panel). The second one is focused to design, manufacturing, and validation of multipurpose test rig that enable time and cost saving during certification process of the selected structure. The paper presents overview of the project and work associated with the design and development of a multipurpose test rig for validation of an innovative rotorcraft vertical V-tail in general. The test rig enables optimized attachment of the fuselage to ground support fixture and optimal loading of the fin with sufficient accessibility for measuring system and non-destructive testing. The developed test rig also enables to manufacture and test conducting of only one fin of the V-tail structure which leads to manufacturing money saving and greater variability in load distribution and load cases applied to the V-tail structure. The missing second tail fin part is substituted with a special dummy with the identical attachment to the fuselage as the left fin. Based on the analysis of possible load introduction systems simulating aerodynamic loads, a system of fixed sleeves was selected for the preliminary test, enabling the realization of both positive and negative loads acting on the tail surfaces. The loading system represents the pressure aerodynamic load on the fin, the load from hinges and the load from the Ruddervator control actuators. This solution also leads to time and cost saving during experimental proof of the structure. For design and validation purposes numerical modelling was used. The aim of the test program is the static verification of the design of the structure to obtain a permit to fly airworthiness.

Virtual testing of aircraft fuselage sections by developing experimental testing methodologies at the stiffened panel level

P*. Kordas* (*ATHENA – Research Center / Industrial Systems Institute*), *K. Fotopoulos, E. Carelas, and G. Lampeas*

Fuselage structures are subjected to combinations of axial, bending, shear, torsion and differential pressure loads. The validation of advanced metallic and composite fuselage designs against such loads is based on the full-scale testing of the fuselage barrel, which, however, is highly demanding from time and cost viewpoint. In order to de-risk the development process and enable almost right-first-time fuselage designs, novel structural concepts are validated at a lower level of the test pyramid, i.e. at the level of a typical fuselage stiffened panel, which should include all critical and complex structural features of the fuselage barrel. Such experimental campaigns at the stiffened panel level should include quasi-static testing at various loading combinations up to ultimate load final failure, as well as fatigue tests at loading conditions representative of the operational conditions of the selected aircraft flight profile. The performance of such tests requires advanced, complex and adaptable test rigs, capable to accurately introduce the fuselage barrel representative load combinations and the representative fuselage boundary conditions on the tested panels. These requirements imply that the stiffened panels geometry, loading and boundary conditions should be appropriately selected, such that the panel response closely approximates that of the respective section of the full-scale fuselage barrel under real flight conditions. The present paper aims to contribute to this ambitious goal, by developing experimental testing methodologies at the stiffened panel level, through detailed simulations of physical tests of both the 'fuselage barrel' and the 'stiffened panel'. Extensive parametric model studies about panel loading and boundary conditions are performed and the the most promising loading concept leading to the optimal definition of boundary conditions and loading systems are defined. The proposed test bench leads to panel responses, which are as close as possible to those of the fuselage barrel in-flight and can be used for the execution of static or fatigue tests on advanced metallic and thermoplastic curved integrally stiffened full-scale panels, representative of a business jet fuselage structure.

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Machine learning for structural numerical modeling: calibration, validation and updating

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Currently, numerical modeling and simulation tools are essential for structural design and evaluation of aircraft structures, allowing to analyze complex structural concepts with different material properties and considering damage tolerance approaches with minimal experimental testing. One of the limitations of these models is the difficulty to capture the real behavior, taking into account the material properties scatter, geometric deviations due to the manufacturing processes, among other effects that are just possible to characterize in service. This article evaluates and discusses the application of model updating techniques to improve the reliability of the numerical models using new approaches supported by machine learning techniques, as graphical neural networks (GNNs) and physics-informed neural networks (PINNs) for model calibration and validation based on experimental inputs and the possibility to use these models during the aircraft life cycle using sensor data and model updating techniques. These techniques are emerging and have potential to create disruptive advances allowing to a more accurate virtualization of the structural behavior for aircraft structures.

Structural analysis of a composite Strut with metal fittings for space structures. The use of micro pinning technology for the joining of CFRP’S with the metal-end connectors

Mr. I. Delasoudas (University of Patras), *N. Sarantinos, V. Kostopoulos*

The micro-pinning technology is an upcoming field of research in the section of the composite materials joining, providing great advantages in the mechanical properties of the joint (such as lightweight connection, increased strength, and significant improvement in damage tolerance etc.) compared with previous technologies (e.g., bolted joints, adhesive bonding). The micro-pinning can be applied both to composite to metal and to composite to composite joints. The impact of this joining method seems to be great, however there is a lack of usage of this technique in real applications beyond laboratory testing. Inspired by that, this study wants to emerge this technology by applying it in space structures (CFRP space struts) and compare it with previous methods of joining. Therefore, finite element models were developed in ABAQUS for structural analysis of a CFRP space strut with aluminum end fittings using two methods of joining: the first connects the composite strut to the metal end fitting with adhesive bonding and the second with the using of micro-pin technology. For the modeling of the micro-pin layer in the structure, cohesive elements were used with certain cohesive zone model at the area of the joint, taken from the detail analysis/modelling of given pin geometry and composite layup that has been experimentally verified. Several numerical models were developed to study how different parameters affect the joining scenario such as the density of the micro-pin grid and the diameter of the micro-pins.

Detailed FE aircraft fuselage sections for water impact simulations in the pre-design process chain

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Crashworthiness considerations are mandatory in the certification process of aircraft to ensure the safety of all occupants in any situation like in the eventual case of an emergency landing on water. The structural investigation of the airframe to sufficiently withstand hydrodynamic loadings caused during water impact and the subsequent landing is part of the certification requirements. The investigation using sub-scale models is very cost-intensive and limited in terms of repeatability and scalability. Comparisons with existing aircraft models are limited in the case of novel technologies or unconventional aircraft designs. Computer-aided tools using numerical representations of the aircraft structure with the Finite Element (FE) method are currently considered in a multidisciplinary environment to predict and analyse the structural behaviour in early design phases. Highly detailed full-models that can sufficiently describe structural deformations are challenged by its computational effort, resulting in simplifications to representative fuselage sections also in combination with simpler element models. Exemplary investigations with representative fuselage structures can be found in [1] and [2]. A python-based process is under development for the generation of detailed FE aircraft fuselage sections for water impact simulations. This capability is integrated in the modelling and sizing framework for aircraft structural analysis PANDORA (Parametric Numerical Design and Optimization Routines for Aircraft) [3]. The modular architecture of the framework provides versatility to incorporate new interfaces and to extend existing packages. The process starts by generating a global FE representation of the aircraft, in which one FE is used to represent each segment delimited by stringers and frames and reinforcements are modelled mostly using simple FE representations. This aircraft model is then reduced to a fuselage section between selected frames. Subsequently, this section is refined in the impact zone by increasing the density of elements in each segment. Finally, extruded representations of the reinforcements using shell elements can be added as an alternative to the simple elements, resulting in a detailed FE aircraft section. The geometrical and structural description of the aircraft is scripted in an XML-format file based on the multidisciplinary Common Parametric Aircraft Configuration Schema (CPACS) [4], which is used as the input in the framework. the fuselage section model with detailed discretization in the impact zone is intended for water impact or crash simulations. The generation of the required inputs for explicit calculations such as the contact definitions or connection models are considered in the process. The integration of ditching capabilities in PANDORA, as presented in [5], was further developed resulting in the generation of a suitable pool for ditching or vertical water impact of the fuselage section for calculations with different solver codes. In Figure 2, the detailed fuselage section is presented in a vertical water impact simulation. The presented work demonstrates the newly integrated capabilities of the framework for the automatic pre-processing of detailed structural FE models of fuselage sections with different discretization approaches for water impact simulations and its application with different explicit solvers and numerical methods. Investigations are analysed in terms of flexibility, performance and handling.

Techniques for adjusting qualities of aircraft structural models for more effective aeroelastic flutter analyses

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Both analytical calculations and numerical modeling of any aeroelastic problem require supplying reasonable input data. To solve some case of aeroelastic flutter there is necessity to prepare structural and aerodynamic qualities corresponding to specified system model as complex flutter equation includes mass matrix, stiffness matrix, damping matrix and aerodynamic unstationary load matrix. MSC Software (now offered under the shield of Hexagon) contain Nastran solver with implemented flutter solution enabling to perform numerical analysis on the basis of integrated aeroelastic aircraft model. The model includes virtual finite element (FE) structural model and aerodynamic panel model connected to FEM by dedicated spline functions. Having fully completed model and required set of initially declared entry parameters for running numerical process one obtains the set of results (velocities, conjugate frequencies and damping factors) necessary to draw flutter characteristics. After results postprocessing the graph of velocity-versus-damping curves gives information of flutter critical point as potentially most hazardous for structural layout. Numerical calculation even if carried out with application of dedicated software and under formally fulfilled model restrictions could give uncertain results. Those uncertainties could occur as effects of various factors resulting from unproper mapping geometric or structural qualities of analyzed aircraft configuration. Geometric errors are rather easy to verify and correct but structural defects of virtual model affecting values of global model matrices are often hard to identify. Aspects important for effective flutter solutions are strictly connected with coincidence of structural properties of real aircraft and its model. Structural aircraft model applied to flutter analysis should have its qualities almost the same as those real or at least very similar. In the paper some flutter cases are presented with various stadiums of model development. There are examples of 2D sectional model, 3D partial model of an isolated wing and whole-aircraft complete model. The analyzed cases were calculated for specific weight, stiffness and damping parameters which were declared with dose of some uncertainties. Some methods were proposed mainly connected with measuring techniques to identify responsive structural parameters as usable in calculational models. The method of weight correction relies on adjustment of weigh value and its distribution along a specific axis. This technique considers checking selected airframe component and tunning its weight parameters to the values obtained for a part of the real construction. For adjusting stiffness of airframe model parts very useful are results obtained from strength or stiffness test conducted for a real airframe. Similarly results of stiffness test are obligatory to adjust equivalent stiffness of counterpart element of control system or to tune parameters of its exact kinematic model. The more effective but costly method is performing ground vibration tests (GVT) of real aircraft to measure precisely resonant frequencies and natural modes of free vibrations. The results obtained should be treated as the referenced for virtual model, but tuning FE model to them requires both adjusting numerical eigenfrequencies and orthogonalizing normal modes. Using these techniques to adjust structural qualities of FE models to obtain correct results of flutter velocities and some effects of their applications in described model case studies are presented and discussed in the paper.

Gust and landing impacts as critical load cases for wings with distributed propulsion

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To achieve climate neutral aviation, the electrification of aircraft propulsion is expected to make a significant contribution. Many recent research activities deal with the concept of distributed propulsion. This concept offers a variety of possibilities for allocating the total power demand of the aircraft to multiple smaller and power-efficient propulsion systems. The need or desire for electrification creates a business case for aircraft manufacturers who seek to update all or part of their existing fleet with electric propulsion systems. This raises the question whether it is possible to retrofit an existing aircraft by integrating distributed electric propulsion into the wing without significant changes to airframe design and consequently high certification efforts. The integration of distributed propulsion and energy storage systems into the wing structure significantly affects the mass distribution of the wing. Compared to conventional aircraft with engines mounted on the inner wing and integral fuel tanks, this substantially changes the loads on the wing, its modal parameters and thus its dynamic behaviour. With regard to meeting the strength requirements of the wing structure important load cases to be considered are gust loads and also landing impacts which are expected to be more critical. This paper studies the impact of gust loads and landing loads on the structural integrity of the wing structure of aircraft retrofitted with distributed electric propulsion. A representative wing structure of a conventional 19-seater commuter aircraft of CS-23 category with one main engine per wing serves as reference. The reference wing meets the strength and stiffness requirements for airworthiness with regard to the original flight envelope. The primary structure of the reference wing is a wing box in aluminium construction and it is idealized with beam elements. The mass distribution is modelled using lumped masses for the primary structure and concentrated masses for the engines and other system components. A future retrofit scenario is assumed by substituting the original fuel-powered propulsion system for a full-electric powertrain with distributed propulsion integrated into the wing structure. Two configurations are considered as available options for the retrofit, namely one with four and one with six electrically-driven propellers. The structural analysis of the wing is carried out with a beam stick model and it consists of two parts: First, a dynamic response analysis is carried out by finite element analysis to determine the time-decay function of the wing deformation upon gust loads. Second, a dynamic response analysis of the wing upon landing impacts is performed analytically by use of the phase plane method. The transient impact load is calculated with help of an analytical model of the main landing gear and serves as time-dependent load input. For both groups of load cases the time-dependent section loads are extracted and a stress analysis is carried out. Critical areas of the wing box are identified and maximum stresses are compared between the conventional wing and the retrofitted wings with distributed propulsion in order to evaluate whether the retrofitted configurations meet the strength requirements with respect to the original flight envelope. This work is concluded by discussion of the criticality of gust and landing impact loads for wings with distributed propulsion because these might constitute critical load cases for the sizing and certification of future electric aircraft.

Single pilot incapacitation (SAFELAND): Part I

Session Chair: Dr. Stefano Bonelli (Deep Blue, Italy)

A Concept of Operations for Single Pilot Incapacitation

Ana P. G. Martins, ***Dr. Joonas Lieb (DLR)****, Max Friedrich*

A major challenge for the implementation of Single Pilot Operations (SPO) in commercial aviation is how to deal with the potential risk of in-flight pilot incapacitation. In this presentation we present a concept of operations aiming at supporting flight and landing of a single-piloted aircraft in case the onboard single pilot becomes incapacitated. In nominal conditions, a ground station operator (GSO) monitors and supports the onboard single pilot as needed. In our concept, three different ground stations are involved: departure, cruise, and approach ground station. During departure and approach, one GSO would assist one single pilot at a time, whereas in cruise (when workload is relatively low) the GSO would support several single pilots simultaneously. Once incapacitation is detected and confirmed, the GSO takes over control of the aircraft and becomes pilot-in-command. In case pilot incapacitation occurs during cruise, the cruise GSO takes over control of the aircraft for a short period of time, and transfers the control of the aircraft to a stand-by GSO who would be responsible for landing the concerned aircraft safely as soon as possible.

Assessing SPO incapacitation using Low Fidelity Simulation

Ms. Ana Lidia de Almeida Castro (EMBRAER), *Ricardo Jose Nunes dos Reis, Gianmaria Mallozzi, Aurora De Bortoli Vizioli, José Ricardo Parizi Negrão*

In the framework of the SAFELAND project, a Low Fidelity Simulation (LFS) tool was developed and applied in collaboration with SAFEMODE project. This tool allows a preliminary evaluation of the system under development during its early stages, being an intermediate step between the concept development and other hands-on simulation activities, such as Real-Time Simulations (RTS). The LFS is simpler and less costly than RTS, but already involves final users in immersive human-in-the-loop activities to experience the system at a low level of maturity, identifying key issues in roles, procedures, and human-automation interaction of the operational concept under evaluation. Therefore, the LFS was carried out to provide a first understanding and assessment of different aspects of the feasibility of the core ideas regarding the SAFELAND concept of operations, which addresses incapacitation during landing of a Single Pilot operated aircraft with the support of a Ground Station. Despite the limitations of the console slide deck and the activity itself, the level of engagement was perceived as high by involved participants and the LFS was considered a valuable tool for a first assessment of the new operational concept. In this way, key points of the concept were uncovered and better understood both during development and execution of the LFS, for example: workload, situational awareness, and feasibility of roles, responsibilities and new procedures. Broader issues were also explored, such as the dynamic between on-board pilot and ground station pilot, in addition to that of the pilots and ATC. The presentation will focus on the LFS application (how it was planned and executed) and the key learnings derived from the tests, including the contributions to the RTS performed in SAFELAND.

