AeroBest 2023

ECCOMAS Thematic Conference on Multidisciplinary Design Optimization of Aerospace Systems

Programme and Abstracts

19-21 July 2023

André C. Marta & Afzal Suleman (chairs)

Last update: July 21, 2023

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Programme Overview

(follow hyperlinks to session details)

Wednesday, July 19^{th}	
8:20 - 8:45	Registration
8:45 - 9:00	Opening Ceremony
9:00 - 10:00	Keynote Lecture I
	Charbel Farhat, Stanford University
10:00 - 10:20	Coffee Break
10:20 - 12:00	SESSION 1 - Multi-Disciplinary Optimization I
12:00 - 13:00	Lunch
13:00 - 14:40	SESSION 2 - Discipline Analysis Models
14:40 - 15:00	Coffee Break
15:00 - 16:40	SESSION 3 - Systems Engineering and Integration

Thursday, July 20^{th}	
9:00 - 10:00	Keynote Lecture II
	António da Costa, Airbus
10:00 - 10:20	Coffee Break
10:20 - 12:00	SESSION 4 - Design Optimization
12:00 - 13:00	Lunch
13:00 - 14:40	SESSION 5 - Aerospace Design and Integrated Systems
14:40 - 15:00	Coffee Break
15:00 - 16:40	SESSION 6 - Multi-Disciplinary Optimization II
19:30 - 22:00	Conference Dinner

Friday, July 21^{st}	
9:00 - 10:00	Keynote Lecture III
	Sergio Ricci, Politecnico di Milano
10:00 - 10:20	Coffee Break
10:20 - 11:40	SESSION 7 - Multi-Disciplinary Optimization III
11:40 - 12:40	Keynote Lecture IV
	Mehmet Yildiz, Sabanci University
12:40 - 12:50	Closing Ceremony

Keynote Speakers

Charbel Farhat, Stanford University

Charbel Farhat is the Vivian Church Hoff Professor of Aircraft Structures in the School of Engineering and the inaugural James and Anna Marie Spilker Chair of the Department of Aeronautics and Astronautics. He is also Professor of Mechanical Engineering, Professor in the Institute for Computational and Mathematical Engineering, and Director of the Stanford-King Abdulaziz City of Science and Technology Center of Excellence for Aeronautics and Astronautics. He currently serves on the Space Technology Industry-Government-University Roundtable. From 2007 to 2018, he served as the Director of the Army High Performance Computing Research Center at Stanford University; and from 2015 to 2019, he served on the US Air Force Scientific Advisory Board.

He is a Member of the National Academy of Engineering, a Member of the Royal Academy of Engineering (UK), a Member of the Lebanese Academy of Sciences, a recipient of a Docteur Honoris Causa from Ecole Normale Superieure Paris-Saclay, a recipient of a Docteur Honoris Causa from Ecole Centrale de Nantes, a recipient of a Docteur Honoris Causa from Ecole Nationale Superieure d'Arts et Metiers, a designated ISI Highly Cited Author in Engineering by the Institute for Science Information (ISI) Web of Knowledge, and a Fellow of six professional societies: SIAM, ASME, IACM, WIF, USACM and AIAA. He was knighted by the Prime Minister of France in the Order of Academic Palms and awarded the Medal of Chevalier dans l'Ordre des Palmes Academiques. He is the recipient of several other professional and academic distinctions.

Professor Farhat and his research group at Stanford University develop mathematical models, advanced computational algorithms, and high-performance software for the design and analysis of complex systems in aerospace, automotive, marine, mechanical, and naval engineering. They contribute major advances to Simulation-Based Engineering Science. Current engineering foci in research are on the nonlinear aeroelasticity and flight dynamics of Micro Aerial Vehicles (MAVs) with flexible flapping wings and N+3 aircraft with high aspect ratio wings, layout optimization and additive manufacturing of wing structures, supersonic inflatable aerodynamic decelerators for Mars landing, and model predictive control. Current theoretical and computational emphases in research are on high-performance, multi-scale modeling for the high-fidelity analysis of multi-physics problems, high-order embedded boundary methods, uncertainty quantification, probabilistic machine learning, efficient model-order reduction for time-critical applications such as design and active control, and digital twins.

Professor Farhat is Editor-in-Chief of the International Journal for Numerical Methods in Engineering and Editor of the International Journal for Numerical Methods in Fluids. He also serves on the editorial boards of ten other international scientific journals. He has been an AGARD lecturer on aeroelasticity and computational mechanics at several distinguished European institutions, and a plenary speaker at numerous international scientific meetings. He is the author of over 650 refereed publications.

Lecture on Wednesday, July 19th, at 9:00

Differentiable Embedded Boundary Method for Efficient Multidisciplinary Design Analysis and Optimization

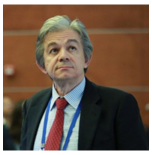
António Teixeira da Costa, Airbus

António graduated with a Master's degree in Aerospace Engineering from Lisbon Technical University (IST) and Aerospace Vehicle Design from Cranfield University.
He joined Airbus in 1998 as an Aerodynamics Engineer at Airbus UK in Bristol, working on the preliminary wing design for the A380 and A400M programmes. He then moved to the Marketing department, based in Toulouse, France, working on sales campaigns to airlines in Asia, Europe, Latin America and Middle East.
In 2005 he was appointed Marketing Director for the Middle East sales unit, managing all the marketing activities for this region. Subsequently, he joined the Strategy department working on future aircraft developments, bringing several developments to light such as the A320neo.
Currently he is the Vice-President of Single Aisle Marketing, responsible for marketing the A220 and A320 aircraft Families.

Lecture on Thursday, July 20th, at 9:00

Airbus - Pioneering Sustainable Aerospace

Sergio Ricci, Politecnico di Milano



Sergio Ricci is a Full Professor at the Department of Aerospace Science and Technology, Politecnico di Milano. He has been Principal Investigator for the more than 12 European funded research projects (EU-FP7, EU-FP6, EU-FP5) of Dipartimento di Ingegneria Aerospaziale, with emphasis to projects GLAMOUR – Gust Load Alleviation techniques assessment on wind tUnnel MOdel of advanced Regional aircraft (2014-2016), NOVEMOR – NOVel AIR VEhicle configurations: from fluttering wings to MORphing flight (2011-2014), SARISTU – Smart Intelligent Aircraft Structures (2011-2015), AWAHL – Advanced Wing And High-Lift Design (2011-2012), FFAST – Future Fast Aeroelastic Simulation Technologies (2010-2013), SMORPH – Smart Aircraft Morphing Technologies (2007-2009), SimSAC – Simulating Aircraft Stability And Control Characteristics for Use in Conceptual Design (2008-2011), 3AS – Active Aeroelastic Aircraft Structures (2005-2007).

Prof. Ricci is the Founder and Editorial Manager of open access International Journal of Aeroelasticity and Structural Dynamics (www.asdjournal.org). He also serves as reviewer for many international scientific journals, such as Aeronautical Journal, Aerospace Science and Technology, AIAA Journal, Journal of Aircraft, Journal of Intelligent Material Systems and Structures, Mechanism and Machine Theory, Chinese Journal of Aeronautics, Computer-Aided Civil and Infrastructure Engineering, and Statistics and Computing.

He is a Member of the International Forum of Structural Dynamics and Aeroelasticity (IFASD) Committee, a Member of the International Council of Aeronautical Sciences (ICAS) Committee, a Member of the ACARE Italy Committee, a Member of Aeroelastic Prediction Workshop (AeP) and a Member of RTO AVT 173 panel on Virtual Prototyping Using Advanced MDO. He is also a member of three professional societies: American Institute of Aeronautics and Astronautics (AIAA), Royal Aeronautical Society (RAeS) and Associazione Italiana di Aeronautica e Astronautica (AIDAA). He has been part of the Scientific committees of several international conferences, such as the International Forum of Structural Dynamics and Aeroelasticity (IFASD), the International Council of Aeronautical Sciences (ICAS) and ECCOMAS Thematic Conferences. He has given many invited lectures in Europe and USA on morphing aircraft and conceptual design tools for fast structural sizing and aeroelastic analysis and optimization.

Prof. Ricci leads the AeroStructures Design Lab (ASDL), specializing in the development of multi-fidelity analysis and design methods to enable fast and efficient generation of aero-structural models for new, environmentally friendly aerospace systems. The availability of a structural model since the beginning of design loop, i.e. at the conceptual design level, allows the designer to immediately evaluate the potential impacts from aeroelasticity on the definition of global aircraft design parameters, as well as the possible benefits from new materials and technology like morphing, in terms of global performances and weight saving. Current topics of research interest include: Automatic generation of low-medium fidelity aero-structural models; Fast structural sizing, aeroelastic analysis and optimization; Multi-objective topological optimization of compliant structures for morphing application; and Active aeroelastic control, including wind tunnel validation.

Lecture on Friday, July 21st, at 9:00

Aeroelastic Multidisciplinary Optimization: Enhancing Aircraft Performance And Safety Through Numerical Tools And Experimental Validation

Mehmet Yildiz, Sabanci University

Prof. Dr. Mehmet Yildiz is the Vice President for Research and Development at Sabanci University. He completed his undergraduate education in 1996 with the first rank in Metallurgical and Materials Engineering Department at Yıldız Technical University and received his MSc. degree also from the Metallurgical and Materials Engineering department at Istanbul Technical University in 2000. Between 1996-2000, he worked in two different companies as an R&D engineer and a project manager in the fields of welding and non-destructive testing. He obtained his Ph.D. degree in 2005 from Mechanical Engineering Department at the University of Victoria, BC, Canada in the fields of computational fluid dynamics and semiconductor single crystal growth and then worked as a research associate and lecturer in the same department until 2007.