Evaluation of Operating Procedures for Single Pilot Incapacitation - Real Time Simulation

Dr. Joonas Lieb (DLR), *Ana P. G. Martins, Max Friedrich*

In this presentation we describe the Real Time Simulation (RTS) conducted in the framework of the SAFELAND project aiming at addressing pilot incapacitation in future Single Pilot Operations (SPO) of an CS-25 aircraft operated under instrument flight rules (IFR). The RTS focused on the ground actors (mainly ATCO and pilots in the role of ground station operators - GSO) and aimed to assess the impact of the concept developed by SAFELAND on the aspects of feasibility, acceptability, Human Performance and Safety. It took place at DLR premises for one week (2nd to 6th of May, 2022) and involved five pilots from SWISS and five Air Traffic Controllers from LFV (i.e. Air Navigation Service Provider from Sweden). Each participant performed two simulated scenarios: incapacitation occurring either (i) in Cruise (En-Route scenario) and (ii) in Approach (TMA scenario) phase. In total, three simulators were used: (i) fully functional A321 Cockpit simulator, (ii) Ground Station Operator simulator (U-FLY) and (iii) Controller Working Position simulator. Considering the exploratory nature and level of maturity (V1) of the project, the assessment was mainly done through qualitative measurements (questionnaires and debriefings).

Single pilot incapacitation (SAFELAND): Part II

Session Chair: Dr. Stefano Bonelli (Deep Blue, Italy)

SAFELAND Final Evaluation Results. Outcomes and insights from the Real Time Simulation, and the Legal and Regulatory analysis (part A & Part B)

Ms. Aurora De Bortoli Vizioli (Deep Blue), Dr. Pasquale Junior Capasso (EuroUSC), Dr. Francesco Godano (EUI), *Gianmaria Mallozzi, Stefano Bonelli*

The SAFELAND final evaluation consisted of a number of activities, including Real Time Simulation (RTS), a safety and cyber-security assessment, and an analysis of the legal and regulatory aspects implied by the concept. Overall, the RTS campaign returned a positive evaluation of the SAFELAND Concept of Operations. Both ATCOs and pilot participants positively evaluated the operating procedures implied by the concept, especially referring to the dynamic of interactions between team members, and to the coordination and communication flow. From the technical point of view, requirements for both the Ground Station and the Controller Working Position were identified, together with new additional supporting systems that could be implemented to enable Single Pilot Operation (SPO) and enhance the safety of the operations. The implementation of the SAFELAND concept would also be grounded in the amendment of some Guidance Material (GM) / Acceptable Means of Compliance (AMC) to regulations, since no current regulations certify commercial SPOs. The most relevant regulatory domains affected would be the rules of the air, personnel licenses, aircraft operations, airworthiness, and accident investigation and occurrence reporting. The legal analysis mainly focused on liability issues, with particular regard to human control and automation. In general, SAFELAND shows no significant legal showstoppers. Evaluation activities raised issues concerning the acceptability of the GSO role (and therefore liability), especially related to the design of the GS and reliance on the automated system. Such issues contribute to challenging the principle of the human-in-control. Further implementation of SAFELAND shall provide a more detailed outline of the role of automation, in order to clarify the GSO role and foster trust in the system.

Small Air Transport (SAT) Technologies

Session Chair: Dr. Vittorio Di Vito (CIRA, Italy)

Hybrid Navigation System Prototype for Small Aircraft Transportation Vehicles

Dr. Tomas Vaispacher (Honeywell – Advanced Technology Europe), *Radek Baranek, Pavol Malinak, Matej Kucera*

The Small Aircraft Transportation (SAT) segment represented mainly by helicopters, piston fixed-wing aircraft, turboprop aircraft, and business jets requires a reliable source of navigation information with an appropriate price. This paper describes the research and development activity funded by Clean Sky 2 Cost Optimized Avionic Systems (COAST) development program targeting affordable hybrid navigation solutions. The affordability is driven by size, weight, and power consumption (SWAP) requirements. The desired level of accuracy, integrity, and availability is being achieved by a hybrid navigation solution based on GPS/INS fusion extended by other navigation sensors. The hybrid core of the system uses GPS with SBAS augmentation to outperform standard tightly coupled GPS-based hybrid systems. The purpose of this article is to describe the current state, algorithmic structure, and hardware maturity of the navigation system prototype. The paper describes individual hardware components, points to the resulting prototype, and summarizes tests in a representative environment. The ultimate goal is to demonstrate the overall performance of the hybrid system based on a low-cost micro-electro-mechanical system (MEMS) Inertial Measurement Unit (IMU). The low-cost inertial sensor is one of the key components securing the affordability of the proposed system, so its testing plays important role. Another assumption considered in the system design was integration of standardly-used onboard sensors. For this purpose, the hardware prototype was tested in a demonstrative and outdoor environment. The results of this exercise are summarized in this paper.

In flight testing of the Flight Reconfiguration System advisory function within the COAST project

Dr. Piotr Grzybowski (Politechnika Rzeszowska im.Ignacego Łukasiewicza), *Tomasz Rogalski*

The Flight Reconfiguration System is one of the technologies developed in the COAST project realized in the Clean Aviation programme. It's purpose is to divert the flight in case of the pilot not being able to conduct the flight (e.g. in case of health issues occurs on-board). It constantly monitors possible destinations and flight parameters and, based on multi-criteria-decision-making methods, it identifies the best destination and route for dealing with emergencies. The present advisory function is one of the extra features designed in the project for those aircraft for which autopilot is unavailable, but on which the pilot can still do basic flying although can't no longer make navigation decisions (e.g. due to stress factors, bad weather, getting lost). The idea behind the function is that by giving the pilot simple commands on where to fly, an emergency destination can be reached. The paper presents the advisory function, methodology for requirements verification, preliminary test trials done with the Hardware-In-The-Loop simulation and most importantly the results of the flight tests conducted in 2022.

Enhancement of the Advanced Weather Awareness System for the development of an Integrated Mission Management System in the COAST project

Mrs. Alessandra Lucia Zollo (CIRA - Italian Aerospace Research Centre), *Myriam Montesarchio, Michele Ferrucci, Edoardo Bucchignani, Davide Cinquegrana*

The COAST (Cost Optimized Avionics SysTem) project, funded by Clean Aviation Joint Undertaking in the European Union's Horizon 2020 Research and Innovation Programme, has been working since 2016 on delivering key technologies for the affordable cockpit and avionics, also enabling single pilot operations of Small Air Transport (SAT) vehicles. The development of the Integrated Mission Management System (IMMS) began in 2020, being a new technology devoted to automatically optimize the trajectory while considering air-traffic, weather conditions, terrain and obstacles. It is based on the integration of evolved versions of three independent COAST systems, already designed in the previous project phases: Flight Reconfiguration System (FRS, managing pilot's incapacitation emergency), Tactical Separation System (TSS, managing tactical traffic separation and enhanced situational awareness) and Advanced Weather Awareness System (AWAS, devoted to provide on board updated data regarding weather hazards occurring during the flight). The present work focuses on the last one, and more in detail on the description of new functionalities introduced to the baseline AWAS system, already presented and demonstrated in flight in 2021, in order to allow the integration in IMMS. Specifically, enhancements to the AWAS technology were required to integrate new input weather data and generate additional information, needed for IMMS, regarding altitude limits of weather hazards and description of geographical areas to be avoided. These data are produced on-ground and sent through satellite link to the AWAS on-board segment, which manages and exchanges them with the other components on the aircraft, to allow IMMS operations. Furthermore, a modification of the AWAS on-board architecture is on-going in order to centralize all functionalities in a single application, including the new ones needed by IMMS. All the achieved progresses in the development of the evolved version of the AWAS system presented in this work will be demonstrated and tested in flight during a campaign planned in 2023 in the framework of COAST project.

Evolution of the Tactical Separation System to support the Integrated Mission Management System in the COAST project

Dr. Vittorio Di Vito (CIRA)*, Giulia Torrano, Giovanni Cerasuolo, Michele Ferrucci*

Small Air Transport (SAT) is emerging as suitable transportation means in order to allow efficient travel over a regional range, in particular for commuters, based on the use of small airports and fixed wing aircraft with 5 to 19 seats, belonging to the EASA CS-23 category. In this framework, Clean Sky 2 Joint Undertaking, in the European Union's Horizon 2020 research and innovation programme, funded the project COAST (Cost Optimized Avionics SysTem), which started in 2016 with the aim of delivering key technology enablers for the affordable cockpit and avionics, while also enabling single pilot operations for aircraft in the SAT domain. In the project, some relevant flight management technologies to support single pilot operations have been designed, developed and demonstrated in flight, and among them the dedicated decision-making support system aimed to assist the pilot in the management of the separation task, under delegation of the separation responsibility to the pilot by the ATC. This technology, the Tactical Separation System (TSS), has been successfully demonstrated in flight in the year 2021. Nevertheless, in order to properly integrate and enhance the individual enabling technologies for single pilot operations, in the COAST project a unique Integrated Mission Management System (IMMS) is being designed. It constitutes a further technological advancement to support more effective and safe management of situations of pilot's incapacitation during the flight, under single pilot operations, and a relevant step forward towards more autonomous aircraft. The IMMS is of relevant importance, both from the single pilot support perspective and from the aircraft autonomy perspective, because it represents a system able to automatically optimize the aircraft path by taking into account trajectory optimization needs that include at the same time consideration of traffic and weather, as well as best destination selection in case of pilot incapacitation. To support the IMMS implementation, therefore, the Tactical Separation System is subject to proper evolution, in order to include specific functionalities that will be needed as part of the IMMS. This paper first outlines the main outcomes from the design and demonstration of the Tactical Separation System as individual technology, then it describes the IMMS and the specific role that the tactical separation functionality will play in such framework and, finally, reports the evolved TSS version design that is currently ongoing in the COAST project.

Design of a countermeasure system for stress management of astronauts in future Lunar and Martian bases

Ms. Miriam Opazo Mendez (Spaceship FR - CNES), *Laure Boyer, Gregory Navarro, Alexis Paillet*

Human spaceflight is entering a new era, with the preparation of crewed missions beyond low-Earth orbit to the Moon and later to Mars. These increasingly longer missions with greater distance to Earth will expose astronauts to various stressors, such as isolation and confinement in a high-risk environment, which will undoubtedly put a strain on the astronauts' psychological well-being. Consequently, taking into account the risk factors derived from psychological stressors of spaceflight will be crucial for the safety and success of long-duration human missions. In light of this, the Spaceship FR team from CNES, the French Space Agency, is working to enhance and optimise the human factor leading to stress, fatigue, and error, in the establishment of a permanent habitat in the Moon or Mars. Thus, the objective of this paper is to identify the stressors that have potential deleterious effects on the astronauts' mental health in order to propose a series of measures to be implemented in a Lunar or Martian outpost that prevent and counteract such effects. This countermeasure system is expected to be implemented in the Spaceship FR ground facility, where its effectiveness could be evaluated.

An Analysis of the Requirements for a Sustainable Lunar Transportation System to enable Initial DIANA Infrastructure

Mr. Denis Acker, *Javier Palacios, Prishit Modi, Elizabeth Gutierrez, Alma Kugic*

The Dedicated Infrastructure and Architecture for Near-Earth Astronautics (DIANA) is a design concept for a self-sustainable lunar village near the de Gerlache crater, on the lunar South Pole, comprising tourists and astronauts alike. The village will be permanently inhabited and will exploit future technologies to achieve independence from a majority of Earth resupply missions. Execution of the initial construction phase of the DIANA infrastructure depends primarily on the persistent supply of in-situ construction material, regolith. Lunar raw materials also primarily contribute to the life support systems (LSS) and the radiation protection for the inhabited modules. To enable ISRU, resources need to be transported using diverse locomotion systems on the unexplored lunar terrain. A self-sustainable lunar base requires to be built on an ecosystem that facilitates continuous transportation of materials, humans (astronauts and tourists) and robotic systems. This paper focuses on a detailed comprehension of the design, feasibility, and economic requirements of a transportation ecosystem concept explicitly dedicated to the establishment and development of the DIANA lunar village. The mission objectives and top level requirements pertaining to the individual transportation systems will be derived from the detected necessities that are defined for alternative transportation technologies that efficiently provide large amounts of lunar raw material for the construction of lunar infrastructure as well as water ice from the de Gerlache Crater, which shall primarily contribute to the LSS and the production of rocket fuel. While transporting humans, factors such as time, comfort, and risk mitigation play a major role, and are therefore, discussed thoroughly within the framework of this study. Using this study as the principal foundation, a phase 0/A design study illustrating a novel transportation infrastructure concept based on magnetic levitation technology would be developed for a time and energy efficient transportation of resources and people across the lunar surface. This transportation concept shall be sustainably manufactured using the abundant lunar resources to minimize costs and resupply missions in the long term to pave the way for an independent lunar village.

International Planetary Sunshade Concept with a Function-integrated and Scalable Support Structure based on Coreless Filament Winding

Mr. Tharshan Maheswaran (University of Stuttgart), *Pascal Mindermann, Denis Acker, Götz T. Gresser, Stefanos Fasoulas*

Climate change is the greatest threat of the 21st century. Despite all our efforts with renewable energy, current reports clearly indicate that our existing actions are insufficient to prevent critical tipping points from being reached. In addition to various terrestrial geoengineering methods, there are currently efforts to investigate new ways of integrating space-based geoengineering into the short-term construction of a buffer solution - the International Planetary Sunshade (IPSS) system. The IPSS system offers unique opportunities to link the challenges of a sustainable energy supply with the essential actions against climate change. A space-based system on this scale poses new logistical and technological challenges that can only be mastered through the collaboration of space agencies, private companies, and the support of society. Therefore, integration into international roadmaps is essential to exploit synergies, shorten development timeframes and promote international cooperation against climate change. To achieve this goal, an evolutionary concept using lunar resources has been designed to achieve stepwise Earth independence and sustainable utilization of essential space resources with particular emphasis on the manufacturability of scalable space megastructures. A scalable supporting structure is a critical element enabling the feasibility of an IPSS system. Therefore, manufacturing technology and related structural concepts that fulfill several relevant criteria need to be adopted, such as material compatibility, complete automatability, on-orbit fabrication, and digital design. Hence, coreless filament winding (CFW) could be a suitable technology. In CFW, impregnated fibers are placed around point-like anchors in a specific sequence. The resulting structures exhibit high mass-specific stiffness, allows adaptivity, and follows integral design principles. The prerequisite for the superiority of such CFW structures is an application- and material-compliant component and fiber net design. Previous experience with CFW cannot be directly transferred to IPSS systems due to the changed requirements in space. In addition, CFW allows in-situ resource utilization and function integration, which are essential for realizing the demanded mass savings. As a first step toward a design of an IPSS structural system, preliminary investigations of the scalability of CFW structures are needed. Moreover, a conceptualization of CFW components suitable for space is required which include functional integration. Therefore, the presented paper will outline the IPSS system concept in conjunction with mechanical tests on the CFW structure to facilitate the future design process of CFW structures in space and accelerate the IPSS system development in general.

FALCon-Project Progressing RLV-Return Mode "In-Air-Capturing

Dr. Martin Sippel (DLR-SART), *Sven Stappert, Sunayna Singh*

The innovative approach for the return of reusable space transportation vehicles has been refined in the EC-funded H2020-project FALCon. Winged stages are to be caught in the air and towed by subsonic airplanes back to their launch site without any necessity of an own propulsion system. This patented procedure is called in-air-capturing a special form of mid-air retrieval. A systematic assessment of different RLV-return and recovery options demonstrates that in-air-capturing (IAC) offers the best performance [1] and at the same time allows minimum environmental footprint for all medium to large launch systems. The advantage of IAC is confirmed for different propellant combinations with an even larger edge in case of hydrocarbon fuels because of the lower engine Isp compared to the LOX-LH2-combination. All results from these studies indicate that in-air-capturing is highly attractive from a launch-cost perspective.

The project FALCon (Formation flight for in-Air Launcher 1st stage Capturing demonstration) funded in Horizon 2020 and running since 2019 has achieved significant progress. Now scheduled to finish after 45 months in November 2022 and with total EC-funding of 2.6 M€, the FALCon project addresses three key areas:

- “in-air-capturing”-Development Roadmap and economic benefit assessment
- “in-air-capturing”-Experimental Flight Demonstration
- “in-air-capturing”-Simulation (subscale and full-scale)

Beyond this overview paper serving as an introduction into the topic, summarizing the expected launcher performance improvement and explaining the structure of the FALCon-project, another paper called A Summary of Full-Scale Simulations of ‘In-Air Capturing’ Return Mode for Winged Reusable Launch Vehicles is submitted. It is expected that the final flight demonstration campaign of FALCon is ongoing exactly at the time of the 12th EASN Conference. Therefore, instead of technical papers on the experimental flight demonstrations it is proposed complementing the project overview by showing a view video of the flight tests as available by mid-October.

A Summary of Full-Scale Simulations of ‘In-Air Capturing’ Return Mode for Winged Reusable Launch Vehicles

Sunayna Singh, Sven Stappert, Leonid Bussler, Martin Sippel, Sophia Buckingham, Cansev Kucukosman, Silvania Lopes, Madalin Simioana

Over the past decades, reusable launch systems have become instrumental to meeting the increasing launch demands at a reduced cost. An innovative approach proposed by DLR involves winged stages captured mid air and towed back to the launch site using a subsonic aircraft [1]. This recovery concept known as ‘In-Air Capturing (IAC)’, shows potential for substantial reduction in inert mass of the Reusable Launch Vehicle (RLV), thereby leading to reduced cost [2]. The EC funded Horizon 2020 project FALCon (Formation flight for in-Air Launcher 1st stage Capturing demonstration) aims at further development of this technology, through full-scale simulations and sub-scale flight testing. This paper will summarize the full-scale simulations of IAC Manoeuvre performed within the scope of FALCon. Trajectory simulations are performed considering large scale tests cases. For the current study, a winged RLV of approximately 80 tons re-enters the atmosphere after stage separation and slows down to a subsonic velocity. Meanwhile the large commercial airliner, A340-600 (selected for the large RLV) is waiting at altitude of 10 km until the RLV is in vicinity. Between 8 km and 2 km altitude, the IAC maneouvre begins. First, the towing aircraft glides from cruise flight to achieve a parallel formation with the RLV. While both the vehicles are in formation flight, a capturing device released from the aircraft (attached to a rope) autonomously finds its way to the RLV and establishes connection. Next, the mated configuration, which is now connected by a rope must pull up from a diving flight to a suitable cruise altitude. The towing aircraft serves as an external propulsion system and tows the RLV back to the launch site. Lastly, the RLV is released onto the runway to land horizontally using its own landing gear. Through the simulation of the complete IAC maneouvre considering full-scale mass and performance characteristics, many design iterations and possible challenges have been established. For instance, to maintain a successful formation, the two vehicles should have comparable aerodynamic performance. To meet this criteria, additional drag generating surfaces like spoilers and landing gear are deployed by the towing aircraft to match the RLV performance [3]. Further, the capturing device, which is required to reach the RLV within a short period of time (approximately 60 s) must overcome strong disturbances from the flexible rope as well as wake of the aircraft [4,5]. It is also important to check if the propulsion capacity of the towing aircraft is sufficient to tow the large RLV [6]. Therefore, this paper will provide an outline of the design considerations, limits and challenges associated with IAC in a full-scale scenario. The project and the

advantages of the IAC-process are presented at EASN in another paper titled FALCon-Project Progressing RLV-Return Mode “In-Air-Capturing”.

Session Chair: Dr. Athanasios Dafnis (RWTH Aachen University, Germany)

Structural efficiency evaluation of innovative reusable launch vehicles

Panagiotis Trifa, Dimitrios Rellakis, ***Dr. Georgia Psoni (HERON ENGINEERING)***

This work is focused on evaluating the structural design of the innovative reusable micro launcher MESO in association with its mass budget, originated from the first design loop of the RRTB project. In this particular design loop, the reusability concept is intergraded by implementing the fail-safe design approach, considering exclusively the use of high TRL aluminum alloys. The structural integrity evaluation is achieved by developing a global finite element model, comprising a set of sub-models, which represent the different sub-structures of the launcher and their interfaces as well. The primary structure of the RRTB vehicle consists of a load bearing tanks configuration, where a common bulkhead separates the oxidizer tank from the fuel tank. The interfaces between different structural groups of the first stage are obtained via longeron assemblies and external rings. The secondary structures of the launcher include the:

- The Interstage, which provides the interface between the second stage and the primary structure of the first stage.
- The Exoskeleton, which supports the Thermal Protection System.
- The Gondola Beams, where the Electric Ducted Fans are attached.
- The Thrust Structure, which provides attachment to the aerospike engine.

The modeling approach with respect to the global finite element model of the launcher, is based on selecting the most appropriate finite elements for each sub-model in an attempt to represent all sub-structures as much realistic as possible. Thus, the main objective of the mesh development is focused on combining accurate output results and computational efficiency at the same time. The first iteration of the load analysis loop resulted in the extraction of the design limit loads. These loads include the most conservative quasi-static loads from the most significant load events encountered by the launcher throughout a single mission. Specifically, both ground and flight cases are investigated, considering the maximum inertial accelerations due to the launcher's motion, in combination with internal and hydrostatic pressure developed because of the stored propellant. Each mission event entails dedicated boundary conditions, which are based on reasonable assumptions in accordance with the respective load case in an effort to capture the structural response of the vehicle as accurate as possible. The FEM is subjected to various types of preliminary structural analysis, taking into consideration the required ECSS design and safety factors. The analyses performed are listed below:

- Linear static analysis for strength assessment and internal loads evaluation.
- Linear buckling analysis for local and global stability assessment.
- Normal modes analysis for stiffness assessment.

The analyses results indicated the location of all weak spots of the launcher and subsequently a preliminary sizing procedure is executed in order to prevent all failure modes according to the structural design requirements of the respective design loop. The conclusions derived from the structural analysis of the 1st design loop influence the design modifications to be considered for the next design loop, where the same steps are going to be followed until the structural design requirements are satisfied once again.

Modular construction and design methods for reusable micro-launcher rocket structures within the RRTB project

Marco Kanngießer, Stefano Piacquadio, Athanasios Dafnis, Panagiotis Trifa, Dimitrios Rellakis, Georgia Psoni, ***Dr. Dominik Pridöhl (RWTH Aachen)***

The rise of small satellites is changing the satellite industry. At the same time, micro-launch vehicles have significantly higher launch costs per kilogram than ride-sharing on large launch vehicles. Technological development and reusability are fundamental steps to reduce launch costs and thus improve access to space. The RRTB project, funded by the EU Horizon 2020 program, aims to develop a novel solution to provide customized service for access to space for the micro satellite market. The first stage of a vertically launching rocket is designed to be reusable following a hybrid re-entry strategy. The project is a multidisciplinary project and currently in its second design loop. Here a combination of a parachute and a Mid-Air Catch concept should be pursued to provide a precisely controlled and safe landing. The Mid-Air Catch idea relies on performing the final landing maneuver and touch-down using a separate flying vehicle that intercepts the descending first stage, and then gently sets the stage down on a rack. The vehicle's first stage is designed to achieve a minimum reuse of 10 times, which means that special attention must be paid to both the vehicle's primary structure and the required thermal protection systems (TPS). Both have to withstand the loads imparted on the vehicle during the mission as well as to provide accessibility for post-flight refurbishment and inspection. The lightweight potential of the load-bearing structure of the rocket is of particular importance in the context of a minimum launch mass. Due to the reusability the structural design of the first stage presents a different approach compared to conventional launcher structures and introduces new unique design challenges and structural solutions. In terms of reusability and the associated maintenance, a modular design approach for several important structural components is pursued. In this way, individual components can be replaced easily and in a time-saving manner during maintenance without significant additional masses for the structure. In this paper the modular construction and design methods are described and the associated possibilities for simple and time-saving maintenance are explained for reusable micro-launchers with additional reentry and landing systems. Furthermore, the corresponding design is discussed and compared with the results of the first design loop in the RRTB project.

Thermal Protection Systems for Reusable Launch Vehicles: lightweight potential of novel sandwich structures with embedded Phase Change Materials compared to ablative materials

Dr. Stefano Piacquadio (RWTH Aachen), *Marco Kanngießer, Kai-Uwe Schröder, Athanasios Dafnis*

Reusable launch vehicles offer high cost-reduction potentials. However, additional dry or wet mass is needed to face the re-entry and landing phases. Ballistic or lifting re-entry is considered by several commercial actors to reduce the complexity of the mission and of the propulsion system. This imposes a need for Thermal Protection Systems. Structurally integrated Thermal Protection Systems, consisting of sandwich structures with different core topologies based on high temperature alloys or ceramic matrix composites, are frequently proposed in the literature to obtain holistic mass reductions. These concepts aim at exploiting the low effective thermal conductivity of cellular solids, in combination with the high specific mechanical properties offered by sandwich structures. However, the application was this far hindered by the high thermal gradients, and thus the high induced thermal stresses, that the components experience. Ablative materials, on the other hand, are often used for reusable launch vehicles with ballistic re-entry trajectories due to their lightweight and the high specific heat absorption with respect to sensible heat storage. Being expendable, a swap or re-application concept is often needed. In this perspective, it is useful to investigate the use of solid-liquid latent heat storage in alternative to the thermochemical heat absorption typical of the ablative materials. Latent heat storage offers much higher specific energy storage potential in comparison to sensible heat storage and contrarily to the products of ablation, the liquid can be contained. Several organic and inorganic Phase Change Materials exhibit low thermal conductivity, which increases the full melting time and is cause for undesired wall temperature increases. Embedding the Phase Change Material in a high thermal conductivity matrix was demonstrated to effectively address the issue. This way, milder wall temperatures and thermal gradients in load bearing Thermal Protection Systems can be obtained. This represents a key enabler for such multifunctional structures, which can lead to wide mass savings. In this work, a case study based on a load bearing component of the MESO launcher developed in the Recovery and Return To Base project of the EU-Horizon 2020 Programme is proposed. Numerical investigations are performed, considering on one hand a conventional structure with a Thermal Protection System composed of an ablative layer. On the other hand an additively manufactured lattice core sandwich structure, with embedded Phase Change Material, is analysed. The lightweight potential and the Thermal Protection performance of the two solutions are discussed.

Iterative design development of a reusable micro-launcher within the RRTB project

Mr. Rasmus Bergström (Pangea Aerospace SL), *Daniele Pilori, Alessandro Zamprotta, Miguel Pinheiro, Giovanni Medici, Gabriele de Zaiacomo, Raquel Marey Oton*

The Recovery and Return-To-Base European Reusable Micro-Launcher project, part of the EC H2020 programme, intends to develop a novel reusable micro launcher system to bring independent and cost-effective access-to-space for the European small satellite market. The multi-disciplinary project focuses on the optimization of aerospike tail-first atmospheric reentry of the MESO vehicle, together with the design and manufacturing of reusable cryogenic tanks, and the effort is divided into two design loops. The first design loop started at the onset of the project in February 2020, with the second design loop starting in February of 2022. The system being developed during each design loop is based on early design decisions and assumptions that are established at the beginning of the design loop, in order to allow for the work with the subsystems to progress. However, these early assumptions are based on unknown or speculative inputs, which adds risk to the project. The multiple design loop approach allows for early design decisions to be revised at the project half-way, excluding or altering unsuitable elements or large problem drivers of the design, therefore acting as risk management, as it fosters later convergence of the design to a realizable outcome. Throughout the work performed in the first design loop several conclusions were reached. The design presented both novel design features, but also issues which became better understood as the fidelity of the subsystem designs and mission analysis increased. These issues ultimately lead to the overall system design and CONOPS to be updated for the second loop, with several of the early design choices being modified based on the results of the first loop. For the second design loop the design is updated to alleviate the most critical problem drivers, and to improve the system's ability to fulfill the top-level requirements and objectives. The updated design leverages on the heritage of the previous design loop, implementing tailored changes based on the outcome of the trade-offs performed at mission and system level. The current paper introduces the system, mission, project, and design loop schedule. Moreover, it focuses on the consolidated system and mission analysis of the first design loop. The fruitful discussions and analyses activities that were triggered to address the identified problems are also reported here, as their implications on the low-level design decisions, assumptions, and requirements were key to pave the way for the second design loop. Finally, the trade-offs and considered options of the second design loop are presented and discussed, as well as the introduction to the updated system architecture and CONOPS, which will be compared with that of the first loop.

Micro-satellite projects as educational tool: The UPMSat-2 mission

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The UPMSat-2 is an educational, scientific and in-orbit technological demonstration microsatellite of 50 kg mass and geometrical envelope of 0.5 x 0.5 x 0.6 m. It is performing its in-orbit operations in a sun-synchronous LEO orbit of 500 km of altitude and asses over the ground station four times a day. It was launched on September the 3rd 2020 at 01:51 UTC from French Guyana spaceport by a Vega launcher. As a technological demonstration platform, UPMSat-2 includes a set of scientific payloads and equipment to be tested in space, including a new attitude determination and control subsystem and a thermal switch, which has been provided by research institutions and private companies. Project-Based Learning has been proved as a useful tool for improving students' motivation and specialization. Students from the Master in Space System (Máster Universitario en Sistemas Espaciales, MUSE), an UPM (Universidad Politécnica de Madrid) official master's program, have been involved in the design, manufacturing and AIT/AIV plan of the UPMSat-2. The UPMSat-2 satellite has revealed itself as a formidable way to gather students and professors around a common engineering task. The UPMSat-2 mission was developed as a logical continuation of its precursor, the UPMSat-1, launched in 1995 on board an Arianne IV. Those projects have been used to give students full competences in the fields of design, analysis, manufacturing, integration, testing and operation of a space vehicle. Therefore, students involved in this project are in contact with commercial enterprises from the space sector, this fact being crucial to increase their motivation. This work analyses the technical characteristics of UPMSat-2, its payloads and main technological contributions are described, as well as the main activities carried out up to the launch. Furthermore, first in-orbit operational data are shown, analysed, and discussed. Finally, the benefits of incorporating actual space systems design and development within aerospace academic programs are also included.

Cube Satellite Battery Charger Regulator Design

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Battery Charger Regulator circuit BCR used on spacecraft power systems, are usually switching regulators to provide maximum power for current operation mode and fixed voltage for voltage mode. In this article, we present detailed design procedures for BCR implemented on Cube-satellite. We will show a small-signal analysis of a battery charger, to perform the control loop design of the maximum power point detection step and voltage mode control loop. We present also a simulation to verify our design.