In 2007, he joined Sabancı University, Faculty of Engineering Natural Sciences as a faculty member in Materials Science and Engineering Program and since 2013, has been leading the effort of establishing Sabanci University-Integrated Manufacturing Technologies Research and Application Center and its industrial leg, Composite Technologies Center of Excellence with Kordsa. He sits in the R&D advisory board of Kastamonu Entegre. He contributed to the establishment of Manufacturing Engineering graduate program at Sabanci University.

Dr. Yildiz's areas of expertise include advanced composite materials, nanocomposites, structural health monitoring and computational mechanics. He published more than 85 SCI indexed high impact factor journals, 8 book chapters, prepared and presented over 135 conference papers and graduated more than 28 MSc. and Ph.D. students.

Lecture on Friday, July 21st, at 11:40

Building Blocks Towards Advanced Thermoplastic Composites for Sustainable Aviation: Integration of Material, Process and Joining, Design, Validation, and Monitoring

Conference Sessions

(follow hyperlinks to manuscript details)

Notice to presenters (underlined): 20-minute presentation slots, including Q&A

Wednesday, July 19th

Session 1 - 10:20-12:00

Multi-Disciplinary Optimization I Chair: Fernando Lau, Instituto Superior Técnico				
time	ID	Title	Authors	Affiliation
10:20	6	DISCIPLINARY SURROGATES FOR GRADIENT-BASED OPTIMIZATION OF MULTIDISCIPLINARY SYSTEMS	Inês Cardoso, Sylvain Dubreuil, Nathalie Bartoli, Christian Gogu, Michel Salaün and Rémi Lafage	ONERA & ISAE-SUPAERO
10:40	7	AEROELASTIC ANALYSIS OF HIGH ASPECT RATIO AND STRUT-BRACED WINGS	Yoann Le Lamer, Joseph Morlier, Emmanuel Benard and Ping He	ISAE-SUPAERO & Iowa State University
11:00	10	AN UNCERTAINTY QUANTIFICATION METHOD BASED ON PROPER ORTHOGONAL DECOMPOSITION AND POLYNOMIAL CHAOS EXPANSION	Luca Battaglia, Federico Carlini, Alberto Clarich and Rosario Russo	ESTECO Spa
11:20	11	AEROELASTIC OPTIMIZATION OF A CELLULAR FLYING CAR WING USING THOMPSON SAMPLING EFFICIENT MULTIOBJECTIVE OPTIMIZATION (TS-EMO) ALGORITHM	Sen Wu, and Tomohiro Yokozeki	University of Tokyo
11:40	12	A PRELIMINARY LOW-FIDELITY MDO APPROACH FOR LOAD ALLEVIATION THROUGH MOVABLES ON HAR WING	Daniel Muradas, Sylvie Marquier, Joseph Morlier and Christian Gogu	Airbus & ISAE-SUPAERO

Session 2 - 13:00-14:40

		Discipline Analysis Models Chair: Viresh Wickramasinghe, National Research Council Canada		
time	ID	Title	Authors	Affiliation
13:00	17	AN ARBITRARY LAGRANGIAN-EULARIAN ALGORITHM TO SOLVE COMPRESSIBLE FLOW PROBLEMS: HEMLAB	Erol Aksoy and Mehmet Sahin	Istanbul Technical University
13:20	19	INTEGRATION OF LIFE CYCLE ASSESSMENT METHODOLOGY AS AN ENVIRONMENT DISCIPLINE MODULE IN MULTIDISCIPLINARY ANALYSIS AND OPTIMIZATION FRAMEWORK	Thomas Bellier, Joseph Morlier, Cees Bil, Annafederica Urbano and Adrian Pudsey	ISAE-SUPAERO & Royal Melbourne Institute of Technology
13:40	20	FIXED-WING UAV MODEL IDENTIFICATION FOR LONGITUDINAL MOTION USING FIRST-ORDER MODELS AND LIMITED FLIGHT TESTING	Nuno M. B. Matos and André C. Marta	Tekever UAS & Universidade de Lisboa
14:00	36	VALIDATION OF EXTENDED FAILURE MODELS AND CRITERIA FOR AEROSPACE COMPOSITES	Giuseppe Corrado, José Reinoso and Albertino Arteiro	Universidade do Porto & University of Seville
14:20	40	DEVELOPMENT OF COMPUTATIONAL AEROELASTIC ANALYSIS TOOLS AND UNCERTAINTY QUANTIFICATION TECHNIQUES FOR RELIABLE FLUTTER PREDICTION	Amin Fereidooni, George Lue, Masayuki Yano and Anant Grewal	Canada National Research Council & University of Toronto

Session 3 - 15:00-16:40

		Systems Engineering and Integration Chair: Ramin Sedaghati, Concordia University		
time	ID	Title	Authors	Affiliation
15:00	22	DESIGN OPTIMIZATION AND HUMAN SUBJECT SHAKER TESTING OF AN ACTIVE HELICOPTER SEAT SYSTEM	Yong (Eric) Chen, Amin Fereidooni, Rene Laliberte and Viresh Wickramasinghe	National Research Council Canada
15:20	25	ADAPTIVE AIRBAG SYSTEMS FOR PROTECTION OF GENERAL AVIATION	Jan Holnicki-Szulc, Rami Faraj, Cezary Graczykowski, Grzegorz Mikulowski, Piotr Pawlowski, Andrzej Świercz, Zbigniew Wolejsza, Lech Knap, Krzysztof Sekula, Dariusz Wiacek	Polish Academy of Sciences & Warsaw University of Technology & Adaptronica Sp. z o. o.
15:40	33	OPTIMAL MULTI-SENSOR OBSTACLE DETECTION SYSTEM FOR SMALL FIXED-WING UAV	Marta Portugal and André C. Marta	Universidade de Lisboa
16:00	35	SOFTWARE SUBSYSTEM AS A NEW CONCEPT IN SATELLITE SYSTEM ARCHITECTURE	João P. L. Monteiro, Paulo J. S. Gil and Rui M. Rocha	Universidade de Lisboa
16:20	43	A SYSTEM-BASED APPROACH FOR TECHNOLOGY ROADMAPPING ASSISTED BY VISUAL ANALYTICS	Gustavo Krupa, Andrea Spinelli and Timoleon Kipouros	Cranfield University

Thursday, July 20th

Session 4 - 10:20-12:00

Design Optimization Chair: Joseph Morlier, ISAE-SUPAERO				
time	ID	Title	Authors	Affiliation
10:20	8	WING STRUCTURAL DESIGN FOR A MAME UAV USING HIGH-FIDELITY NUMERICAL TOOLS	Vítor M. T. Silva, Nuno M. B. Matos and André C. Marta	Universidade de Lisboa & Tekever UAS
10:40	9	WING AERODYNAMIC DESIGN FOR A MAME UAV USING HIGH-FIDELITY NUMERICAL TOOLS	Rúben S. Gameiro, Nuno M. B. Matos and André C. Marta	Universidade de Lisboa & Tekever UAS
11:00	23	NEURAL LEVEL SET TOPOLOGY OPTIMIZATION USING UNFITTED FINITE ELEMENTS	Connor N. Mallon, Aaron W. Thornton, Matthew R. Hill and Santiago Badia	Monash University & CSIRO
11:20	32	DESIGN OPTIMIZATION OF TRUSS STRUCTURES USING A NON- UNIFORM CELLULAR AUTOMATA PARADIGM	Mohamed El Bouzouiki, Ramin Sedaghati and Ion Stiharu	Concordia University
11:40	37	STRESS-BASED SPATIAL GRADIENT RECONSTRUCTION FOR SHAPE SENSITIVITY ANALYSIS	Robert A. Canfield	Virginia Tech

Session 5 - 13:00-14:40

Aerospace Design and Integrated Systems Chair: Amin Fereidooni, Canada National Research Council				
time	ID	Title	Authors	Affiliation
13:00	14	FROM MDO TO MANUFACTURING: APPLICATION CASE FOR UNMANNED AERIAL VEHICLES	Luiz F. T. Fernandez, Murat Bronz, Thierry Lefebvre and Nathalie Bartoli	ONERA & ENAC
13:20	29	SKY SAILING OF TETHERED AEROSTATS FOR EFFICIENT AERIAL MONITORING	Andrzej Świercz, Cezary Graczykowski, Lech Knap, Zbigniew Wolejsza and Jan Holnicki-Szulc	Polish Academy of Sciences & Warsaw University of Technology
13:40	38	EXPLORING THE POTENTIAL OF DEEP LEARNING IN OPTIMIZING AN AERIAL PHOTOGRAMMETRY MISSION	Shahab Sotouni, Matthew Tucsok, Kumaraditya Gupta, Iraj Mantegh and Homayoun Najjaran	Univ. of Victoria & Univ. of British Columbia & Birla Institute of Technology and Science & National Research Council Canada
14:00	39	COMPUTATIONAL CHALLENGES IN THE MODULAR DESIGN OF FUTURE AIRCRAFT CONCEPTS WITH FLUTTER CONSTRAINTS	Alvaro Cea, Peter Nagy, Nicolas Roussouly, Rafael Palacios, Marco Fossati	Imperial College London & University of Strathclyde & Institute of Technology IRT Saint-Exupéry
14:20	42	INTEGRATION OF A THERMAL MANAGEMENT SYSTEM IN A HYBRID ELECTRIC AIRCRAFT – FUTPRINT50	Felipe Reyes Barbosa, Higor Feltrin Teza, Felipe Issamu Kitadani Odaguil, Ricardo Gandolfi, Dominik Eisenhut, Felix Brenner, Jonas Mangold, Nicolas Moebs, David Bento	Embraer Europe & Embraer SA & University of Stuttgart & Universidade de Lisboa