Breadboard of Microchip and Avalanche Photodiode in Linear and Geiger Mode for LiDAR Applications

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Currently small satellite missions have become more common. This has driven satellite instruments to be more compact and efficient, consuming less resources of the satellites. One example of a small probe mission is the HERA mission. This probe has a LiDAR that assists in autonomous close navigation operations and provides scientific data by measuring the asteroid wobble and providing to a shape model of it. The LiDAR uses a microchip laser and an InGaAs based sensor with an integrated amplifier. Microchip Q-switched lasers are small solid state back pumped lasers.

This LiDAR could be improved by replacing its sensor by one capable of detecting just a few photons, a Single Photon Avalanche Diode (SPAD), relaxing the energy requirements on the Microchip laser.

In this paper we report: 1) a breadboard of a microchip Q-switch laser, using a 1mm erbium and ytterbium co-doped phosphate glass, a COMLAO crystal with 98% initial transparency and an output coupler of 98% reflectivity. 2) The test and comparison of a commonly used InGaAs LiDAR avalanche photodiode (APD) with a InGaAs/InP SPAD, designed specifically for single photon counting. A system for the simultaneous operation in vacuum at negative Celsius temperatures for these photodiodes, with peak sensitivity at 1550 nm, was assembled allowing the operation in two distinct regions that enabled two different operation modes: Linear and Geiger. By using proper TIA, Passive and Active Quenching electronics for each mode and photosensor, the behaviour and differences between them were studied.

Conceptual Design of a Mechanically Deployable Morphing Aeroshell for Atmospheric Re-entry

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Morphing deployable aeroshells are increasingly emerging as innovative concepts to perform controlled re-entry and precise landing of CubeSat class systems. Shape morphing during atmospheric entry could enable trajectory control by providing enhanced versatility and flight maneuverability, otherwise not achievable by state-of-the-art rigid decelerators. Also, tailored heat flux and optimal induced temperature distributions can effectively protect the payload from the re-entry environment. This paper is framed within a scientific cooperation between Italy and Brazil running in the framework of the SPLASH project, funded in part for the Italian side by a grant from the Italian Ministry of Foreign Affairs and International Cooperation (MAECI), and by CONFAP, through the involved State Funding Agencies (FAPs), for the Brazilian side. In this work, the benefits of mechanically deployable decelerators are firstly analyzed considering the low ballistic coefficient with respect to more traditional rigid aeroshells. After that, a new concept of mechanically deployable re-entry aeroshell having shape-changing capabilities is preliminary studied for a reference mission scenario in order to achieve multiple target shapes enabling adaptive re-entry capabilities and enhanced versatility. Such preliminary studies are focused on the morphing mechanism for structural shape control based on a set of finger-like articulations having a multi-hinge assembly combined with a flexible thermal protection system to enable shape adaptation. Multi-body analyses and preliminary aerothermal assessments provide guidelines and constraints for potential actual implementation.

The design of a flexible RF generator for driving Acousto-Optical devices in space applications

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The use of Acousto-Optical (AO) devices in space applications is growing, mainly due to their robustness, flexibility and wide applicability. These devices are not only used for filtering purposes in spectral imaging [1, 2], but also in optical communications [3] and spatial tracking systems [4]. Some possible AO devices usable in space applications are AO Tunable Filters (AOTFs), Modulators (AOMs), Deflectors (AODs) and Frequency Shifters (AOFSs). Though these device's applications differ, controlling these devices is uniformly done by using Radio-Frequency (RF) signals. This RF signal is converted by a transducer into an acoustic wave, which propagates inside the AO device. The interaction between the incoming light beam and the acoustic waves inside the birefringent AO material, creates multiple output beams. Hence, several techniques can be applied, like filtering, modulation, deflection and frequency shifting, depending on the used AO device. This research focuses on the design of a flexible, uniform RF generator, applicable for all AO devices in the space applications domain. The generator has to cover, amongst other requirements, a wide frequency range (from 40 up to 300 MHz), and need to provide a clean output signal, with unwanted components such as harmonic and spurs limited to -30 dBc or lower. The clean RF output maximizes the performance of the AO device, while the use of components available in space qualified grades eases integration with future space missions. Its design combines a commercially available space qualified Phase-Locked Loop (PLL) chip, a microcontroller, electronically switched filter banks, and supporting components. This design aims at having a miniaturized, space qualified, general-purpose RF generator for AO devices operating over a wide range of optical wavelengths for use in varied space applications.

Plasma-based micro-propulsion system for nanosatellites

Prof. Konstantinos Kontis (Glasgow University), *Hassam Israel Guevara Jelid*

A study has been conducted to build a direct current (DC) plasma-based micro-thruster chip for the micro-propulsion system used in nano and picosatellites, enabling accurate manoeuvre operations in space and producing thrust in the range of nN to µN. It contributes to the investigation of plasma events in micro-gaps as a source of thrust creation under vacuum conditions. Prior to fabrication, the nominal parameters for the micro-thruster chip design that delivers the most efficiency between the maximum thrust and the lowest power consumption were identified: maintaining the 2-dimensional geometry of a chip's design, which is 5mm x 7.4mm x 0.75mm and providing the ability to connect to the microSD card's electrical connection. A comprehensive method for the nanofabrication of the micro-thruster was established based on fifty cleanroom processes, including photolithography, wet etching, dry etching, metal deposition, and bonding procedures. Defining an unusual method for photoresist mask coating for conformal metallisation coating. The device's performance was examined by a series of measurements using flow diagnostics.

Plume regolith interaction facility to study the effect of regolith liberated by a rocket plume impingement

Prof. Konstantinos Kontis (Glasgow University), *Senthilkumar Subramanian, Craig White, Takahiro Ukai, Hossein Zare-Behtash, Jim Merrifield, David Evans, Ian Coxhill, Tobias Langener, Jeroen Van den Eynde*

As soft landings become more common on astronomical bodies, the need to consider the effects of plume impingement becomes more important. Partially in response to the progression of the Google Lunar XPRIZE, scientists at NASA's Granular Mechanics and Regolith Operations Lab. are pursuing an experimental and theoretical campaign to provide guideline rules concerning soft lander propulsion systems and keep-out zones. These will be designed to: (i) mitigate surface alteration, preserving the moon as a natural laboratory and (ii) protect landing sites of significant historical interest (Apollo / Lunar Surveyor). In addition, the subject of lunar surface alteration by propulsive descent and landing was reinvigorated in recent years by the NASA Constellation Programme: a programme which has since been cancelled. In any case, the study of plume-surface interaction and surface alteration remains highly relevant to future mission requirements. The global objective is investigate the interaction between rocket engines and regolith at a fundamental level, in support to all planetary and lunar landing environments studies. These studies are vitally important as the interaction between the hovering and landing plumes with the regolith can have a severe impact on the mission objectives and also the engine performance. To achieve this global objective a facility was designed and manufactured in which it is possible to carry out different measurements on flows with dust particles to fulfil the following detailed objectives of this activity:

1) Assessment of scaling phenomena, vacuum effects and pulsing of rockets;
2) The erosion effect of the plume impingement on the planet surface (airless bodies and Martian conditions);
3) The lateral extent and depth of regolith contamination due to rocket plumes
4) The impact of the plume/regolith interaction on the spacecraft;
5) The effect of the regolith liberated by the rocket plume impingement on the spacecraft forces and moments and particularly on the engine and engine-nozzle during lunar/planetary landing operations;
6) Brown out due to plumes and surface dust.

Satellite Star Tracker Breadboard with Space Debris Detection Capability for LEO

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In this work, the possibility of having a star tracker running space debris algorithms is evaluated. These attitude devices are usually used in satellites for attitude determination and therefore have a wide potential of being a major tool for space debris detection. To evaluate the possibility of having a star tracker running both stellar identification and space debris algorithms, a simple star tracker breadboard was developed. The breadboard was built with commercial off-the-shelf components, and it is representative of current star tracker resolution and field of view. Star tracking and Space debris algorithms were implemented and tested, respectively: Tetra, and ASTRiDE. The dual-purpose star tracker concept was tested by taking pictures of the night sky that included satellites streaks. The rapid increase of space debris poses a risk for space activities, so it is vital to detect it. Ground-based radar and optical telescopes techniques used for debris detection are limited by a size threshold, detecting only a tiny amount of the total. Seeking to overcome such limitations a dual-purpose star tracker, with stars detection and optical debris detection capability is proposed.

Systems / Prognostics / Security: Part I

Session Chair: Prof. Matteo Dalla Vedova (Politecnico di Torino, Italy)

Modelling and Simulation of Urban Air Mobility: An Extendable Approach

Mr. Nabih Naeem (German Aerospace Center), *Patrick Ratei, Prajwal Shiva Prakasha, Thomas Zill, and Björn Nagel*

This paper presents an extendable approach to the modelling and simulation of Urban Air Mobility (UAM). UAM constitutes the use of low capacity aircraft for air travel over short distances particularly in urban areas at low altitudes. It involves a multitude of complexities including the airspace, fleet, demand and vertiport management. Simulation is a key enabler for understanding these complexities and the interaction of the different stakeholders within the UAM paradigm. The authors aim to present a comprehensive framework to model the different aspects of UAM which can be further extended to place emphasis on any topics of interest. This work builds upon past research of the authors and presents a framework for simulation and modelling which includes the modelling of passenger demand, passenger mode choice, vehicle allocation for heterogenous fleets, route planning, deadheading, vertiport scheduling, and flight scheduling with stop overs. The approach presented in this work can be used to model both on-demand and scheduled operations, while the primary focus is placed on the former. Moreover, different methods can be implemented for the detailed modelling of the stakeholders, in addition to parametrically varying aspects such as the fleet size, number of vertiports, and others. This framework underpins the ongoing research of the advanced modelling and simulation of UAM with higher fidelity modelling of the aforementioned fields. In addition to the extendable aspects of the framework, detailed description of the simulation implementation is presented. Furthermore, the simulation is used as the basis for the system of systems driven aircraft and fleet design research presented in tandem with this work. The aims of this paper are two, firstly to offer a framework for the modelling of UAM by breaking down its complexity into manageable and realistic blocks where the relevant logic can be implemented (Vertiport Manager, Air Traffic Manager, Passenger, etc.) while allowing for the interaction of these blocks. By breaking down the complexity into understandable blocks, the emergent behavior of the system of systems simulation may be more easily observed or understood. Secondly, it is to provide an understanding of the developed simulation to the reader as a background to the system of systems driven aircraft and fleet design research.

Development of a UAM Vehicle Family Concept by System of Systems Aircraft Design and Assessment

Mr. Patrick Ratei (German Aerospace Center),, Nabih Naeem, Prajwal Shiva Prakasha, Thomas Zill, Björn Nagel, Martin Wagner

Aeronautical system architectures and aviation use cases feature complex interactions of several subsystems, systems, and operational concepts or tactics. The evaluation of manifold impacts on performance and effectiveness due to the multi-level interdependencies necessitate holistic System of Systems (SoS) design and assessment. Hence, a tool for conceptual aircraft design is concurrently developed as part of an evolving agent-based simulation framework for SoS fleet operations as depicted in Figure 1. While the general principle of the framework is transferable to other aviation use cases, the proposed framework is tailored to the emerging aviation segment Urban Air Mobility (UAM). The concept of UAM promises a modern air taxi transport solution providing on-demand air mobility as well as time savings compared to congested terrestrial transportation in major cities and metropolitan areas. Due to the new development of several complex, distributed and interconnected systems, e.g. electric

Vertical Take-Off and Landing (eVTOL) aircraft of various configurations, passenger demand, on-demand dispatch including deadhead flights, and re-energizing strategies, a holistic SoS approach is needed for the design of efficient, market- as well as operations-tailored aircraft, aircraft families, and fleets for the air transport system. Therefore, two disparate eVTOL aircraft configurations (i.e. multirotor and tiltrotor) of varied ranges, speeds and capacities are designed subject to modularity considerations and assessed regarding performance and effectiveness when operated as a homogeneous air taxi fleet considering the deployment for different UAM use cases (i.e. intra-city and suburban). Eventually, measures of effectiveness at SoS level are obtained from the simulation and used to evaluate each design to arrive at optimal SoS driven concepts (see Figure 1). By this newly introduced feedback loop, the importance of SoS (simulation) driven aircraft design will be demonstrated and discussed for its relevance in such operations driven air vehicle and aviation use case developments. Finally, a SoS simulation driven UAM vehicle family concept will be presented.

System of Systems Driven Fleet Design for Urban Air Mobility: Heterogeneity over Homogeneity

Mr. Nabih Naeem (German Aerospace Center), *Patrick Ratei, Prajwal Shiva Prakasha, Thomas Zill, and Björn Nagel*

Urban Air Mobility (UAM) represents a new paradigm in aviation involving high intensity short distance air travel using low capacity vertical take-off and landing aircraft. As this new paradigm necessitates a departure from many traditional aspects of the existing air transportation system, a large body of research is necessary to better understand the novel requirements and how they can be served by different technologies. These aspects include but are not limited to airspace management, vertiport design and management, aircraft design with innovative subsystem technologies, etc. A wide range of operational scenarios is envisioned for UAM involving different ranges, tempos of operations, and expected demand. This translates to a suite of different vehicles being developed by the industry with different architecture and top-level requirements. The aim of this work is to evaluate the need for heterogenous fleets to suit the different operational scenarios envisioned for UAM. Two optimized aircraft concepts, a multirotor and a tiltrotor concept, derived from a system of systems driven aircraft design approach is first evaluated in a homogenous fleet, and then in a heterogenous fleet with varying degrees of heterogeneity. The ideal mix of heterogeneity is identified for a given setup considering economic and ecological efficiency from which generalizations are drawn. For this evaluation, a nominal use case is setup to represent a mixed operational scenario of intra-city and suburban scenarios. The fleets are evaluated against Measures of Effectiveness (MoEs) including passenger throughput, share of received requests that were served, wait time of passengers, deadhead ratio, load factor, and total energy consumption of the network. These MoEs are obtained using an agent-based simulation of UAM system of systems.

Analysis of the fixing process of FBG optical sensors for thermomechanical monitoring of aerospace applications

Prof. Matteo D.L. Dalla Vedova (DIMEAS - Politecnico di Torino), *Alessandro Aimasso, Alfredo Esposito, Paolo Maggiore*

In aerospace, many components can be defined as “safety critical”. As a result, it is crucial to early identify the failure precursors when the effects on the systems performances are still practically insignificant. For this reason, complex networks of sensors have been developed and integrated into different parts to monitor several operational parameters, useful for evaluating their health (such as temperatures, displacements, vibrations, etc.) Clearly, due to the importance of data collected, the technology employed shall be very reliable, even while working in harsh environments. Sensors based on optical fiber Bragg grating (FBG) meet all these requirements. In particular, one of their most interesting peculiarities is related to the possibility of embedding the fiber into a specific component: this could be extremely advantageous for structural monitoring, above all for safety critical panels, by operating temperature and strain control. However, the gluing phase of the fiber is really crucial, from the moment that the process shall be reliable and, above all, shall not influence the sensors output. To obtain this, the effects of the glue's retire and its viscous assessment shall be analysed and quantified. This work analysed the gluing method of an optical fiber with an FBG sensor on a composite sample. Moreover, at first a gluing strategy was defined and then, in a second time, it was repeated while collecting data during the overall process. More in detail, the method applied to the two different samples previsED a fiber with an FBG sensor, firstly pre-tensioned and then glued on the support. Once the glue dried, the fiber was covered with a resin film. The first sample was prepared, and it remained unused for about two months. Then, the second one was built in the same way and with the same materials. Furthermore, data from both FBG (that mounted on the older sample and the other on the new) were collected during the gluing phase (of the second sample) and in the following days. By comparing the two different sensors performances, it was possible to describe how the gluing and the resin curing processes affected the measures. The results showed that the assessment of the resin evolved in different phases, but all of them were united by the fact that the overall process makes sensors measures not reliable during this specific transitory phase. Indeed, putting the two samples in the same environment, the output of the newer sample showed a marked descending trend. By observing the evolution of the linear fit gradients, it can be stated that the variations reach their maximum in the middle of the gluing process, when the fiber is detached from the tensioning device. In this phase the gradient is more than 10 times higher than previous moments and about 30 times higher than the ending curing phase. Finally, at the end of the overall process, data output resulted stable: this was crucial to consider, from this moment, FBG employable for reliable thermal or strain measures. In conclusion, this work describes a possible methodology about the optical fiber integration on a composite sample for aerospace applications. Moreover, the analysis of significant effects of the gluing process on data collected for a not-negligible period is fundamental to increasing optical sensors reliability, allowing of using them for prognostic and diagnostic scopes. Furthermore, the data strong dependence on the integration methodology makes it crucial and strategic the definition of a standard process for optical sensors integration in aerospace structures.

Prognostics of aerospace electromechanical actuators: comparison between model-based metaheuristic methods

Prof. Matteo D.L. Dalla Vedova (DIMEAS - Politecnico di Torino), *Leonardo Baldo, Ivana Querques, Paolo Maggiore*

The deployment of Electro-Mechanical Actuators (EMAs) as aircraft flight control actuators is an imperative step towards more electric concepts, which propose an increased electrification in aircraft subsystems at the expense of the hydraulic system. The last-mentioned subsystem is hence decreased in size or completely removed indeed. EMAs show several advantages with respect to traditional electrohydraulic actuators (EHA) such as: general system-level weight reduction, hydraulic fluid phase-out, reduction of maintenance checks etc. Despite the strong benefits linked to EMAs adoption as primary and secondary flight control actuators, their deployment is still slowed down due to the lack of appropriate know-how, statistical data and analyses concerning their often-critical failure modes. One way to support their adoption in safety critical domains lies in the usage of Prognostics and Health Management (PHM) approaches, which check if EMAs performances are coherent with the relative operational limits and expected trends. These prognostics frameworks could assist EMAs in the areas of fault detection and identification (FDI) as well as diagnosis and prognosis. In fact, prognostics algorithms allow failures identification in their early stage, before they could induce catastrophic failure conditions through their propagation and irreversibly compromise aircraft mission. The result is a substantial increase in the reliability of the overall sub-systems. A very promising approach involves the development of model-driven prognostics methodologies based on metaheuristic bio-inspired algorithms. In fact, a model-based approach is necessary to supply the shortage of historical data which make data-driven methods often unapplicable. Furthermore, the algorithms draw inspiration from biological phenomena. In this sense, the natural species adaptation in nature can be seen as a form of optimization. This type of approach is becoming increasingly popular in the development of new optimization techniques: they succeed in approaching complex problems even if their base concept is fairly easy to implement. In this paper, two types of algorithms will be approached: the evolutionary (Differential Evolution (DE)) and swarm intelligence (Particle swarm (PSO) and grey wolf (GWO)) methods. A variety of different optimization strategies are applied, showing to be capable of successfully distinguish between nominal performance and various failures. To support the optimization strategies, two models were developed: a reference, high fidelity model and a monitoring, low fidelity counterpart. To all intents and purposes, the former is a virtual test bench, validated with experimental data, hence providing accurate dynamic trends. The behavior of EMA individual components is described by appropriate governing equations which are integrated into the modular elements of the system. The low fidelity model relies on parameters approximations, in order to reduce the computational costs and allow a more efficient evaluation of the health status of the real system, with minimal errors. Following a literature assessment of various EMA failure modes through FMECA analyses, a total of six failure modes has been selected and implemented: dry friction, backlash, short circuit, eccentricity, proportional gain and noise. The optimization algorithms are then applied in order to iteratively find the monitoring parameters that modify the output of the monitor model so as to minimize the error defined by a suitable fitness function. To evaluate and quantify the accuracy of each algorithm, the percentage error with respect to the ideal values in the respective fault conditions in the reference model is evaluated. The balance between accuracy and computational cost is assessed thanks to a custom-built performance coefficient. The overall results are very promising and show that these algorithms could be employed in pre-flight checks or during the flight at specific time intervals. Therefore, EMA actual state can be assessed and PHM strategies can provide pilots and the ground crew with the right tools and knowledge to monitor the system and to plan and act accordingly (e.g. estimating components Remaining Useful Life (RUL)), thus enhancing the system availability, reliability and overall safety.

Novel active control technique of aircraft flaps asymmetry

Prof. Matteo D.L. Dalla Vedova (DIMEAS - Politecnico di Torino), *Leonardo Baldo, Josè M. Cejudo Ruiz*

This paper proposes an active monitoring strategy to control aircraft trailing-edge high-lift devices (flaps) asymmetry. A variety of system faults can cause asymmetry in the control surfaces, including breaking a transmission torsion bar and control surface actuator wear and tear. The authors' novel asymmetry active monitoring approaches detect and identify flaps position asymmetry. Once the failure side has been identified, the active control activates the wingtip brakes to stop the uncontrolled flap surface. The still controlled flaps are driven to the failure surface braking point to reduce flap asymmetry. As a result, the undesired aircraft roll moment (due to flaps asymmetry) will be controlled, and the aircraft maneuverability after failure will be (partially) restored. The proposed asymmetry active monitoring technique has been widely tested in different operational and failure conditions, using wear-free or wear-out actuators and considering every failure side scenario. The behavior of the proposed active model is evaluated in terms of time response and stability margin under certain operating conditions.

Lumped parameters multi-fidelity digital twins for prognostics of electromechanical actuators

*Gaetano Quattrocchi, **Prof. Matteo D.L. Dalla Vedova (DIMEAS - Politecnico di Torino),** Pier Carlo Berri*

The growing affirmation of on-board systems based on all-electric secondary power sources is causing a progressive diffusion of electromechanical actuators (EMA) in aerospace applications. As a result, novel prognostic and diagnostic approaches are becoming a critical tool for detecting fault propagation early, preventing EMA performance deterioration, and ensuring acceptable levels of safety and reliability of the system. Moreover, prognostics provides other benefits, such as the capacity to better schedule equipment maintenance, manage warehouse and service crews, and lower system management costs. Frequently, these approaches require the development of various typologies of numerical models capable of simulating the performance of the EMA with different levels of fidelity: on the one hand, monitoring models, suitably simplified to combine speed and precision with reduced computational costs, and on the other hand high-fidelity (and computational-intensive) models, to simulate the behavior of the actual system, generate databases, develop predictive algorithms and train machine learning surrogates. For these reasons, in previous publications, the authors already proposed a high-fidelity multi-domain numerical model (HF), capable of accounting for a wide range of physical phenomena and progressive failures in the EMA, and a low-fidelity digital twin (LF). The LF is directly derived from the HF one by reducing the system degrees of freedom, simplifying the EMA control logic, eliminating the static inverter model and the three-phase commutation logic. It is mainly intended for preliminary design, prognostics, or monitoring applications. It should be noted that, in several applications (e.g. model-based prognostic algorithms of the electric motor), the LF model manifests evident limitations due to the significant simplifying hypotheses characterizing it. Therefore, in this work, the authors propose a new EMA digital twin, called Enhanced Low Fidelity (ELF), that, while still belonging to the simplified types, has particular characteristics that place it at an intermediate level of detail and accuracy between the HF and LF models. While maintaining a low computational cost, the ELF model keeps the original architecture of the three-phase motor and the multidomain approach typical of HF. Moreover, since it too is sensitive to progressive failures, it allows to evaluate the dynamics of the three-phase stator circuit and, therefore, to simulate the response of HF model and actual system with satisfactory accuracy. These models were validated using a dedicated test bench, which replicates the functioning of a simple EMA both in the case of nominal conditions and under progressive mechanical failures. The comparison of the preliminary results shows a satisfactory consistency between the experimental equipment and the numerical models.

Valve digital twins for electro-hydraulic actuator prognostics: synthetic fluid dynamic models sensitive to hydraulic capacity

Prof. Matteo D.L. Dalla Vedova (DIMEAS - Politecnico di Torino), Parid Alimhillaj

Modern flight control system design necessitates using highly detailed models to analyse individual components or subsystems; on the other hand, more fundamental and synthetic models with adequate accuracy are required for preliminary design, monitoring, diagnostics, or prognostic issues. As regards this second category of models, in literature are available several simplified numerical solutions able to simulate, with different levels of accuracy and details, the fluid dynamic behaviours of a given valve geometry. Typically, the aforementioned simplified models calculate the differential pressure regulated by the valve as a function of its spool opening and the flow rate disposed of by the valve itself. In some specific applications (e.g. asymmetric hydraulic jacks, regenerative actuators, or transmissions where the effect of fluid compressibility is not negligible), models with differential pressure output are inadequate. In these cases, new simplified fluid dynamic models must be used to calculate the flow rate delivered by the valve as a function of the spool displacement and the differential pressure. Thus, this paper proposes a new synthetic fluid-dynamic valve model (i.e. a lumped parameters model with a semi-empirical formulation) accounting for the effects of spool position, hydraulic capacity, variable supply pressure and leakage between the output ports that connect the valve to the motor element. The advantages and disadvantages of the suggested model are evaluated, by comparison with other simplified numerical algorithms available in the literature, analysing the corresponding fluid-dynamic characteristics and comparing the dynamic behaviours of numerical models simulating a typical flight control servomechanism. Furthermore, it is validated with a high-fidelity digital twin that replicates valve behaviour while accounting for spool shape, hydraulic capacity, fluid characteristics, and local internal fluid-dynamics (laminar or turbulent regime, cavitation, etc.).

Modeling the electrical part of an aeronautical EMA using Simscape

Dr. Gaetano Quattrocchi (Politecnico di Torino), *Matteo D.L. Dalla Vedova, Paolo Maggiore, Raffaele Giordano*

In recent years, a strong drive toward the more electric design philosophy has been present. The main reasons to adopt a single form of secondary power for all non-propulsive systems is complexity reduction, maintenance costs reduction and performance optimization. For this reason, proper modeling of such systems is essential to favor increased adoption in the industry. In this paper, a component-level model of an electro-mechanical actuator (EMA) is presented; in fact, EMAs are the most basic actuator capable of converting electrical to mechanical power. In aerospace, EMAs are already used as primary flight controls actuators for small UAVs and as secondary flight controls actuators (e.g. flaps) on larger aircrafts. The new EMA model using a permanent magnet synchronous motor (PMSM) has been created in Simscape, starting from an established MATLAB Simulink model, validated on a test bench. In particular, the main electrical elements, including inverter and stator phases, are now modeled using Simscape components. The new environment allows modeling using physical components with energy flows and easy, multi-domain analysis of complex systems, coupling phenomena of different nature (e.g. mechanical, electrical, thermal). The Simscape model has then been tested against the Simulink model to verify accuracy and robustness, with good results. Such a model will prove useful to explore the behavior of the EMA in out of design conditions and system response in presence of faults of different nature.

Design of a phase calibrator to evaluate non-matched microphones for intensity probes

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Intensity measurements represent a well-established method to determine the sound power of an emitting object. The principal strength of this technique relies upon the possibility of performing the measurements in situ, with no special required conditions concerning the surrounding sound field. Commercially available sound intensity probes rely on two-phase matched microphones properly spaced concerning the desired frequency range. Given the physical and mathematical principles behind the intensity method, phase differences between the signals assume a crucial role. This paper aims at studying the possibility of performing intensity measurements with two standard Class-1 microphones and preamplifiers. A phase calibrator has been designed to identify phase mismatches between the microphones and provide the required corrections at specific frequencies. A numerical model of the calibrator acoustic model has also been implemented. We have also performed a sensitivity analysis concerning the microphone spacing to evaluate the operative frequency range given a set error bound.

Design and Preliminary Performance Assessment of a PHM System for Electro-Mechanical Flight Control Actuators

Dr. Andrea De Martin (Politecnico di Torino), *Antonio Carlo Bertolino, Giovanni Jacazio, Massimo Sorli*

The evolution towards "more electric" aircrafts has seen a decisive push in the last decade, due to the growing environmental concerns and the development of new market segments (flying taxis). Such push interested both the propulsion components and the aircraft systems, with the latter seeing a progressive trend in replacing the traditional solutions based on hydraulic power with electrical or electromechanical devices. Flight Control Systems (FCSs) are one of the aircraft systems affected the most, since the adoption of Electro-Mechanical Actuators (EMAs) would provide several advantages over the traditional electro-hydraulic p or mechanical solutions for both primary and secondary flight control surfaces, such as the complete avoidance of leakages, simplifications in the power lines layout and an easier implementation of additional functionalities (i.e. load allievation). However, in particular when compared to hydraulic actuators, technological barriers for a wide adoption of EMAs still persist, mainly due to their sensitivity to certain single point of failures that can lead to mechanical jams. As such, EMAs are so far not employed for flight safety critical applications as solutions are heavy and costly (redundancy, fail safe behavior, etc.), while their certification is made more difficult due to the additional design complexity. The development of an effective and reliable Prognostics and Health Management (PHM) system for EMAs could help in mitigating the risk of a sudden critical failure by properly recognizing and tracking the on-going fault and anticipating its evolution, thus boosting to the acceptance of EMAs as primary flight control actuators in commercial aircraft. The paper is focused on the results of the preliminary activities performed within the CleanSky 2/Astib research programme, dedicated to the definition of the iron-bird of a new regional-transport aircraft able to provide some prognostic capabilities and act as a technological demonstrator for new PHM strategies for EMAs employed in flight control systems. The paper is organized as follows. At first, a proper introduction to the research programme is provided, along with a brief description of the employed approach. Hence the simulation models adopted for the study are presented and used to build synthetic databases to inform the definition of the PHM algorithm. The prognostic framework is then presented, and a preliminary assessment of its expected performances are discussed.

A data-driven approach for health status assessment and remaining useful life prediction of aero-engine

Dr. Maria Grazia De Giorgi (University of Salento), *Nicola Menga, Antonio Ficarella*

Aircraft engines are systems for which very high reliability is required. To satisfy this request, the aeronautical companies implement an appropriate maintenance plan to which the engines used during flights are subjected. An inaccurate maintenance plan can lead to unnecessary expenses. In order to make the maintenance plan as efficient as possible, nowadays advanced diagnostic and prognostic techniques are used on aeronautical engines. However, the development process of these techniques requires the presence of datasets containing a certain amount of data relating to flight missions and to the engines state of health during their operative life. Unfortunately, aeronautical companies do not easily provide their own flight mission data, moreover, it is evident how to create a dataset by performing a series of true experimental flights is not possible for researchers, because of the high costs that would result from it. A great alternative, is to create a dataset by the means of adequate flight simulation software. In the present work, Simulink T-MATS library is used to develop a method for generating datasets containing data about aircraft engine degradation. The final goal is to generate a series of degradation trajectories in order to use them for prognostic purposes. First of all, a Simulink model of the engine VIPER 632-43 is created using T-MATS library and validated. Subsequently, a mathematical law describing component degradation and taken from available literature is implemented. The degradation is implemented as flow capacity and adiabatic efficiency variation in the map of the component chosen to be degraded, i.e. the compressor. Furthermore, an algorithm was written with MATLAB and used to automatically create a dataset containing degradation data by exploiting Simulink and T-MATS library to perform. The generated dataset, was subsequently used to train a nonlinear autoregressive network with exogenous (NARX), a particular neural network suitable for time-series data, to predict the engine Remaining Useful Life (RUL). a similar approach, could be very useful to decrease maintenance costs and increase flight safety.