Session 6 - 15:00-16:40

Multi-Disciplinary Optimization II Chair: Frederico Afonso, Instituto Superior Técnico				
time	ID	Title	Authors	Affiliation
15:00	15	MULTI-OBJECTIVE BAYESIAN OPTIMIZATION WITH MIXED-CATEGORICAL DESIGN VARIABLES FOR EXPENSIVE-TO-EVALUATE AERONAUTICAL APPLICATIONS	N. Bartoli, T. Lefebvre, R. Lafage, P. Saves, Y. Diouane, J. Morlier, J. H. Bussemaker, G. Donelli, J. M. Gomes de Mello, M. Mandorino, P. Della Vecchia	ONERA & ISAE-SUPAERO & Polytechnique Montréal & German Aerospace Center & EMBRAER S.A. & University di Napoli Federico II
15:20	16	AN EXPLORATORY STUDY OF OPEN-SOURCE FRAMEWORKS FOR MDAO	Roberto di Giuseppe, Scott Delbecq and Valérie Budinger, Vincent Pauvert	ISAE-SUPAERO & Safran Tech
15:40	21	THERMO-MECHANICAL LEVEL-SET TOPOLOGY OPTIMIZATION OF A LOAD CARRYING BATTERY PACK FOR ELECTRIC AIRCRAFT	Alexandre T.R. Guibert, Murtaza Bookwala, Ashley Cronk, Y. Shirley Meng and H. Alicia Kim	University of California San Diego & University of Chicago
16:00	27	TOPOLOGY OPTIMIZATION OF A SOLID GRAIN HYBRID ROCKET LAUNCHER	Mirko Melis, Alain Souza and Frederico Afonso	Universidade de Lisboa
16:20	44	MULTI-OBJECTIVE AEROELASTIC ANALYSIS AND OPTIMIZATION USING SURROGATE MODELS	Alessandra Lunghitano, Frederico Afonso and Afzal Suleman	Universidade de Lisboa

Friday, July 21st

Session 7 - 10:20-11:40

Multi-Disciplinary Optimization III Chair: André Marta, Instituto Superior Técnico				
time	ID	Title	Authors	Affiliation
10:20	30	LEVEL SET TOPOLOGY OPTIMIZATION FOR COUPLING MULTIPHYSICS WITH AUTOMATIC DIFFERENTIATION	Andreas Neofytou and H. Alicia Kim	University of California San Diego
10:40	31	DEVELOPMENT OF A FE CODE FOR ADJOINT-BASED COUPLED AEROSTRUCTURAL OPTIMISATION	Luca Scalia, Rauno Cavallaro and Andrea Cini	Universidad Carlos III de Madrid
11:00	41	DEVELOPMENT OF EFFICIENT NUMERICAL METHODS FOR AERODYNAMIC SHAPE OPTIMIZATION	Sara Pucciarelli, Afzal Suleman and Fernando Lau	Universidade de Lisboa
11:20	45	TOPOLOGY OPTIMIZATION OF ORIGAMI STRUCTURES BASED ON CREASE PATTERN AND AXIAL RIGIDITY	Vincenzo Cretella, Abdolrasoul Sohouli, Alfonso Pagani and Afzal Suleman	Universidade de Lisboa & Politecnico di Torino & University of Victoria

Abstracts

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DIFFERENTIABLE EMBEDDED BOUNDARY METHODS FOR EFFICIENT MULTIDISCIPLINARY DESIGN ANALYSIS AND OPTIMIZATION

Charbel Farhat*[1,2] and Jonathan Ho[3]

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Abstract. *In the context of CFD and fluid-structure interaction (FSI), embedded boundary methods (EBMs) are Eulerian methods that operate on non body-fitted fluid meshes in which discrete representations of obstacle surfaces are embedded. They are attractive for numerous reasons. They introduce such a high degree of automation in the discretization of complex computational fluid domains that they can almost be considered as mesh free methods. They are also the most robust solution methods for flow problems past obstacles that undergo large motions, deformations, shape changes, and/or surface topology changes. Such problems arise in FSI and multidisciplinary design, analysis, and optimization (MDAO). However, EBMs typically generate discrete events that are sources of roughness and spurious oscillations in the flow results computed at an embedded, discrete, boundary surface or in its vicinity. At best, such numerical flaws are sufficiently small not to affect the quality of the computations. However, they inhibit differentiation with respect to any evolutions of the embedded surfaces. Therefore, they hinder the application of EBMs to the gradient-based solution of MDAO problems, where they are however pressingly needed to avoid remeshing and the pitfalls of transferring numerical results from one CFD mesh to another. For this reason, this lecture will present a new approach for constructing discrete-event-free and differentiable EBMs based on a new concept of a nodal status, that of a smoothness indicator nodal function, and a moving least squares approach for suppressing spurious oscillations from integral quantities computed on embedded discrete interfaces. The enabling capabilities of the proposed approach will be demonstrated for complex FSI problems such as limit cycle oscillations of complete fighter jet configurations in the transonic flow regime; and MDAO of aircraft configurations characterized by large shape adjustments and large surface topology changes in various flow regimes.*

Keywords: CFD, fluid-structure interaction, embedded boundary method, gradient-based optimization, limit cycle oscillations, large shape adjustments

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AIRBUS - PIONEERING SUSTAINABLE AEROSPACE

António Teixeira Da Costa

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Abstract. *Airbus is a global aerospace pioneer, operating in the commercial aircraft, helicopter, defence and space sectors. It has built on its strong European heritage to become truly international. It has constantly innovated since its inception, bringing novelties such as the two-crew cockpit, fly-by-wire or composite structures. Looking into the future, the aerospace sector faces a new challenge which is that of sustainable flying. Airbus is embracing this challenge through an industry-wide multi-prong approach that is based upon: fleet renewal with the latest generation aircraft, introducing disruptive technologies, improving the air transport operations and infrastructure, introducing Sustainable Aviation Fuel (SAF), and applying carbon offsetting and capture techniques. The combined effect of these measures is expected to bring the air transport sector to net zero carbon emissions by 2050. From a future aircraft design standpoint, disruptive technologies are being developed across all domains to improve aircraft weight and aerodynamics, as well as developing radically new propulsion systems. Several novel propulsion technologies are entering the testing phase that hold promise for future aircraft applications, such as distributed hybrid propulsion and open fan engines. The energy sources are also being disrupted to remove the need to rely on fossil fuels, with two major pathways emerging, namely SAF that allows up to 85% reduction in carbon emissions across the lifecycle, and hydrogen that could reach up to 100% reduction. These developments can only be brought to life with the intellectual and innovation power of highly skilled professionals, therefore Airbus is actively recruiting the future team members to pioneer sustainable aerospace for a safe and united world.*

Keywords: aerospace, next generation, disruptive technologies, carbon emissions, future aircraft design, sustainable aviation fuel, propulsion technologies

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AEROELASTIC MULTIDISCIPLINARY OPTIMIZATION: ENHANCING AIRCRAFT PERFORMANCE AND SAFETY THROUGH NUMERICAL TOOLS AND EXPERIMENTAL VALIDATION

Sergio Ricci

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Abstract. *Aeroelastic Multidisciplinary Design Optimization (MDO) has emerged as a powerful approach to address the complex design challenges faced in the aerospace industry. The integration of numerical tools such as computational fluid dynamics (CFD) and finite element analysis (FEA), enable engineers to explore a wide range of design variables and constraints efficiently. These tools provide insights into aerodynamic performance, structural integrity, and control system stability, aiding in the identification of optimal or near-optimal designs. While numerical simulations and optimization algorithms provide valuable insights into the behavior and performance of aircraft designs, experimental validation remains crucial to confirm and refine the results but mainly to bridge the gap between simulations and real-world performance. However, this represents a challenge still today due to the complexity and cost of wind tunnel and in-flight testing, together with the safety issues. In recent years, a lot of interest arose around the possibility to perform at affordable cost low speed aeroelastic wind tunnel test. Despite specific phenomena such as the ones related to highly transonic regime cannot be investigated, the low-speed wind tunnel tests can be helpful if used like a design tool, and not just as a verification step. Aiming at this goal, it is necessary to develop a set of dedicated equipments, technologies and ad hoc implemented test strategies. In conclusion, aeroelastic multidisciplinary optimization, supported by numerical tools and experimental validation through wind tunnel testing, appears like a comprehensive framework for designing high-performance and safe aircraft. The integration of these approaches allows engineers to achieve optimal designs that balance aerodynamic performance, structural integrity, and control system stability, ultimately pushing the boundaries of aircraft design in terms of efficiency and safety. Further research in this field holds the potential to revolutionize the aviation industry by delivering advanced aircraft designs with enhanced performance characteristics, helping the zero-emission long term targets. The presentation, after a quick recap on basics concerning aeroelastic MDOs, will present a summary of ten years of aero-servo-elastic testing at large POLIMI's wind tunnel.*

Keywords: fluid-structure interaction, computational fluid dynamics, finite element analysis, optimal design, numerical simulations, wind tunnel testing

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BUILDING BLOCKS TOWARDS ADVANCED THERMOPLASTIC COMPOSITES FOR SUSTAINABLE AVIATION: INTEGRATION OF MATERIAL, PROCESS AND JOINING, DESIGN, VALIDATION, AND MONITORING

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Abstract. *Automated Fiber Placement (AFP) is an automated manufacturing technique that can produce large-scale structural composite parts in a repeatable manner with a high production rate. The AFP technique has been gaining notable attention and importance due to i) the need for producing large-scale/high-volume composite structures such as fuselage and wing skins and ii) enabling simultaneous lay-up and consolidation, thereby leading to a significant reduction in material and labor costs. An AFP machine can have a robotic arm with a fiber placement head or end effector that lays up thermoset, thermoplastic, or dry fiber tows in different orientations, which can be determined in accordance with the loading configurations. Today, mostly carbon fiber-reinforced thermoset-based composite materials are used for manufacturing aerospace structural parts. However, the well-proven shortcomings of thermoset polymers such as limited shelf life, long processing times, relatively low fracture toughness, and poor absorption ability against water and chemicals force the aviation industry to seek for alternative composite material solutions, particularly for new-generation aircraft components. Carbon fiber-reinforced high-performance thermoplastic composites can be regarded as a very competitive alternative to their thermoset-based counterparts due to their following important attributes; high toughness, damage tolerance, unlimited storage life without any need for cold storage, recyclability, high chemical/solvent resistance, and relatively easier processability as they do not entail complex chemical reaction or curing process. Moreover, thermoplastics can readily lend themselves to automated manufacturing processes such as AFP. However, the high-performance thermoplastic composite structures manufactured with the AFP process can only be realized by successful implementations of material selection, process design, joining practices, design, and validation with prototyping for any specific application. Additionally, the fundamental steps of the composite value chain should be followed with continuous inspection considering the service conditions. In this framework, this talk will highlight the steps of the composite value chain for future practices with advanced thermoplastics by addressing the integrated and complementary building blocks of i. material characterization, ii. process design, iii. joining challenges, iv. mechanical characterization with inspections, and v. service life performances. The composite value chain will be evaluated with different case studies. First, the importance of accurate material input to the process design will be pro-*

vided with an improved thermal model considering the degree of intimate contact, degree of bonding, and fiber orientation. Next, the process design practices will be introduced considering the energy efficiency and digital transformation challenges by promoting in-situ consolidation. Moreover, the new opportunities with thermoplastic resin systems for joining technologies will be emphasized in a competitive manner with different welding mechanisms and adhesive joints which become ground for novel multifunctional material solutions to facilitate the joining performance. Then, the new challenges with new materials and processing techniques will be discussed from destructive and non-destructive mechanical characterization perspectives. Finally, the durability of the future material will be reported under harsh service conditions at different processing conditions.

Keywords: composite materials, manufacturing technique, automated fiber placement, large-scale structures, high-volume structures, high-performance thermoplastic

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DISCIPLINARY SURROGATES FOR GRADIENT-BASED OPTIMIZATION OF MULTIDISCIPLINARY SYSTEMS

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Abstract. *Many engineering problems are described by complex multidisciplinary systems, whose behavior is dictated by a non-linear system of equations called multidisciplinary analysis (MDA). When optimizing these systems, the resolution of the MDA at each evaluated design space point often represents a heavy computational burden, particularly when high-fidelity solvers are used. In this work, we address the high computational cost of the MDA by replacing the disciplinary solvers by Gaussian Process (GP) surrogate models. This approach allows to uncouple the disciplinary solvers, similarly to what is done in the Individual Disciplinary Feasible formulation. Moreover, a procedure for the adaptive enrichment of the disciplinary surrogates is proposed to reduce the uncertainty of the surrogates in the explored regions of the design space. The use of GP surrogates further presents the advantage of an analytical gradient computation, which allows for an easy implementation with gradient-based solvers. The performance of the proposed approach has been tested on the analytical benchmark Sellar test case, as well as an aircraft design problem which couples the aerodynamics and structural disciplines. Both test cases show that the proposed approach requires less disciplinary solver calls than classical gradient-based solvers. Finally, the proposed methodology has been integrated in ONERA's WhatsOpt collaborative environment. WhatsOpt generates the OpenMDAO skeleton code, where the implementations of the disciplines can then be plugged into. Thanks to the graphical interface of WhatsOpt, users can easily implement their models and choose the proposed approach to solve the optimization problem.*

Keywords: Multidisciplinary optimization, Gaussian processes, Disciplinary surrogates

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AEROELASTIC ANALYSIS OF HIGH ASPECT RATIO AND STRUT-BRACED WINGS

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Abstract. *High Aspect Ratio (HAR) and Strut-Braced Wings (SBW) configurations represent promising avenues of research for meeting the challenge of reducing aviation carbon emissions. Both high and low fidelity models have already been developed for the above-mentioned configurations as well as for the NASA Common Research Model (CRM) that will serve as a baseline for performance comparisons. These aero-structural models are then implemented within an in-house aeroelastic framework for analysis and optimization. High-fidelity models correspond to a RANS aerodynamic analysis associated to a 3D wingbox finite-elements (FE) analysis. Conversely, low-fidelity models resort to a VLM aerodynamic analysis associated to a 1D beam model FE analysis. The objective of this work is to use the so developed models to perform multidisciplinary optimization in order to assess performance improvements potential at preliminary design stage. Different levels of fidelity were developed with a multifidelity approach in mind for further developments. The use of a multifidelity approach makes it possible to reduce computational costs by mainly resorting to low-fidelity computations and only running high-fidelity computations when necessary. Then, aeroelastic optimization is carried out on a modified version of the CRM wing with a higher aspect ratio to study aerodynamic gains. Afterwards, a SBW configuration, here the PADRI geometry, is examined to evaluate its mass reduction potential in addition to the drag reduction provided by the increased aspect ratio. This work currently focuses on aeroelastic optimization using a single fidelity, but is to be further extended to a multifidelity approach.*

Keywords: High Aspect Ratio (HAR) wings, Strut-Braced wings (SBW), Aeroelasticity, Multidisciplinary Design Analysis and Optimization (MDAO)

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WING STRUCTURAL DESIGN FOR A MAME UAV USING HIGH-FIDELITY NUMERICAL TOOLS

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Abstract. *With the rapid growth of the UAV market, the search for more efficient solutions promotes a huge competitive advantage for manufacturers. With the implementation of optimization techniques and the use of high-fidelity analysis in aircraft design, it is possible to develop better solutions. This work addresses the desire of a leading UAV manufacturer to improve its fleet to remain competitive in the surveillance UAV market. For this, a structural analysis tool using the finite element method is demonstrated, which is then used as part of a structural optimization framework. For this demonstration, static analyses of the wingbox of an existing UAV model, with a CFRP material with different lay-ups in certain areas of the model, are carried out for cruise and 4g load case, obtaining results of deformation and failure of this wing. These results help to identify possible weaknesses of the wing, as well as evaluate how the wingbox structural behaviour changes. The goals of this work include the validation of the numerical design framework using available experimental data and the study of alternative wing structural solutions. The results of the experimental and computational analyses presented slight differences. This was the expected behaviour due to model simplifications, which allowed for the the framework to be validated and proven useful. Three new optimal wingbox solutions were found, having a theoretical mass reduction of about 50%, while respecting a safety factor of 1.5. The first was optimised without displacement constraints and the other two had a maximum allowed displacement. These two differ on the optimization starting point to check for possible local minima, which were found.*

Keywords: optimization, design framework, adjoint method, finite element method, composite materials, fiber orientation

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WING AERODYNAMIC DESIGN FOR A MAME UAV USING HIGH-FIDELITY NUMERICAL TOOLS

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Abstract. *The UAV market is currently very competitive, with the frequent launch of new products and a wide range of solutions already available, forcing manufacturers to explore the design space faster and more efficiently than in the past. A cost effective approach is to develop growth versions, improving an existing product with new technologies and design tools. Some of these tools include high fidelity computational fluid dynamics methods and numerical optimization, which will be used in this work on a numerical design framework to explore the aerodynamic shape optimization of a wing, as part of the development of a growth version of a MAME UAV for a leading Portuguese manufacturer. A comprehensive aerodynamic analysis of the current UAV wing will be performed, followed by an optimization procedure that intends to minimize drag subject to a prescribed lift coefficient constraint. To that end, two different starting geometries for the optimizer will be considered and parameterized with common design variables, including twist and chord distribution, angle of attack, sweep and airfoil shape. Using RANS models, it will be possible to optimize the aerodynamic shape for viscous flow, approximating the reality to a great degree, and new optimized geometries for different sets of design variables will be obtained with a significant drag coefficient reduction from the starting geometry. The optimized geometries will approach an elliptical distribution, although they will not exactly match it, which is to be expected considering the trade-offs needed between skin friction and induced drag. Despite the fact that the results obtained here are not considered the final design, as more shape parametrizations and design variables are yet to be explored in future work, they provided a good insight on how the different parametrizations are handled by the design optimization framework and considerations that should be taken.*