UAV / UAS

Session Chair: Prof. Pericles Panagiotou (Aristotle University of Thessaloniki)

Reinforcement learning attitude control of aerial vehicles: analysis, experiments, and comparisons

Mr. Burak Han Demirbilek (ASELSAN Research Center), *Mehmet Baskın, M. Muhsin Cosdu*

The control system of an aerial vehicle can be composed of the inner loop(stable control of control surfaces) and the outer loop(high-level, mission-level command) control. As expected, the success of the outer loop control depends on the inner loop. In general, current inner loop control methodologies often include controllers that use linear models for such systems, which is sufficient in most cases. However, controllers based on linear systems could not be enough in some scenarios, such as sharp maneuver ability or high agility. In this study, artificial neural network based controllers are trained with reinforcement learning techniques to overcome the existing performance of methods in such scenarios. This study compares deep reinforcement learning methods to classical Proportional Integral Derivative (PID), Linear Quadratic Gaussian (LQR), and Model Predictive Control (MPC) methods. In many scenarios such as highly nonlinear, action-limited reference tracking and stabilization problems in Quadcopter UAVs. In addition to the classical comparison metrics of control systems, we propose and test new concept metrics such as adaptability, robustness, and computational complexity of neural network algorithms.

Design, manufacturing and flight-testing of a fixed-wing, small-scale UAV for the transportation of blood bags to remote locations

Anastasios Karageorgiou, Panagiotis Kantouris, Nefeli Metallidou, Anna Charizani, ***Prof. Pericles Panagiotou (Aristotle University of Thessaloniki)***

The current work presents the design, manufacturing, and flight-testing of a fixed-wing, small-scale Unmanned Aerial Vehicle (UAV). The research activities presented in this paper have all been conducted by the Aristotle Space & Aeronautics Team (ASAT), a Greek aerospace student team, for their participation in the international student competition Air Cargo Challenge (ACC) 2022. Its mission is to carry bags of blood to a remote location. The design requirements refer to a short take-off distance of 60m of rough terrain, climb time of 60s and a cruise/loiter time of 120s. Size restrictions also apply, as the aircraft must fit inside a 1.5m x 1.5m x 0.5m volume, in its deployed form. A step-by-step presentation of the design procedure is conducted, emphasizing on the critical design decisions, such as the airfoil, cargo bay location, wing platform design. The corresponding trade studies are shown, along with the main advantages of the resulting configuration, which is an inherently stable, high-wing, tractor UAV. The in-house manufacturing process is consequently described, focusing on the molds tooling, as well as on the carbon fiber and fiberglass manufacturing techniques. Finally, the flight testing results are shown, including the initial struggles that lead to the fine-t uning of the UAV. The test results are validated against the design data and the overall performance of the aerial vehicle is discussed.

Design and SITL Performance of an online Distributed Target Estimation for UAV Swarm

Mr. Fausto Francesco Lizzio (Politecnico di Torino), *Stefano Primatesta, Haoyu Guo, Giorgio Guglieri*

Distributed control of Unmanned Aerial Vehicles (UAVs) has recently received a considerable amount of attention. This is due to the cost-effectiveness of the aerial platforms, the scalability of the control strategies, and the added value provided by multiple agents in terms of redundancy, greater coverage and time efficiency. Formation control [1] is one of the first issues to handle when dealing with a UAV swarm, as the drones are often asked to attain a desired shape in space during the completion of a task. Distributed formation algorithms usually require the presence of a unique target to be followed by each agent to avoid the fragmentation of the swarm. Most of the literature regarding distributed UAV formation considers a collaborative target that shares its state information to the entire or a fraction of the swarm. However, this is not always the case in real missions, as the precise state of the target may be unknown and must be estimated. Thus, it is clear how formation control and target estimation are strictly related topics, [2]. The aim of this work is to define a strategy for an online collaborative target estimation performed by a swarm of UAVs in formation flight. For the formation task, we start from the flocking consensus algorithm introduced in [3], and, specifically, we consider a tailored version of this method presented by the authors in [4]. With respect to the standard algorithm, the proposed version is able to eliminate the steady-state errors arising in the inter-agent distances through an integral action and obtain a smoother transient behaviour through a damping term. However, in this previous work, the exact position of the target chased by the UAVs was simply broadcast to all of them, so that the target acted as the leader of the swarm. Moreover, the communication topology of the drones was fully connected. In this work, the formation algorithm developed in [4] is applied in cascade with a distributed target estimation one. In particular, a Kalman Consensus Filter in the Information form is employed. This choice is motivated by the ease of the information fusion step in distributed networks provided by this form of the filter, which reduces it to a trivial sum [5]. With this configuration, the swarm does not chase the exact position of the target, but rather the location provided by the collaborative target estimation process. This results in a leaderless scheme that further stresses the capability of the formation algorithm and brings the simulation closer to a real setup. The results of a preliminary simulation performed on Matlab/Simulink are shown in Figure 1, where three UAVs carry on the estimation and tracking of a moving target while maintaining safe inter-agent distances. In this paper, we employ the ROS/Gazebo environment in the Software-In-The-Loop (SITL) mode provided by the PX4 stack. By doing so, it is possible to interface the autopilot as it would be done in an actual implementation and to use the navigation information that would be available on board on a real aerial platform. The simulation is carried on so that each UAV performs a noisy measurement of the target position through a range- bearing sensor. This information is first managed locally by each drone and, then, fused with the information collected by the other agents to obtain a global estimate of the target's state. Implementation details will be reported to address the feasibility of the method. Several simulation rounds will be carried on to validate the application's performances in the presence of increasing levels of process and measurement noise, and with different communication topologies. Metrics as the estimation errors and the inter-agent distances will be provided to evaluate the coupling between the formation and the target estimation tasks. This will help in addressing the impact that online distributed estimation may have in real flight scenarios as patrolling, surveillance, and infrastructure inspection.

Vision-Based Real-Time Motion Estimation of Ground Vehicles from Aerial Imagery

Mr. Yagiz Kurt (Middle East Technical University), *Halil Ersin Soken*

Target tracking problems date back to the eighteenth century, with the first attempts to determine the orbits of visible planets. In the 1960s, target tracking was primarily used in military applications such as ballistic missile defense, battlefield situational awareness, and orbital vehicle tracking. Today, target tracking has been applied to the ever-growing number of civilian applications such as air traffic control, building surveillance, and emerging applications such as supply chain management and wildlife tracking. The variance of applications and tracking performances keep increasing by involving learning algorithms and improving computer power. Recent developments in small-size and high-performance Graphics Processing Units (GPU)s make the use of online tracking algorithms possible on Quadrotor Unmanned Aerial Vehicles (UAV)s. Quadrotor UAVs used in surveillance are not still fully adapted to our daily lives since the autonomy level is not sufficient and the reliability of algorithms is not well verified. It is usual to detect relatively large moving objects on a stationary frame. However, there are challenges in detecting small objects from real-time footage taken by quadrotor UAVs. UAVs always navigate in different altitudes, and the object scale varies violently, which burdens the optimization of networks. Moreover, high-speed and low-altitude flights bring in the motion blur on the densely packed objects, which leads to a great challenge of object distinction [1]. Due to these challenges, learning-based object detection and tracker performance are highly reduced. As for considering the scope of this research, tracking multiple objects involves various research fields such as target motion prediction, computing a similarity/distance score between pairs of detections, data/measurement association, and appearance models. In this research, maneuvering target motion estimation modules found in target tracking algorithms in the case of only camera source existence are studied. Present learning-based object detection algorithms can provide the position of the center of the detected object in 2-D space and bounding box ratio/size in the image frame. Bounding box size helps us to estimate the actual size of the detected specific type objects. With that knowledge, we might be able to infer the distance between the object and the UAV for specific types of objects with approximately known dimensions, such as a car. On the other hand, position measurements are used to estimate the velocity and acceleration of the targets to be tracked. Remark that for the maneuvering targets orientation estimation, rotation angle information is not feasible to obtain from the camera sensor using traditional object detection networks since they use horizontal bounding boxes. Moreover, most of the datasets [2, 3, 4] and networks are not suitable for training rotation-invariant features to localize the objects since the objects are labeled with horizontal bounding boxes (HBBs). To overcome the problem of creating appropriate bounding boxes for oriented objects, recently published datasets, where the object instances are annotated with oriented bounding boxes (OBBs), are used to train very light networks to perform real-time performance on UAVs. In the presence of rotation angle measurement, estimation of the turn rate of the vehicles during maneuver is enabled. Alongside the measurement uncertainty, the target motion uncertainty is present when a target undergoes a known or unknown maneuver during an unknown time period. In general, it is only possible to account for target motion uncertainty by having different motion models [5]. In the presence of target motion uncertainty and measurement uncertainty, performances of various Kalman Filters, Multiple Models, and Particle Filters are evaluated and compared based on their speed and accuracy. In the end, the filter performing optimum results is implemented inside the target tracking algorithm. In this way the performance of the filter is evaluated on real case scenarios taken by quadrotor UAVs.

Visual Odometry aid for Unmanned Aircraft Navigation in Unknown Environments

Ms. Semra Sultan Uzun (Middle East Technical Universty), *Halil Ersin Söken*

In autonomous systems, the accuracy and reliability of the localization is crucial for the controlling the system and performing the required tasks. However, this is a challenging problem in unknown and GPS-denied environments due to lack of navigation aids. In this case, the pose estimation can be done with the inertial measurement unit (IMU) only. However, the estimation error grows over time and decreases the accuracy for a long time flight. To improve the estimation accuracy vision aided navigation can be used for localization and pose estimation. In recent studies, it is showed that pose estimation can be supported by visual sensors during flight by detecting the features or objects in the environment. These features' locations can be known and marked in a map before the mission or a map can be built by simultaneously recovering poses of cameras and structure of the environment, which is known as SLAM (Simultaneous Localization and Mapping) technique in literature. Although, this improves dramatically the pose estimation accuracy since it takes into account the correlation between the observed features and the camera pose, the computational load is heavy. Another way of using the camera measurement is visual odometry. It aims to estimate only the camera pose according to the displacement measured from a sequence of camera images without reconstructing the 3D scene. If enough features are detected, the angular and translational velocities can be estimated by looking at the variation of the relative positions of the detected features. This study proposes a computationally light yet accurate visual odometry technique to aid the IMU measurements of an Unmanned Aircraft in an unknown environment. For this purpose an algorithm is designed to estimate the angular and translational velocities of the aircraft. Information obtained by the camera is integrated with the IMU measurements using an Extended Kalman Filter. The proposed algorithm is tested in simulation environment.

Path planning of autonomous drones using reinforcement learning

Ms. Elena Politi (Harokopio University), *Iraklis Varlamis, Konstantinow Giorgas, George Dimitrakopoulos*

Autonomous BVLOS drones are gradually gaining their share in the UAV market. Together with the demand for extended levels of autonomy comes the necessity for high-performance obstacle avoidance and navigation algorithms that will allow autonomous drones to operate with minimum or no human intervention. Traditional AI algorithms have been extensively used in the literature for finding the shortest path in 2-D or 3-D environments and navigating the drones successfully through a known and stable environment. However, the situation can become much more complicated when the environment is changing or not known in advance. In a previous study we examined two well-established path planning techniques, namely A* and Dijkstra algorithms, in an environment with stable obstacles, and demonstrated how the input from an onboard LiDAR can help in gradually building a navigation path from the departure to the destination point. In this work, we examine i) how the input from a simple camera can be used to replace the LiDAR and detect potential obstacles and ii) how more advanced artificial intelligence techniques, such as reinforcement learning, can be employed to successfully navigate a drone within unspecified environments. Reinforcement learning is a machine learning training method where an intelligent agent learns the optimal behavior trying to reach a certain goal. The learning occurs when the agent is rewarded for each desired action taken while being punished for the undesired ones. In the under study scenario, the multirotor agent was rewarded for every action that would bring it closer to the landing site while being penalised for any action towards a different direction or for colliding with any intermediary obstacles. In order to validate the performance of our proposed solution, we perform our experiments in a virtual environment, which allows us to run simulation experiments, using multiple obstacles and choosing different departure and arrival points. More specifically, by utilizing the AirSim framework that is provided by Microsoft we were able to control programmatically a multirotor agent which allowed us to run our experiments and collect a lot of data used both for the algorithms and their evaluation. The experiments run on two world environments, a basic world environment that contains geometric shapes as obstacles provided by AirSim, and a complete city environment that has been developed by the University of Tampere representing its Hervanta Campus. The first results are promising for the RL algorithm and prove that autonomous drone navigation can be performed successfully in dynamic and non-predefined environments. Of course, similar experiments have to be performed in real-world environments, transferring the navigation algorithms on the edge (i.e. drone) and testing their performance and potential difficulties.

UHURA project session

Session Chair: Mr. Hans Maseland (NLR, Netherlands)

The UHURA project at a glance – motivation and objectives

Mr. Apurva Hasabnis (DLR), *Jochen Wild, Henning.Strüber, Frédéric Moëns, Bart van Rooijen, Hans Maseland*

The project UHURA is focusing on the unsteady flow behavior around high-lift systems and will first time deliver a deeper understanding of critical flow features at new types of high-lift devices of transport aircraft during their deployment and retraction together with a validated numerical procedure for its simulation. UHURA performs detailed experimental measurements in several wind tunnels to obtain a unique data set for validation purposes of Computational Fluid Dynamics (CFD) software, including detailed flow measurements by Particle Image Velocimetry (PIV) and other optical measurement technologies. Advanced CFD methods promising significant improvements in the design lead time are validated against this database to obtain efficient and reliable prediction methods for design.

After closure of the project, this session is intended to provide an overview on the project achievements. We will outline the generated database of unsteady high-lift flow of a deflecting Krueger flap. We will also present our experience with different approaches for the dynamic CFD simulation of this kind of flow. In this first talk, the motivation and the objectives are detailed further to provide an understanding for the simulation challenge and its importance for the design of next generation aircraft implementing laminar wing technology for fuel saving.

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Krueger Design and Motion Requirements

Henning.Strüber, Jochen Wild, Antoon Vervliet, ***Mr. Frédéric Moëns (ONERA)***

The industrial valid design of a folding bull nose Krüger leading edge device will be presented. It serves as a geometrical basis for the UHURA project, which investigates the retraction and deployment process with numerical and experimental means. A set of realistic aerodynamic and kinematic requirements was applied, such as deflection angle range and deployed target position to enable insect shielding. In order to achieve an industrial relevant design solution of a Krüger device, realistic space allocation constraints and structural keep-out-zones were defined within the fixed leading edge. Numerical shape optimization of the Krüger device was performed to balance size, shape and deployed position with optimal aerodynamic performance, respecting the given requirements and constraints. Based on that, layout and sizing of the kinematic structural and connecting elements was carried out. Industrial viability was ensured by applying aerospace design rules, as well as relevant material selection, deformation and tolerance analysis.