Keywords: Optimization, adjoint method, aircraft design, computational fluid dynamics, free-form deformation, geometric parametrization

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AN UNCERTAINTY QUANTIFICATION METHOD BASED ON PROPER ORTHOGONAL DECOMPOSITION AND POLYNOMIAL CHAOS EXPANSION

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Abstract. *Many industrial processes and product performance are affected by uncertainties that can arise from different factors, such as dimensional tolerances, manufacturing errors, and fluctuations in operating conditions. In engineering design problems, the uncertainties of the design parameters are transferred to the system responses. In these cases it would be better to describe both the parameters and the responses by statistical distributions rather than single deterministic values. To deal with problems affected by several uncertainties and expensive simulation time, e.g. CFD analyses, it is particularly important to develop methodologies that are at the same time accurate and that rely on a limited number of sample evaluations.*
In this paper, we propose an Uncertainty Quantification (UQ) method based on non-intrusive Snapshot Proper Orthogonal Decomposition (POD) Reduced Order Model (ROM) and Polynomial Chaos Expansion (PCE) to efficiently compute the uncertainty propagation on a vectorial field of interest due to uncertain input parameters. The method is applied to the CFD problem of the flow over an airfoil with parameterized uncertain angle of attack and inflow velocity to estimate the uncertainties of the pressure field in each mesh cell.

Keywords: Industrial Design, Proper Orthogonal Decomposition, Reduced Order Model, Uncertainty Quantification, Polynomial Chaos Expansion

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AEROELASTIC OPTIMIZATION OF A CELLULAR FLYING CAR WING USING THOMPSON SAMPLING EFFICIENT MULTIOBJECTIVE OPTIMIZATION (TS-EMO) ALGORITHM

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Abstract *A computational model of a wing with octahedron cellular internal structure designated for a flying car has been proposed. The wing model is subjected to variation by around 20 aerodynamic and structural design variables. The objective is to find the best combinations of design variables that maximize the aerodynamic performance and minimize the structural weight, subjected to maximum allowable stress, and static and dynamic aeroelastic instability constraints, including divergence and flutter speeds. The lifting-line theory for low-speed subsonic flight has been adopted as the aerodynamic model, while the structural and aeroelastic properties were calculated using finite element (FEM) software package MSC Nastran. By incorporating the aerodynamic, structural and aeroelastic simulations with an algorithm called Thompson Sampling Efficient Multiobjective Optimization (TS-EMO) developed by E. Bradford et. al.* [1]*, a two-dimensional Pareto front depicted by several points demonstrating the compromisation between aerodynamic and structural weight has been obtained. The combinations of design variables behind these points provide Pareto-optimal design ideas of the flying car wing. It is anticipated that the Pareto-optimal designs could provide ideas about how a structurally optimal geometry of octahedron cells should look. Similar design and optimization methods might be implemented to other novel designs of wing internal structures.*

Keywords: Thompson Sampling Efficient Multiobjective Optimization (TS-EMO); cellular structured wings; multiobjective optimization (MOO); multidisciplinary optimization (MDO); flying cars

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A PRELIMINARY LOW-FIDELITY MDO APPROACH FOR LOAD ALLEVIATION THROUGH MOVABLES ON HAR WING

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Abstract. *As part of the current efforts targeting further development on cleaner and more efficient aviation, this study proposes a new MDO approach for an optimized High Aspect Ratio (HAR) wing weight using a load alleviation. Load Alleviation Function (LAF) aims at diminishing the peak wing bending moment due to a manoeuvre or a gust by redistributing the lift to a more inboard position on the wing using movables to decrease the overall wing weight. Nowadays, movables are exclusively designed to master the control of the aircraft, and LAF takes advantage of these control surfaces characteristics despite not being designed for it. The challenge of LAF tuning on a HAR will come from the high wing deformation. So this study aims to address the handling qualities (HQ) and LAF aspects in an optimization process of the control surfaces positioning, actuators power, sizes and deflections covering both disciplines, with a wing weight reduction intent. The challenges faced within the project reside in the couplings of the numerous disciplines present in the overall aircraft design: aerodynamics, loads, static aeroelasticity (movable control reversal), HQ, stress, and mass. A highlight will be made on the aerodynamic and loads disciplines, as current MDO publications do not consider a broad number of load cases and flight points with the right coverage of the sub-loads disciplines (such as gust and its aerodynamic specificities), which are crucial in the ranking of different designs, and crucial in the assessment of its feasibility, and finally for certification. This study aims to define the MDO framework by identifying the right compromise between disciplines and fidelities whilst preserving the computational resources. In the first stages, the project focuses on the lower-fidelity approaches through open-source means to verify its feasibility and compile the requirements, targeting to include multi-fidelity approaches at future stages of the research project.*

Keywords: Load Alleviation Function, Multidisciplinary Design Optimization, Multi-fidelity, Handling Quality, Aircraft Control, High Aspect Ratio, Aeroelasticity, Loads

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FROM MDO TO MANUFACTURING: APPLICATION CASE FOR UNMANNED AERIAL VEHICLES

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Abstract. *This paper explores the concept of coupling an MDO problem directly to a manufacturing process. The design parameters required for various disciplinary analyses are used to automatically generate geometries that comply with the selected manufacturing processes. Such geometries are then manufactured to validate our proposal. This strategy reduces the manufacturing time of unmanned aerial vehicles (UAVs) as the CAD modeling becomes automatic and parametric, also allowing for easier comparison of different geometries. It can also potentially improve the MDO process by closing the information loop with manufacturing constraints. We employ the Engineering Sketch Pad (ESP) and leverage from additive manufacturing techniques usually applied in UAVs. The choice of ESP facilitates reproducibility, as it is an operating system agnostic open source CAD, and gradient based optimization, due to its capability of computing gradients of the geometric outputs with respect to the design parameters. The manufacturing processes of wings and propellers are addressed. For the same representative wing geometry, we present different modeling strategies for mass and inertia prediction and for manufacturing using 3D printing. ESP is also employed to predict wing mass and inertia. The maximum difference in weight between the manufactured wing and its predicted value using ESP is roughly 7%. The propeller is 3D printed in resin with stereolithography (SLA) technique, and is defined by means of its airfoils, radius, and chord and twist angle distributions. We conclude about the applicability of the presented strategy, as well as its potential and limitations. All the scripts are shared with the community so researchers can apply it to validate their own MDO problem.*

Keywords: Additive Manufacturing, MDO of UAVs, UAV design and manufacturing

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MULTI-OBJECTIVE BAYESIAN OPTIMIZATION WITH MIXED-CATEGORICAL DESIGN VARIABLES FOR EXPENSIVE-TO-EVALUATE AERONAUTICAL APPLICATIONS

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Abstract. *This work aims at developing new methodologies to optimize computational costly complex systems (e.g., aeronautical engineering systems). The proposed surrogate-based method (often called Bayesian optimization) uses adaptive sampling to promote a trade-off between exploration and exploitation. Our in-house implementation, called SEGOMOE, handles a high number of design variables (continuous, discrete or categorical) and nonlinearities by combining mixtures of experts for the objective and/or the constraints. Additionally, the method handles multi-objective optimization settings, as it allows the construction of accurate Pareto fronts with a minimal number of function evaluations. Different infill criteria have been implemented to handle multiple objectives with or without constraints. The effectiveness of the proposed method was tested on practical aeronautical applications within the context of the European Project AGILE 4.0 and*

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AN EXPLORATORY STUDY OF OPEN-SOURCE FRAMEWORKS FOR MDAO

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Abstract. *Multidisciplinary Design Analysis and Optimization (MDAO) is a key methodology used by engineers and researchers to explore and optimize engineering systems composed of multiple disciplines and couplings. The techniques of this field are particularly relevant for designing complex systems such as aeronautical systems. Today MDAO is adopted worldwide and several open-source tools are available. Although the underlying features are standard, these tools differ for some typical features, such as numerical methods, visualization tools or available integrated/external optimizers. Choosing among these tools for a given engineering application is not straightforward. This article focuses on three frameworks that arise from different environments and respond to different needs: OpenMDAO, GEMSEO, CoSApp. A study case is first proposed as a reference problem and then analyzed. The three MDAO architectures implemented (MDF, IDF and NVH) show a similar range of performance. Thus the need to test the frameworks on a more complex problem to obtain more discriminating results and specific features is highlighted. After a brief presentation of the three frameworks, several quantitative criteria are computed, such as the lines of code required to define the multidisciplinary optimization problem on the three platforms and the performance of the solving process. In addition, qualitative criteria concerning the reconfiguration of the MDO process and the problem visualization are assessed.*

Keywords: MDAO, design optimization, system analysis, aeronautical systems

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AN ARBITRARY LAGRANGIAN-EULARIAN ALGORITHM TO SOLVE COMPRESSIBLE FLOW PROBLEMS: HEMLAB ALE

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Abstract. *Capabilities of In-house HEMLAB solver is extended by implementing an ALE approach to solve rigid grid motion and is employed to asses the hover performance of S-76 main rotor. In the study, firstly, we verified our algorithm on baseline cases proposed under HiOCFD4 workshop. Then, we performed Euler simulations of S-76 main rotor with swept-tapered tip. Since the rotor problems requires high resolution grids, adaptive mesh refinement is exploited in the study. pyAMG anisotropic metric mesh adaptation library was integrated to HEMLAB previously to do mesh refinement. In the study the capabilities of HEMLAB solver is further tested on such a complex flow physics.*

Keywords: FVM, ALE, Rotor simulation, Adaptive Mesh Refinement (AMR)

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INTEGRATION OF LIFE CYCLE ASSESSMENT METHODOLOGY AS AN ENVIRONMENT DISCIPLINE MODULE IN MULTIDISCIPLINARY ANALYSIS AND OPTIMIZATION FRAMEWORK

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Abstract. *As sustainability becomes one of the main challenges of the aerospace industry, we need to find new ways to integrate it into the design phase of aerospace systems. The Multidisciplinary Analysis and Optimization (MDAO) framework is a great host for an environmental discipline thanks to its modularity. However current Life Cycle Assessment (LCA) software do not integrate well with other computation tools, and are designed for low amounts of simulations on massive databases, while MDAO requires often many iterations with only slight variations. This work presents newly developed tools aiming at bridging those two valuable methods to enable better use of LCA within MDAO. Symbolic links between classic design variables and associated LCA parameter, python-based tools compatible with* `OpenMDAO`*, and optimization of the LCA algorithms to allow for multiple runs on variations of the same overall system makes it possible to integrate LCA considerations inside an MDAO model at reduced performance cost. The resulting framework makes ecodesign more accessible as environmental impacts can be used inside the design process, possibly as main objectives or constraints.*

Keywords: environment, life cycle, sustainability, multidisciplinary, ecodesign

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FIXED-WING UAV MODEL IDENTIFICATION FOR LONGITUDINAL MOTION USING FIRST-ORDER MODELS AND LIMITED FLIGHT TESTING

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Abstract. *System identification plays an important role in the determination of an aircraft behaviour that helps predict and simulate different scenarios crucial for control, mission or safety assurance analysis. This work describes the system identification process of a medium sized UAV through the usage of limited flight test data and a non-linear model dynamic simulator. The proposed solution uses parameter based first-order models to describe the various aerodynamic properties of the UAV. The parameter estimation is based on a least square error optimization algorithm in a time-domain formulation starting from a low-fidelity aerodynamic analysis solution. The work focuses on the longitudinal motion by using routine flight test data of pitch down and pitch up manoeuvres to excite the longitudinal dynamics. The optimization geared towards parameter tuning used a combination of pitch and altitude UAV model response as measure of accuracy. Very significant improvements in the UAV model response are obtained with the resulting optimizer found relevant longitudinal aerodynamic and control derivatives. The pitching moment derivatives proved to be the most important parameters, as expected. The process hereby described is meant to be usable on any fixed-wing UAV with limited planned flight test data achieving reasonable accuracy.*

Keywords: aircraft design, optimization, aerospace, system identification, aircraft dynamics

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THERMO-MECHANICAL LEVEL-SET TOPOLOGY OPTIMIZATION OF A LOAD CARRYING BATTERY PACK FOR ELECTRIC AIRCRAFT

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Abstract. *A persistent challenge with the development of electric vertical take-off and landing vehicles (eVTOL) to meet flight power and energy demands is the mass of the load and thermal management systems for batteries. One possible strategy to overcome this problem is to employ optimization techniques to obtain a lightweight battery pack while satisfying structural and thermal requirements. In this work, a structural battery pack with high-energy-density cylindrical cells is optimized using the level-set topology optimization method. The heat generated by the batteries is predicted using a high-fidelity electrochemical model for a given eVTOL flight profile. The worst-case scenario for the battery's heat generation is then considered as a source term in the weakly coupled steady-state thermo-mechanical finite element model used for optimization. The objective of the optimization problem is to minimize the weighted sum of thermal compliance and structural compliance subjected to a volume constraint. The methodology is demonstrated with numerical examples for different sets of weights. The optimized results due to different weights are compared, discussed, and evaluated with thermal and structural performance indicators. The optimized pack topologies are subjected to a transient thermal finite element analysis to assess the battery pack's thermal response.*

Keywords: Multiphysics topology optimization, level-set method, structural battery pack, electrochemical model, electric vehicles

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DESIGN OPTIMIZATION AND HUMAN SUBJECT SHAKER TESTING OF AN ACTIVE HELICOPTER SEAT MOUNT SYSTEM

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Abstract *Helicopter aircrew are exposed to high levels of Whole-Body Vibration (WBV) in fight operations, which may degrade their ride comfort and performance in the short-term, and contribute to adverse health issues in the long-term. The patented active seat mount technology presented in this paper was developed to reduce the whole-body vibration of the helicopter aircrew through active cancellation of the N/rev vibration peaks related to the helicopter main rotor speed. The latest development of the active seat mount technology included structural redesign for integration into the helicopter cabin and extensive control law tuning tests conducted on a shaker table with human subjects in order to verify and validate the performance, reliability and safety of system prior to flight tests. The shaker test results demonstrated that the redesigned active seat mount achieved significant reduction of the occupant WBV levels at the bottom seat cushion interface per ISO2631-1 metrics and also reduced the occupant head vibrations simultaneously. The promising results demonstrate that the active seat mount is capable of improving the ride quality of the Bell-412 helicopter in representative flight conditions and mitigating adverse long-term health issues of the helicopter pilots.*

Keywords: helicopter vibration, active seat mount, aircrew whole-body vibration, adaptive vibration control, shaker testing, Bell-412 helicopter

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NEURAL LEVEL SET TOPOLOGY OPTIMIZATION USING UNFITTED FINITE ELEMENTS

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Abstract. *To facilitate widespread adoption of automated engineering design techniques, existing methods must become more efficient and generalizable. In the field of topology optimization, this requires the coupling of modern optimization methods with solvers capable of handling arbitrary problems. In this work, a topology optimization method for general multiphysics problems is presented. We leverage a convolutional neural parameterization of a level set for a description of the geometry and use this in an unfitted finite element method that is differentiable with respect to the level set everywhere in the domain. We construct the parameter to objective map in such a way that the gradient can be computed entirely by automatic differentiation at roughly the cost of an objective function evaluation. The method produces optimized topologies that are similar in performance yet exhibit greater regularity than baseline approaches on standard benchmarks whilst having the ability to solve a more general class of problems, e.g., interface-coupled multiphysics.*

Keywords: neural, unfitted, level set, topology optimization

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ADAPTIVE AIRBAG SYSTEMS FOR PROTECTION OF GENERAL AVIATION

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Abstract *The contribution describes three innovative external airbag systems developed by the authors for the protection of flying objects during emergency landings. The first one is the AdBag system dedicated for small drones, which is designed to protect the carried equipment and prevent damages to objects or injuries to people at the crash location. The second system is external airbag designed for ultralight aircraft Skyleader 600, which provides significant reduction of touchdown velocity and deceleration levels during emergency landings, thereby improving protection of the pilot and the passengers. Finally, the last presented solution is the Spring-Drop system with specialized airbag deployment technique, which is dedicated for specialised airdrop operations where the touchdown conditions can be extremely harsh and unexpected, while protection of transported cargo is of crucial importance. Both conceptual studies, numerical simulations and experimental tests of the three proposed systems are presented and discussed.*

Keywords: External airbags, adaptive system, emergency landing, human safety

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TOPOLOGY OPTIMIZATION OF A SOLID GRAIN HYBRID ROCKET LAUNCHER

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Abstract. *To reduce the environmental impact of conventional rocket fuels a hybrid fuel combining a liquid oxidizer and a solid grain is being considered. However, this solution increases the complexity of the combustion process when compared to solid or liquid options. Thus, to obtain a fuel that simultaneously minimizes the environmental impact while providing the highest performance possible a Multidisciplinary Design Optimization (MDO) problem should be stated. We propose to develop a MDO framework that couples topology optimization to design the solid grain geometry considering manufacturing constraints with a propulsion model to predict the specific impulse generated. In the end, a multi-objective function comprising structural and performance goals is established.*

Keywords: Topology optimization, hybrid propulsion, multidisciplinary design optimization, rocket launcher

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SKY SAILING OF TETHERED AEROSTATS FOR EFFICIENT AERIAL MONITORING

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Abstract *This contribution introduces the concept of sky sailing, which combines the advantages of airships and standard fixed-wing aircraft, albeit in a vertical plane alignment. The proposed vehicle is equipped with rigid aerodynamic sails and auxiliary engines, enabling navigation and control with minimal power consumption along the desired trajectory. The proper orientation of the airship relative to the wind direction is achieved through the adjustment of the sails' angle of attack and the use of auxiliary lateral engines. Consequently, the system enables efficient maneuvering, particularly in windy conditions, while requiring low energy input. In the current stage of our research, we focus on 2D sky sailing in a horizontal plane. This study formulates mathematical model which employs a combined approach of analytical methods and numerical simulations based on finite volume method. Then, the corresponding control problem aimed at following the desired fly path with the lowest possible energetic cost. The motivation behind this work stems from the potential applications of aerial monitoring, such as crop or forest surveillance.*