CFD Methods for Unsteady High-Lift Simulation

***Mr. Frederic Moens (ONERA),** Stefan Wallin, Hans Maseland*

Laminar wing technology is seen as one of the major sources for drag reduction on the airframe of a transport aircraft and will be a key technology to achieve the targets for emission reduction. In recent EC funded projects, the Krueger flap leading edge device was found to be the most promising concept of a dual-functional leading-edge device for laminar wings for low-speed conditions (take-off and landing). While the studies focused on the general performance (CL_Max) and integration, the behaviour of the system during its deployment or retraction proves to be a major issue due to a very different kind of motion compared to conventional leading edge highlift devices (Fig. 1). Fig. 1: Different positions of a Krueger slat during its deployment phase. During the deployment phase, the Krueger device is deflected from the lower side against the flow, passing critical stations when perpendicular to the flow, forming large scale separated flow on the lower side when moved around the leading edge. Similar behaviour is observed during the retraction phase of the Krueger after take-off. The numerical methods used to simulate this sequence have to consider two main topics. The first one is to deal with the change of the Krueger setting during this deployment/retraction phase. But, contrary to a trailing edge flap or a standard leading-edge slat, the shape of the element changes dramatically. Grid techniques used have to deal with this kinematic deployment process. Different methods have been considered (chimera overset grids, grid deformation, immersed boundary conditions, dynamic meshing) and evaluated. The second topic to consider for numerical methods is about unsteady flow aerodynamics. The unsteady aerodynamic field characteristics have to be interpolated/extrapolated between two steps of the grid update without loss of information, and they have to deal with the different time scales between the turbulent flow propagation and the Krueger movement. Therefore, there is a need for fast and efficient unsteady solvers. Among the improvements of URANS solvers, some advanced methods have been evaluated. Finally, some fluid-structure interaction tools have been considered in order to evaluate the loads existing on the different Krueger elements (panel and bull nose).

Validation Experiments

***Mr. Geoffrey Tanguy (Univ. Lille, CNRS, ONERA),** Bart van Rooijen, Andreas Schröder, Jochen Wild*

In the future, aircraft designs may require laminar wings to meet the emission reduction targets set by ACARE FlightPath 2050 for future air transportation. The integration of high lift system for laminar wings remains one of the main challenges in the field as classical high-lift configurations using slat devices are proscribed with laminar wings due to the introduction of turbulence into the flow over the upper side of the wings. In addition, there is a need to shield the leading edge of the wings during low altitude flights, where pollution and insects could adversely impact the laminarity of the main wings for cruise conditions. The slotted Krueger device's capability to shield the leading edge of the wing during take-off and landing along with its promising performances make it a suitable candidate for laminar wing devices. Although in principle the aerodynamic performance of a Krueger flap is known, the unsteady behaviour of the flow during deployment and retraction is completely unknown. This is as even more important as during deployment the Krueger flap is exposed to highly unfavourable positions perpendicular to the flow. The Unsteady High-lift Aerodynamics – Unsteady RANS Validation project (UHURA) investigates experimentally and numerically the aerodynamics of a Krueger flap leading edge device. The Krueger is an additional lift surface that is deployed from the lower side of the wing for take-off and landing (Strüber and Wild, 2014). Building on the learnings from the EC funded project DESIREH, the objective of the UHURA project is to investigate the unknown aerodynamic characteristics of the slotted Krueger device during deployment and retraction. Within the UHURA project, three wind tunnel campaigns are performed in three different wind tunnels with two models to cover a broad range of conditions including variation of Krueger span (full span – part span), wing sweep angle and Reynolds number. This work presents the experimental set up and results for the three campaign held in the ONERA L1, DNW-NWB and DNW-LLF wind tunnels. The ONERA experiment features PIV measurements on the lower surface of the 2D wall-to-wall mounted wing in order to obtain a detailed flowfield during the deployment of the Krueger. The transient wall static pressure during the movement of the Krueger is measured with MEMS sensors integrated within the flap and the leading edge. The DNW-NWB investigated the effect of sweep angle over the Krueger flowfield using a 2.5D cantilever wing. In addition to the wall static pressure, the wake of the wing is measured with a 5-hole probe rake. Finally, the effect of Reynolds number is investigated at the LLF facility with the use of a 1:3 scaled wing model with realistic actuation and kinematics to achieve a chord based Reynolds number of 6×106. The LLF campaign features Stereo-PIV measurements on the lower surface of the wing, unsteady wall static pressure and Krueger flap deformation measurements using Stereo pattern recognition (SPR) system. The large experimental database will be used to validate the numerical work of the UHURA project and to identify the flow behaviour and its impact on the wing performances during the deployment and retraction of the Krueger device.

Urban Air Mobility (UAM):
Workshop I: Scaled Demonstrators
Session Chair: Dr.-Ing. Christian Eschmann (DLR, Germany)
Workshop II: Future Energy Sources for Aviation
Session Chair: Mr. Marcello Kivel Mazuy (CIRA, Italy)
Workshop III: Circular Aviation System
Session Chair: Mrs. Ligeia Paletti (NLR, The Netherlands)

Urban Air Mobility (UAM) has gained popularity in the past decade as the next revolution for mobility. It promises to be a more efficient and sustainable form of transport, using the unutilized airspace in urban environments to improve services and mobility. It promises to contribute to a climate-neutral air transport system, without compromising on safety and security and while respecting the societal concerns on noise and pollution. But how can UAM system and solutions be designed and demonstrated to be the efficient and sustainable mode of transport it is advertised to be? In three workshops, different aspects are presented, which need to be considered for UAM to become a reality, in the current societal context focused on sustainability, efficiency and social acceptance. The workshops aim at creating awareness of the challenges embedded in UAM and identifying possible solutions to be investigated further, in a collaborative spirit which includes universities and research establishments, all other aviation stakeholders, and the citizens.

Workshop I: Scaled Demonstrators

Chairman: Dr.-Ing. Christian Eschmann (DLR)

In aeronautical research, infrastructures make an essential contribution to technology development. For decades, classic large-scale facilities, such as wind tunnels, have been used for this purpose, but recently simulators of all kinds or entire high-performance clusters have also been increasingly employed. Since the construction and maintenance of such facilities is very personnel- and cost-intensive, the European Commission has been pursuing a more efficient and uniform approach for infrastructures across Europe. In the case of UAM, these are primarily UAS (unmanned aerial system) test centres for conducting extensive flight test campaigns. In this context, scaled demonstrators are becoming an increasingly important tool for flight tests, as well as for design and validation. Scaled demonstrators are scaled-down models of the intended future aircraft and serve as realistic flight test vehicles. However, this is not only about low TLR research, but also about the scaled testing of individual technology components (such as sensors), through sub-systems to entire systems. In the workshop, the entire spectrum of potential applications for scaled demonstrators will be presented - from current, existing test vehicles to possible future configurations.

Workshop II: Future Energy Sources for Aviation

Chairman: Mr. Marcello Kivel Mazuy (CIRA)

Hybrid Electric Propulsion (HEP), H2 and in general Sustainable Aviation Fuels (SAF) are widely considered as the most promising and sustainable solutions for an energy efficient, green and quieter aeronautical propulsion. Despite this, several goals must be still achieved to make these technologies viable. In particular, the propulsion system integration into the A/C and the overall feeding system, including new challenges as electric and thermal Management, are key issues to be solved for an acceptable technology shift. Also, we can just think for example of the ‘weight issue’. However, the ‘greening’ effect of future energy sources for aviation implies new challenges. If CO2 emissions of aviation are well established and their impact on climate (radiative forcing) can be reasonably well quantified, non-CO2 impact and noise might be considered as well. In general, for current air transport applications non-CO2 emissions impact (NOx, contrails) on radiative forcing remains widely uncertain (but know as significant) and noise issues for new disruptive configurations also to be assessed. These uncertainties become more important for the new and unknown future UAM scenario. For example, what about the psychological effects of this new swarm noise above people heads? What is the increased level of humidity due to the water vapor, and consequent combination with other exhausts, in the city? The overall scope of the workshop is to assess in an ideal urban context such innovative propulsion solutions, both in terms of technologies and configurations, on a wide spectrum, from applicability to safety/security till social acceptance issues, by thinking outside the box with fresh and open-minded academic skills. Potential links with a circular approach and scaled demonstration will be also addressed in order to provide additional food for thoughts for the other workshops.

Workshop III: Circular Aviation System

Chairwoman: Mrs. Ligeia Paletti (NLR)

There is currently a lot of buzz around “Circular Economy”, especially following its connection with the EU Green Deal. Yet, what Circular Economy really means and entails are aspects still elusive for many. In general, it is thought that Circular Economy has “something to do with” recycling: recycling of materials (like recycled plastic). In some cases, Circular Economy has “something to do with” reusing things: second hand products or finding new uses for parts (like chairs from car seats). Circular Economy encompasses those aspects, and more. Circular Economy is defined as a “system solutions framework”. When the system considered is Aviation, the Circular Economy becomes one framework to define solutions which will contribute to the goal of climate-neutral aviation by 2050 and to the other goals expressed in the ACARE Vision. In this workshop, the participants will take an active role in creating an ideal (UAM) Air Transport System which is circular and in alignment with the goals of the EU Green Deal.

U-space, digital services for urban air mobility

Session Chair: Dr. Cristina Barrado (Universitat Politècnica de Catalunya, Spain)

On-board performance monitoring and alerting mechanism & navigation specifications for drone flight operations

Mr. Pablo Haro (EUSPA)

The proposed paper describes an ongoing research study performed by the European Union Agency for the Space Programme (EUSPA) on a navigation specifications' concept including an on-board performance monitoring and alerting (OBPMA) mechanism for drone flight operations. The general principles of this mechanism are based on Performance Based Navigation (PBN) as described by ICAO Doc 9613 and the EUROCAE ED-75D 'MASPS: RNP for RNAV'. It is subsequently tailored to drone flight operations case. The proposed concept is motivated as a response to the requirements stated by EASA in the Special Condition (SC) for Light UAS – Medium Risk, (Issue 01, 17 Dec 2020) applicable to SAIL III and IV of the specific category of operation. Three airworthiness specifications have been identified in the SC Light UAS – Medium Risk, Subpart F – Systems and Equipment, where the proposed OBPMA mechanism would play a role and could be considered as a suitable means of compliance (MOC): Light-UAS.2510 Equipment, Systems and Installation; Light-UAS.2511 Containment, and Light-UAS.2529 UAS Navigation Function. The concept has already been introduced to the EUROCAE WG-105 UAS and further discussions and consolidation is underway. Within Performance Based Navigation (PBN), the proposed mechanism is based on area navigation including the requirement for onboard performance monitoring and alerting, i.e. built on Required Navigation Performance (RNP) navigation specifications tailored to drones. The aim of the OBPMA mechanism is to ensure containment of the drone within a narrow 3D corridor along the desired flight trajectory, i.e. in the domain of the Total System Error (TSE). The desired flight path must be entirely contained in the drone's flight geography, both in the horizontal and vertical planes. When flying that path, there will be errors in the horizontal and vertical components. In both cases, the TSE includes three error sources, i.e. the Navigation System Error (NSE), Flight Technical Error (FTE) and Path Definition Error (PDE). A number of RNP navigation specifications are proposed for fixed wing and rotary wing drones considering different GNSS positioning sensors and a reasonable behaviour of the autopilot. Performance requirements in terms of accuracy, integrity (integrity risk, alert limits, time to alert), continuity and availability are derived for the GNSS sensor. Finally, when the alerting mechanism detects that the drone's true position may be out of the 3D containment corridor, appropriate contingency actions must be executed. The alert can be triggered by two processes, one previously outlined (positioning integrity mechanism) and another one in charge of monitoring the FTE.

BUBBLES: A new Concept of Operations for Separation Management in the U-space

Ms. Cecilia Claramunt Puchol (Universitat Politècnica de València), *Juan Vicente Balbastre Tejedor, Norberto Vera Vélez, Joan A. Vila Carbó*

Over the last decade, the unmanned aircraft industry has attracted a great deal of interest due to its potential and multitude of applications, especially in urban environments. This has led authorities and the general public to raise different issues and concerns, among which safety is the most important. Safety is one of the pillars of BUBBLES, an Exploratory Research (ER) project funded by SESAR Joint Undertaking (SJU) that aims to define a new Concept of Operations to provide separation management in the U-space. The main contribution of BUBBLES is to provide guidelines for dealing with conflict management in tactical phase, i.e., the separation provision phase, in U-space airspaces. In the context of BUBBLES, this work defines the principles on which separation management in the U-space is based (operation-centric, risk-based, time-based, and performance-based), as well as the basic building blocks that support it and how they should be assembled and operated. Then to carry out the process of separation provision, which is an iterative process consisting of four steps (conflict detection, solution formulation, solution implementation, and solution monitoring), this work defines a conflict model and a traffic classification. After that, it proposes how to deal with the conflict horizon to support conflict detection and defines the separation modes and methods to be used during solution formulation and implementation. Another important aspect to consider for the separation provision is the selection of appropriate separation minima. In this sense, this work proposes the calculation of dynamic separation minima, which are adapted to the traffic class, the operational environment, and the Communication, Navigation and Surveillance (CNS) systems performance. This concept of dynamic separation minima has been validated through test-flights in a real rural environment. BUBBLES proposes the Separation Management Service to make available all the information required for U-space airspace users in a centralized way so that all tactical conflicts occurring within the U-space airspace are resolved according to a pre-established set of rules and procedures, and a target effectiveness of the separation provision barrier is achieved.

A Drone Operation Plan model to support the effect of uncertainty in advance U-Space Capacity Planning Processes

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The rapidly expanding adoption of drone operations to support diverse business objectives will require an efficient and highly automated drone traffic management system that can help balance demand against novel capacity measures. It is envisaged that the drone traffic demand over urban environments will become a challenge for the capacity of the low-level airspace and can also potentially represent an impact to the population above which drones will operate. The SESAR 3 JU funded project 'DACUS' (Demand And Capacity management in U-Space) examines this complexity and investigates the Demand and Capacity Balancing (DCB) process in particular. Unlike conventional aviation which, beyond the immediate vicinity of airports, operates at high altitude, drone operations in the urban environment will be at very low altitudes. This will result in new impacts including noise and visual annoyance, privacy issues and safety/risk to the population below in the case of a vehicle failure or collisions between two drones. DACUS therefore is designed to investigate the use of new, societal, and risk-based Demand Capacity Management (DCM) services to help plan drone operations in the urban space. One of the main challenges in the development of solutions for DCM/DCB in U-space is how to share Drone Operation Plans (DOP) that include all the necessary information for the U-space services to evaluate/manage the demand and the associated uncertainty of those operations at various phases of the operations planning process. This paper introduces a model to define DOPs that are enriched with information that can facilitate the drone traffic management in capacity-constrained scenarios. The model contributes towards assuring a central and reliable point-of-information across a set of diverse U-space processes, that take place at different phases of the drone missions. The model aims to capture varying degrees and sources of uncertainty regarding the planned operations and to support further evaluation on the impact of that uncertainty on the demand-capacity balancing services. The paper also discusses the use of a U-space Common Information management service (UCIS) and how it can be used to support a series of DCM/DCB services that are deployed along side other U-Space services to support risk-based capacity management at the different phases of the Drone operating process. Considering the technical capabilities of the drone, variations in the operating environment (e.g. due to weather) and the operational characteristics of each particular mission, a model for operation plans in the JSON standard file format is designed. To cover the most representative mission types (transport/delivery, surveillance and inspection), two types of airspace occupancies are taken on board, namely linear trajectories and occupancy volumes with temporal features. Moreover, the lack of information in the drone operator's planning and preparation processes can be modelled in the DOP as an uncertainty in time or a geospatial variation. Additionally, the model supports the integration of resolution plans to cope with a wide range of non-nominal scenarios and contingency events. Integration of risk-based DCM services that can consume DOP information from UCIS that include uncertainty and contingency information and the inclusion of uncertainty effects in the collision risk service for both technical and operational influences permits analysis of the impact that uncertainty may have at different phases of the planning process. The DOP model has been implemented on an UCIS testbed. In this testbed the DACUS service models and prototypes enable the simulation of expected DCB processes along different phases of the Drone operating process. To validate the developed model, selected high traffic demand scenarios are simulated and the information of the operation plan is either updated or directly applied within the DCM/DCB processes. A first scenario involves the adaptation of the operation plan based on environmental information available during the flight planning stage. Technical and mission-based uncertainties are included in the collision risk analysis service which uses a Monte-Carlo simulation methodology to evaluate the risk to the population and identifies potential collision risk hotspots due to the propose set of operations. In a second scenario, a variety of DCB measures are implemented and tested in the tactical/execution phase to evaluate the impact in key performance areas including capacity, efficiency, equity and predictability and the resolution plans are applies. The simulated DCM/DCB processes make fully use of the information included in the DOPs. The performed simulation of high-traffic demand scenarios show that the DOP model is suitable for the needs of multiple U-space service and functions. As next, further U-space services and capabilities shall test the integration of the proposed DOP model.