Keywords: Airship, flight control, optimization, aerospace

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LEVEL SET TOPOLOGY OPTIMIZATION WITH AUTOMATIC DIFFERENTIATION

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Abstract. *Automatic differentiation is implemented in level set topology optimization. The modularized LSTO architecture used here allows for the combination of the classical level set method with automatic differentiation. Stress minimization is used to conduct a comparative study in the computational efficiency, memory requirements and their effects on scaling of different operator overloading AD libraries. Then, the sparsity of the level set method in combination with a hybrid AD mode is employed to improve the efficiency and memory consumption of the operator overloading technique in automatic differentiation.*

Keywords: Level set topology optimization (LSTO), automatic differentiation (AD), operator overloading (OO), sparsity, hybrid implementation

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DEVELOPMENT OF A FE CODE FOR ADJOINT-BASED COUPLED AEROSTRUCTURAL OPTIMISATION

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Abstract. *With the current environmental challenges, there is a relevant pressure on the aeronautical sector towards more sustainable aircraft. As a consequence, both new design methodologies and unconventional aircraft layouts are under investigation. Optimisation considering the strong coupling between different disciplines is becoming a paradigm to support new efficient designs. In this paper, an existing framework to carry out high-fidelity aerodynamic/structural optimisation is enhanced with the development of a structural solver. The framework is modular, and uses algorithmic differentiation to provide discrete-exact adjoints. The structural solver is being developed to tackle large-scale problems, providing responses that can be used as objectives and/or constraints in the optimisation, and maintaining the framework requirements on modularity and sensitivity evaluation. Preliminary capabilities of the structural solver in a purely structural optimisation, or within an aerostructural optimisation are proved.*

Keywords: Aerostructural optimisation, adjoint method, algorithmic differentiation, finite element method, aerospace, new generation wings, highly flexible wings

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DESIGN OPTIMIZATION OF TRUSS STRUCTURES USING A NON- UNIFORM CELLULAR AUTOMATA PARADIGM

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Abstract *The conventional uniform Cellular Automata (CA) approach requires identical uniform cells (all cells must have the same number of neighbouring nodes) for design optimization of truss structures. As in CA every node of a truss structure represents a cell (one-to-one relationship between nodes and cells), conventional CA has difficulties to address nodes located on the boundaries and also to consider the position of the nodes as design variable for layout optimization. In this study, a modified non-uniform Cellular Automata (CA) algorithm for the optimal topology, sizing, and layout design of truss structures has been proposed. The proposed approach builds upon the success of our previous study that utilized non-uniform CA for a sizing and topology optimization of truss structures under stress and displacement constraints. Specifically, the new algorithm incorporates the Fully Stressed Design (FSD) method and the distribution of strain energy to identify optimal cell coordinates. By considering simultaneous sizing, topology and layout optimization, the proposed non-uniform CA algorithm can effectively minimize the weight of truss structures subjected to displacement and stress constraints. The efficacy and accuracy of this approach are demonstrated through its successful application to various benchmark truss design problems.*

Keywords: Non-uniform Cellular Automata, Sizing, topology and layout Design Optimization, Truss Structures, Stress and Displacement Constraints

1. INTRODUCTION

Optimizing truss structures involves finding the best connection, member sizes, and shape to minimize weight and cost while improving strength and stability. Various methods, including mathematical programming, convex approximation, fully stressed design (FSD), and metaheuristic techniques, have been used to optimize sizing and layout variables. Single-level methods simultaneously consider these variables, while bi-level methods solve for joint coordinates and cross-sectional areas separately. The present study proposes a non-uniform cellular automata (CA) algorithm for truss optimization that minimizes strain energy and redistributes it evenly within the structure. Cross-sectional areas and node coordinates are optimized separately using the FSD approach in conjunction with a strain energy criterion. An alternating procedure couples these variables until the optimal solution is found.

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OPTIMAL MULTI-SENSOR OBSTACLE DETECTION SYSTEM FOR SMALL FIXED-WING UAV

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Abstract. *This work provides a solution for the safety enhancement of small fixed-wing UAVs regarding obstacle detection during flight. The main goal is to implement an optimal multi-sensor system configuration. To achieve it, preceding works regarding the integration of available sensors in such systems were studied. As a result, select sensors (ultrasonic sensor, laser rangefinder, LIDAR and RADAR) were modeled for collision detection and avoidance simulations using the potential fields method. An optimization study using a genetic algorithm was conducted to find the sets of sensors and respective orientation that result in the best collision avoidance performance. To do so, a set of randomly generated collision scenarios with both stationary and moving obstacles were generated. This study resulted in relatively simple detection configurations that still provided high collision avoidance success rate. The ultrasonic sensor revealed to be inappropriate given its short range, while the laser rangefinder benefited from long range but had very limited field-of-view. In contrast, both the LIDAR and the RADAR are the most promising, as they exhibit not only a significant range but also a broad field-of-view. The best multi-sensor configurations were either a front-facing LIDAR or RADAR, complimented by a pair of laser rangefinders pointing sideways at an angle of 10 or 63 degrees, respectively. Once the hardware that should integrate an optimal system was known and available, the assembly of the final system, including the sensors and a PixHawk flight controller, was designed. The appropriate software (PX4 and QGroundControl) was also built and adapted to the current work. To validate the proposed system, all sensors were first individually tested before assembling the complete system. The bench tests attested the accuracy of the sensor specifications and previous simulations. As such, ground tests using a simple rover shall follow. Once the system is validated under these conditions, flight tests may begin.*

Keywords: Sense and avoidance, collision avoidance, sensor fusion, optimization, laser rangefinder, LIDAR

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SOFTWARE SUBSYSTEM AS A NEW CONCEPT IN SATELLITE SYSTEM ARCHITECTURE

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Abstract. *Satellite systems increasingly rely on software in order to deliver the intended functionality. While the reliance on software has enabled the miniaturization of space systems, as well as improved performance in various technologies such as image processing or telecommunications, it has also brought up some issues in reconciling hardware and software architecture. As an approach for better integration of hardware and software architectures in modern space systems, we argue that some software modules should be considered independent at the first level of the hierarchical system decomposition. We argue that such software modules are not contained within a more abstract entity featuring hardware and software, which we would typically call a "subsystem". Rather, it is a "software subsystem" which can be developed separately from the processing platform including the devices (sensors, actuators, external memory, etc.) and the processor on which it is deployed, and can be deployed to one or more processing platforms whose hardware, firmware and other software components may be developed by separate contractors. We demonstrate the feasibility of this approach through a case study using a software-intensive university CubeSat. We show that this approach allowed for extensive code reuse, simplified the implementation of subsystem interfaces, and enabled better engineering solutions through increased specialization during the design phase. We also discuss some limitations of the approach, such as increased software overhead and integration issues with off-the-shelf subsystems. We conclude that the concept of abstracted software subsystems can contribute to better satellite system performance by allowing further software specialization in an industry which has traditionally been conservative in this domain.*

Keywords: Satellite, Software, Architecture

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VALIDATION OF EXTENDED FAILURE MODELS AND CRITERIA FOR AEROSPACE COMPOSITES

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Abstract. *In the aerospace sector, to cope with the most recent sustainability goals, aerostructures will need to be designed and built by using advanced materials with unprecedented efficiency. Furthermore, performance-based certification using virtual qualification and certification tools is expected to become widely applied. In this context, research in advanced composite materials and their failure analysis plays a crucial role for optimization of aerostructures. As part of the European Industrial Doctorate (EID) OptiMACS, focussed on the development and application of new methods and criteria for multidisciplinary optimization of aerospace composite structures, advanced failure criteria and damage models have been extended to more general stress states, and validated. They include advanced phenomenological failure models based on invariant structural tensors for first-ply failure (FPF) "hot-spot" analysis considering general three-dimensional (3D) stress states. The 3D invariant-based criteria are then used to generate "omni strain" failure envelopes that enable quick last-ply failure (LPF) analysis of multidirectional composite structures, showing a satisfactory agreement with experimental data under complex triaxial stress states. It is, therefore, demonstrated that "omni strain" failure envelopes provide reliable and fast laminate failure analyses that can be particularly useful during conceptual and preliminary design. Finally, the 3D invariant-based criteria are coupled with continuum damage mechanics to model damage onset and propagation, and validated through virtual testing of undisturbed and notched coupons. Application of the continuum damage mechanics model is demonstrated through a local model of the bolted connection of a stringer runout, confirming the accuracy of these analyses in the context of detailed design.*

Keywords: Design, failure, polymer-matrix composites (PMCs), aerospace

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STRESS-BASED SPATIAL GRADIENT RECONSTRUCTION FOR SHAPE SENSITIVITY ANALYSIS

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Abstract. *Continuum Sensitivity Analysis (CSA) is an approach for calculating analytic design derivatives. Spatial derivatives of the response, at least on the boundary, are needed to formulate CSA for* shape design variables *that alter the shape of a structure. Inaccurate spatial derivatives on the boundaries has historically hampered the use of the so-called* boundary velocity *form of shape CSA. Spatial Gradient Reconstruction (SGR) has proven to be a remedy for inaccurate spatial derivatives of structural response, at least for displacements and their derivatives; however, SGR for stresses on the boundary where surface tractions may be applied, continues to be problematic. Here stress-based SGR, used in the literature for stress error estimation, is developed for shape CSA. Stress-based SGR with and without enforcement of traction boundary conditions are compared with stresses and stress gradients recovered from displacement-based SGR. Traction enforcement, together with equilibrium constraints, is found here to improve stress-based SGR, making it more accurate than without traction enforcement and more accurate than stress gradients recovered from displacement-based SGR.*

Keywords: continuum sensitivity, shape derivatives, sensitivity analysis, two-and three-dimensional structural analysis, nonintrusive

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EXPLORING THE POTENTIAL OF DEEP LEARNING IN OPTIMIZING AN AERIAL PHOTOGRAMMETRY MISSION

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Abstract. *In this paper, we investigate how deep learning can improve different parts of aerial photogrammetry. We focus on creating flexible waypoints on-the-fly (Next Best View planning) and dealing with challenges when working with multiple drones. By checking if real-time adaptive waypoint generation for drone navigation is possible and exploring issues in multi-drone systems like task assignment and formation changes, we hope to find ways that deep learning neural networks can enhance aerial photogrammetry, ultimately making data collection more efficient and accurate, and moving the field forward.*

Keywords: Uncrewed Aerial Vehicles (UAVs), Aerial Photogrammetry, Deep Reinforcement Learning, Next Best View Planning, Multi-Agent Systems, Proximal Policy Optimization

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COMPUTATIONAL CHALLENGES IN THE MODULAR DESIGN OF FUTURE AIRCRAFT CONCEPTS WITH FLUTTER CONSTRAINTS

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Abstract. *An approach to integrate flutter constraints in an existing environment for aircraft design optimization is discussed, together with a methodology to generate parametric models of varying fidelities that is used to underpin the development. Geometrically nonlinear effects in the aeroelastic response are included in the analysis and the approach blends medium fidelity aerodynamic models with CFD data using a novel infrastructure based on parametric ROMs and sectional polars reconstruction. A strut-braced wing aircraft designed without stability constraints is shown to undergo a strut-driven instability and possible solutions are assessed. Lastly, the developed multidisciplinary tools are deployed in a proof-of-concept of optimization with flutter constraints.*

Keywords: design optimization, aeroelasticity, high-aspect-ratio wings, bi-level MDO formulation

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DEVELOPMENT OF COMPUTATIONAL AEROELASTIC ANALYSIS TOOLS AND UNCERTAINTY QUANTIFICATION TECHNIQUES FOR RELIABLE FLUTTER PREDICTION

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Abstract *In this presentation, the development of an OpenFOAM based CFD-CSD solver and its application for Uncertainty Quantification (UQ) of flutter predictions is described. In particular, a coupled compressible solver based on the construction of convective and viscous flux Jacobians is developed, and the Lower-Upper Symmetric Gauss-Seidel algorithm is implemented to solve the resultant matrix. This aerodynamic solver is then coupled with a six DoF structural dynamics solver to form an aeroelastic analysis tool. The simulation results obtained from this aeroelastic tool are then employed to construct a surrogate model using the Gaussian Process (GP) approach. Combined with an error-informed and efficient sampling strategy, the developed UQ framework is applied on the benchmark problem of Isogai 2D NACA 64A010 airfoil. It is shown that the developed framework is more efficient and much faster than the conventional approach in detecting the flutter boundary while providing a probabilistic error estimate of the results.* .

Keywords: Uncertainty Quantification, Gaussian Process, coupled compressible solver, flux Jacobian, Lower-Upper Symmetric Gauss-Seidel

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THE DEVELOPMENT OF EFFICIENT NUMERICAL METHODS FOR AERODYNMIC SHAPE OPTIMIZATION

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Abstract. *The current trend in the aeronautical industry is pushing into an increasing efficiency of the aircraft through all phases of the mission with a consequent reduction on the pollution impact. Morphing architectures address those requests by adapting the aircraft shape in order to ideally fly in optimum condition. Optimizing those shapes is highly complex since it requires a trade-off among different objectives and constraints. Moreover the optimization process requires a several number of real-time iterations, therefore the computational expensive gradient-based optimization coupled with the adjoint method is unusable. To address the iterative demand, these authors will present a data-based approach to perform the aerodynamic analysis and optimization of a morphing airfoil in a wide range of Reynolds, angle of attack (AOA) and Mach. The main objective of this work is building an iterative surrogate model that can be used in the MACH-Aero framework despite of the more expensive default solver (ADflow). Surrogates models, for example artificial neural network, relies heavily on data and this can be used in order to compute the aerodynamic coefficients without solving the governing equations. Therefore the authors have created a dataset of thousands of high-reliable computational fluid dynamics (CFD) simulations with the purpose of training a multi-layer perceptron network from subsonic range up to the transonic one. In the first instance, the optimization will be focused on those regimes since they characterize the flight mission profile of a common civil aircraft. Once the network is trained, it returns as output the lift, drag and pitch coefficients.*
Hence hundreds of airfoil shapes are collected from the University of Illinois at Urbana-Champaign (UIUC) database and the supercritical airfoils database by NASA. In order to create a representative dataset, we have validated the samples taking as reference the NACA0012 experimental results, collecting a percentual error of 3% on the drag coefficient. Based on those residuals, thousands of simulations have been run for several Mach, AOA and Re. Since only Python scripts have been used (such as PyHpy for the meshing, Prefoil for the space sampling, PyOptSparse for the optimization algoritms), a pipeline has been created in order to automatize the creation of the dataset. In conclusion this work tried to explore the potential of data-driven approaches in optimizing the shape and performance of morphing airfoils, contributing to the continuous pursuit of enhanced aircraft efficiency and reduced environmental impact.

Keywords: Aerodynamic shape optimization, machine learning , morphing architectures, design, , aerospace.

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INTEGRATION OF A THERMAL MANAGEMENT SYSTEM IN A HYBRID ELECTRIC AIRCRAFT – FUTPRINT50

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Abstract *Hybrid-electric aircraft (HEA) are one of the approaches currently under study by the industry to reduce emissions and tackle climate change. The use of batteries and high-power electrical equipment in such aeroplanes poses new challenges that are not usually found in conventional gas-turbine vehicles, such as the necessity of thermal management systems (TMS). In this paper, one of these systems is developed and integrated to the 50 passenger HEA developed in the scope of Futprint50.aximum 300 words).*

Keywords: Thermal management, hybrid-electric aircraft.

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A SYSTEM-BASED APPROACH FOR TECHNOLOGY ROADMAPPING ASSISTED BY INTERACTIVE VISUALISATION

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Abstract. *System analysis is necessary to identify and characterise the emerging behaviour of multiple components, or sub-systems, synthesised together to fulfill a new function. Although this is well known, it is hugely important to consider a system-based approach for the exploration and understanding of the behaviour of new technology in existing and mature systems. One example is the introduction of a considerable amount of energy storage in the form of batteries in conventional aircraft configurations. We would like to identify how such technology influences the behaviour of the aircraft but also what is the required level of performance of this technology for any meaningful impact on the environmental targets. We performed such analysis using an open case study of a regional aircraft and open models for the simulation of battery behaviour, the design space exploration, and the interactive visualisation of multidimensional data. The results show that considerable advancements are required in all three key aspects of batteries, energy density, durability, and safety. In this study, we have quantified the required energy density above which meaningful trade-off analyses can be performed and such characteristics provide input to technology roadmaps.*

Keywords: interactive visualisation, technology roadmap, aircraft energy storage, design space exploration

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MULTI-OBJECTIVE AEROELASTIC ANALYSIS AND OPTIMIZATION USING SURROGATE MODELS

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Abstract *Aeroelastic analysis plays a crucial role in the design and evaluation of aircraft structures, ensuring their structural integrity and dynamic stability under aerodynamic loads. However, conducting detailed aeroelastic simulations using high-fidelity computational methods can be computationally expensive. This paper proposes a novel approach to reduce the computational cost of aeroelastic analysis through the use of surrogate modelling techniques based on machine learning. Surrogate models act as efficient approximations of the complex aeroelastic simulations, providing accurate predictions of critical parameters while significantly reducing the computational cost. The Goland wing configuration is utilized as a test case, and aeroelastic simulations are performed using the SHARPy framework, an open-source Python tool developed by Imperial College London, to generate the dataset required for surrogate model training. The trained surrogate regression models are capable of predicting important aeroelastic quantities, including flutter speed, mass, and lift and drag coefficients. Moreover, a multi-objective optimization framework is employed to maximize the lift-to-drag ratio and minimize the structural mass while considering a flutter constraint, improving the effectiveness of the preliminary design process.*

Keywords: multidisciplinary, design, optimization, aerospace, aeroelastic, surrogate, multi-objective

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TOPOLOGY OPTIMIZATION OF ORIGAMI STRUCTURES BASED ON CREASE PATTERN AND AXIAL RIGIDITY

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Abstract. *Origami structures present desirable stowage properties for application in deployable space structures. The present work proposes a design method for origami structures using topology optimization to find the axial rigidity distribution of the trusses and the crease pattern that maximizes the displacement at set locations under prescribed forces and boundary conditions. In the first part, a linear truss method is used to determine small strain and small rotation mechanics of flexible origami, functional to study their behavior at the initiation of folding. Subsequently, a modified nonlinear truss method is implemented to consider large displacement and large rotation mechanics. To carry out the optimization process, constraints on the number of fold lines and on the material distribution are applied. Previous studies on topology optimization of origami structures have considered only folding and bending in their analyses. Here, it is shown that including also the axial rigidity as a design variable leads to new promising origami designs.*

Keywords: Topology optimization; Origami structures; Linear analysis; Nonlinear analysis; Truss method.