A Comparative Study Between Different Parameter Tuning Strategies for PID Attitude Controller of Drones

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As drones try to work in more complex missions with recent developments in geographic positioning technologies, precise attitude control of drones gains importance. Attitude control heavily affects the linear speed, which in turn determines the absolute position of the drone. In addition, some tasks can require a drone to be in a specific rotational position to be executed, such as performing a landing or carrying a liquid load. For these reasons, a robust and precise attitude control algorithm is vital for drones. Generally, flight controllers use an attitude control structure based on the PID algorithm. Although the implementation of the PID algorithm can differ slightly between different flight controllers, the essence of all these algorithms is the same. This essence is defining a PID feedback loop using the attitude reference that is calculated according to the instantaneous requirements of the mission and output angular rate to drone to be mixed in with linear speed references to calculate motor speeds. These systems are tested quite well, and some boundaries on the control parameters which will work with most of the drones are already established in flight controllers. However, as mentioned, these systems are optimized to work in a wide range of drones that have other characteristics such as actuator power, frame shape, or flight weight. These characteristics affect control parameters vastly; thus, particular control parameters, such as PID coefficients, are required for precise attitude control of the drone. In order to find these specific parameters, some tuning algorithms can be established. In this paper, different tuning methodologies will be comprised using non-linear drone simulation software. Also, this structure can be feasible to tune control parameters for real experiments in different environments. There are many different tuning methodologies in the literature, especially regarding the tuning of the PID controller because of its common use. Many approaches use analytic methods use a known plant model and a known control strategy. However, these approaches are generally not sufficient for the actual system due to non-linear or unexpected effects of the system. Therefore, to develop an algorithm that will be feasible for real-life applications, the plant model should be treated as an unknown, and the tuning algorithms should learn the system response with testing control parameters. Furthermore, the analytic models are used for the application where there is only a single feedback loop to tune, while attitude control for drones requires at least three different feedback loops for each rotational axis; roll, pitch, and yaw. However, since the rotational axes of the drone are coupled, treating parameters individually does not yield satisfying results for all possible rotations that a drone can make. Due to this reason, the algorithm should evaluate control parameters for all three rotations together to obtain adequate results. In this context, four different eligible approaches are selected for the comparison. These selected methodologies were the Ziegler-Nichols method [1], stochastic gradient descent [2], genetic optimization algorithm [3], and a reinforcement learning-based approach [4]. To compare the performance of the PID controller with different coefficient sets, a previously designed simulation environment [5] is selected. The reason behind this selection was that this system could interpret nonlinear effects and noise, which is closer to the actual work environments of the drone. Also, this system establishes some evaluations about the performance of the control algorithm such as rise time, overshoot percentage, steadystate error, etc. that can be used as the cost for tuning algorithms and define a stable framework to compare different algorithms. The control parameters are tested with various references and optimization metrics such as computational cost, minimum error, and adaptability to different references collected for comparison. After the assessment of the results, the most feasible and efficient tuning strategy will be selected to be used in further studies. This study helps to create a tuning framework that is applicable to the actual drones and that is able to optimize different drone structures or work environments. This framework can even be useful for comparing different control schemes, in the sense of comparing them at their peak performance with carefully adjusted parameters.

Way of future orbital and planetary robotics

Session Chair: Mrs. Wiebke Brinkmann (DFKI GmbH, Germany)

Ontology-Driven Robot Design for Future Orbital and Planetary Robotics with korcut

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The development of robots is a multidisciplinary and challenging task where the complexity grows with the capabilities and functionalities of the system, and even more when the environment imposes exceptional requirements, as in space missions. Several key points to consider when planning such a mission, e.g., the minimal space required for the system to be transported into space and its extremely compact design, multifunctionality, versatility, modularity or configurability as well as recovery purposes. Due to the interdisciplinary nature of robotic system design, robot development requires know-how of mechanical, electrical and systems engineering as well as computer science and artificial intelligence (AI). Despite the existence of various domain-specific methodologies and tools to support robot development, each tool still requires expert knowledge, and thus domain-specific experts. Ontology-driven knowledge representation for robotic system design as a method is a suitable way to collect and represent this needed knowledge about all phases of the life cycles of robotic systems in space is essential. The Q-Rock development cycle intends to overcome developmental difficulties

of custom-designed robotic systems by integrating existing AI technologies to (a) enable the automated exploration of robot capabilities from robot hardware, (b) suggest robot designs that satisfy users' needs, and (c) refine suggested robot designs. In this paper, we introduce Knowledge-based Open Robot voCabulary as Utility Toolkit (korcut) as a core component aiming to support system development for terrestrial and extraterrestrial environments, a reference implementation of the Q-Rock development cycle to support ontology-driven robot design. We use korcut to improve the robot design process from the requirements to the development phase for modular robots through the use of semantic component descriptions in state-of-the-art open-source 3D modelling software. Furthermore, the korcut ontology family includes various sub-ontologies developed to perform specific space-related tasks, such as the definition of a Standard Interconnect for On Orbit Servicing and Orbital Factory (EU Horizon 2020 PERASPERA OG PERIOD project) or astronaut-robot collaboration related to the Human-Machine Interaction task for lunar task domains (KIMMI-SF project). This paper describes korcut and provides an evaluation of its current applications from a methodological, knowledge representation and software tool perspectives. Finally, we provide a critical analysis for future work.

Outcomes of the PERIOD project on In-Space Manufacturing, Assembly and Refuelling Technologies

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When one thinks about how satellites and spacecraft are constructed today, the picture which immediately springs to mind is the large clean room, the heavy personnel needs and the large launch vehicles required to transport a volume-constrained payload to space. The PERIOD project (EC Horizon 2020 project 101004151) seeks to disrupt the status quo by showing there is an alternative to the traditional approach of manufacturing, assembling and validating space hardware on-ground with direct in-orbit manufacturing and assembly using robotics, autonomy and modularity. The advantages are multiple, ranging from almost unlimited overall volume and design of large satellite antennas to multiple options for building larger space infrastructures such as large reflectors and modular space stations. On top of this, In-Space Manufacturing and Assembly (ISMA) technologies would allow for the upgrade and repair of existing spacecraft and satellites already in orbit, thereby encouraging the sustainable usage of space through plug and play modularity. The ISMA industry can revolutionize the space market by achieving a sustainable space ecosystem and enabling new services and applications. The PERIOD consortium, including Airbus Defence and Space, DFKI, EASN-TIS, GMV, ISISPACE, SENER Aeroespacial, and Space Applications Services, is confident that in a decade from now, considering a stepwise evolution, many different capabilities will be needed and introduced. Large-antenna commercial satellites autonomously assembled in space will provide citizens with a wide range of services, and scientific satellites will allow us to see further into deep space than ever before. Payloads will be autonomously exchanged on standard reconfigurable satellites. Most satellites will be repaired, serviced, or de-orbited in space, meaning that we will be able to better face the space debris issue. Advanced space robotics will be used for local and autonomously manufacturing and assembly on the space stations in LEO and lunar orbit and indeed on the lunar surface. Similar robotic technologies and autonomous industrial processes will be used for producing resources in space. Major results of the PERIOD project will be reported on the following topics from the phase A/B1 work:

- Status on the developed core Strategic Research Cluster (SRC) PERASPERA building block technologies ESROCOS (European Space Robotics Control and Operating System), ERGO (European Robotic Goal-Oriented Autonomous Controller), and InFuse (Data Fusion)
- Evaluation of the multifunctional Standard Interconnect (SI) interfaces SIROM, HOTDOCK and iSSI for the specific assembly demonstration scenario
- Preliminary design concept of the orbital demonstrator for satellite manufacturing & assembly and for coupling & refuelling experiments
- Results from the ISMA breadboard testing in a relevant scenario

The successful implementation and validation of ISMA technologies will lead to the generation of independent European capacities allowing Europe to build future orbital infrastructure and to be competitive on the ISMA markets.

Ground Interaction Models for Increased Autonomy of Planetary Exploration Systems

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Planetary exploration of celestial bodies, such as Moon and Mars, using robotic systems has been common practice for decades. However, to reach scientifically interesting places such as craters and sub-surface lava tubes, they need high mobility capabilities to traverse sandy and rugged terrain, to avoid or overcome obstacles, and to cope with different slopes. There exist manifold locomotion concepts, e.g. wheeled rovers, legged walking systems, or hybrids that use legged-wheels or wheeled-legs. They all have their pros and cons, and thus are better or less suited for different terrains. During the exploration of unknown areas, regardless of the type of locomotion, the robots should autonomously be able to detect the traversing terrain and to identify whether it is harmful or not. To guarantee mission success, an intelligent system should autonomously navigate around risky environments or, if possible, adapt their locomotion pattern accordingly. The approach presented in this paper follows the idea to learn online meaningful models of robot-ground interaction. They allow, on the one hand, the realistic simulation of robot movements on different surfaces in order to predict mobility characteristics as precisely as possible in advance. And, on the other hand, having a digital twin of the real counterpart allows a continuous comparison with the sensor values actually measured and to detect anomalous behavior. Due to the fact that the real conditions (gravity, soil composition) cannot be exactly reproduced on earth, the robots need to be able to learn the ground interaction models online during their traversal from their own sensor readings. For a generic approach to learn ground interaction models, six robotic systems developed for planetary exploration will be used. With three technically different rovers and three technically different walking systems, a broad spectrum for ground interaction will be analyzed. By collecting performance data on plain ground, loose soil, rubble, and lava floor, a quantitative comparison of varying walking and roving systems of variables sizes and locomotion principles can be done, and various ground interaction models can be learnt. For collecting data, the default locomotion behavior will be used, but also the usage of specific probing behaviors maximizing the information gain will be learned and analyzed. Deep Neural Networks will be used to learn efficient models that predict the ground interaction of the respective wheel or leg contacts. The learned ground interaction models are then integrated into a real-time physics simulator to improve the simulation of the holistic robot behavior by reducing the simulation reality gap. The usage of this internal simulation online on the system to predict the nominal robot performance and to compare this to the actual sensor readings enables to continuously determine soil properties and to detect non-nominal conditions which can then be handled in time through path planning or behavioral adaptation. The paper will describe the concept in more detail, the experimental setup for reproducible experiments, an overview on the selected robots, and first results.

Process and performance evaluation of Automated Fiber Placement (AFP) for CF/LM-PAEK composite

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DOMMINIO project is an EU funded collaborative research project focused on the development of an innovative digital methodology to design, manufacture, maintain and pre certify multifunctional and intelligent airframe parts. DOMMINIO will develop an innovative methodology to ensure cost-effective, efficient and sustainable manufacturing of high quality multifunctional and intelligent airframe parts, based among others on Automated Fiber Placement (AFP) technology. In the last few decades, the transition to the usage of more advanced composites together with the increase in aircraft performance and productivity rate have increased the challenges faced by designers and manufacturers to produce cost-effective structures and components using greener materials and technologies, allowing cost, weight and fuel consumption reduction with shorter manufacturing cycles and increasing energy efficiency in aircraft fabrication. Nowadays, AFP process is applied in high quality production processes especially in the field of large, low-curved aeronautical shell structures likewise fuselage sections or wings. AFP allows the consolidation of pre-impregnated preforms in form of tapes that are put in contact and consolidated by supplying heat and pressure. In this study, experimental investigations were performed with the aim of gaining a better understanding of the effect of the AFP process parameters on the mechanical properties of carbon fibre (CF) /low-melt polyaryl ether ketone (LM-PAEK) composites. Taking as a starting point the evaluation of tooling temperature in the mechanical performance and crystallinity. The results of which were used for a further study, allowing a more exhaustive mechanical characterisation of the material to be undertaken, setting as process parameters of the material those resulting from the previously addressed study based on maximising the Single Lap Sear Strength (SLSS) and considering the crystallinity and voids evaluation.

Improving thermal management of FFF nozzle for aerospace applications

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Fused filament fabrication (FFF), is an additive manufacturing process used to produce prototypes and small to medium series. This process involves a layer-by-layer deposition of a filament. The interlayer adhesion is dependent of the temperature management of the process: a real-time measurement of the thermal behaviour of the nozzle is necessary to gain process understanding and develop validated predictive models to allow the use of FFF in highly regulated sector such as the aerospace. Here, the instrumented FFF nozzle design was optimized through thermal and topological simulations. The optimized nozzle was manufactured in metal additive manufacturing to integrate cooling channel, which kept the filament solid before the liquefier, thermocouples and pressure sensors at selected sites around the nozzle. The thermal simulation of the optimized nozzle and the development of predictive models of the FFF process will be used for real-time quality control. Finally, this new FFF nozzle, as a part of Domminio project, will be integrated to the manufacture airframe parts.

Development and characterization of magnetic nanoparticle reinforced filament for additive manufacturing applications

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Hybrid nanomaterials have recently received voluminous interest due to the combination of unique properties of organic and inorganic components in one material. Magnetic polymer nanocomposites are of particular interest because of the combination of excellent magnetic properties, stability, and good biocompatibility. Among different fillers, iron oxide nanoparticles with their intrinsic magnetic properties, are most significant due to their potential applications in multidimensional fields. Herein manufacturing and characterization of functional nanocomposite thermoplastic (TP) filaments for use in additive manufacturing applications are presented. Nanocomposites were prepared via melt blending method using a co-rotating twin-screw extruder. TP matrices of poly-ether-ketone-ketone (PEKK) was compounded 20−35 nm spherical magnetic nanoparticles (MNPs), namely, Fe3O4, NiFe2O4 and CoFe2O4. The MNP filler content varied from 2.5–10% by a mass fraction. PEKK nanocomposite pellet/filament samples were evaluated in terms of thermal properties via Thermogravimetric Analysis (TGA) and Differential Scanning Calorimetry (DSC). TGA results showed that the a-stage of decomposition does not differ significantly between the tested samples, while the respective rate at b-stage increases as a function of MNPs concentration. DSC analysis showed that glass transition temperature (Tg) of all samples (152 – 154 oC) is not related to the MNPs type or concentration. Micro-Computed Tomography analysis was used to assess the anisotropy and particle size distribution of nanocomposite samples. Developing innovative TP nanocomposites will allow a faster and leaner integration and repair to be adaptable to additive manufacturing and 3D printed structures, compared to thermoset repair processes, promoting advanced applications in many fields of Nanotechnology.