



17th World Congress on
Computational Mechanics (WCCM)
and 10th European Congress on
Computational Methods in Applied
Sciences and Engineering
(ECCOMAS)
19 - 24 July 2026, Munich, Germany

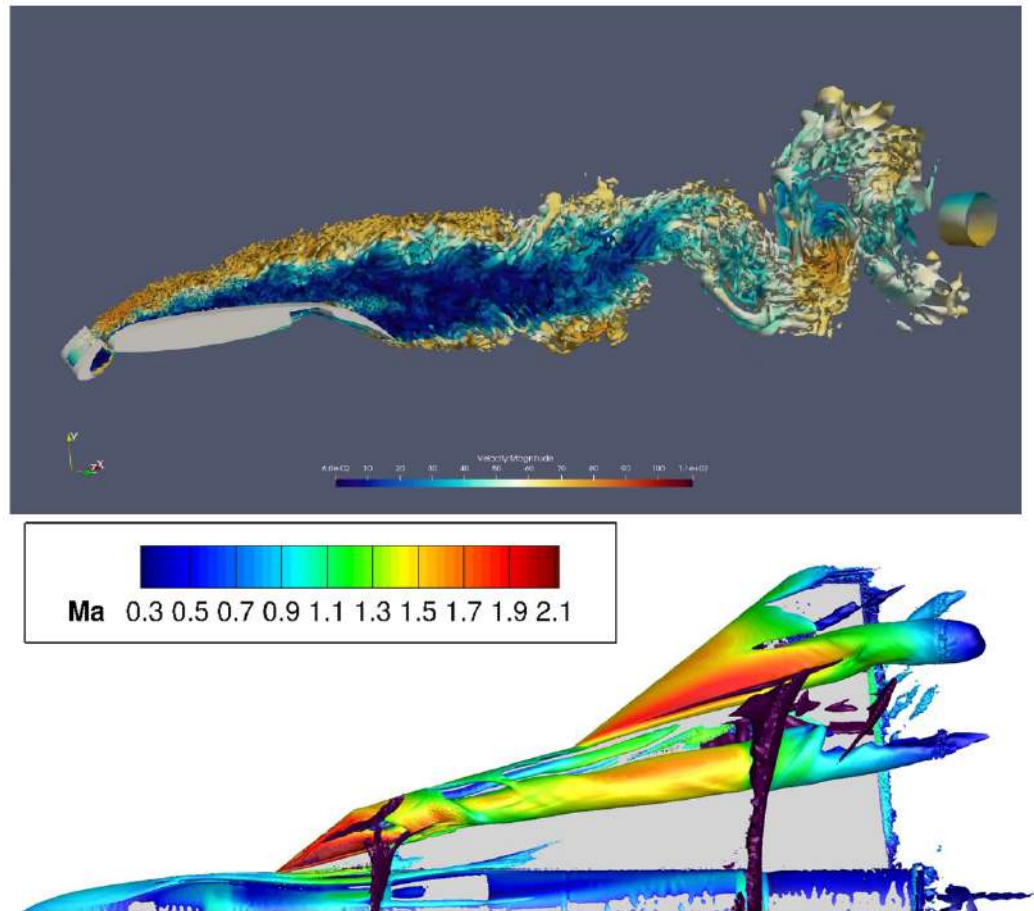
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*Green and Digital Technologies for
Climate, Energy and Transport Challenges
Special Technology Sessions – Book of Abstracts*



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Cover Figure 1:

STS 422-14 Numerical Simulation of Realistic Aeronautical Configurations Using a ^[1]Coupled Lattice-Boltzmann - Immersed Boundary Solver - R. Jaeger, I. Cheylan, J. Jacob, and J. Favier -- Q-criterion

Cover Figure 2: STS 422-1 Vortex Evolution on Hybrid-Delta-Wing Configurations at Transonic Flow Conditions - Yasin Ozdemir¹, Christian Breitsamter -- Iso-surfaces of the non-dimensional Q-Criterion of 50 for a triple-delta-wing configuration at $Ma = 0.85$ and $Re = 1.20 \cdot 10^7$ under symmetric flow conditions at $\alpha = 16^\circ$ and $\beta = 0^\circ$.

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WCCM–ECCOMAS 2026

STS Book of Abstracts

17th World Congress on Computational Mechanics (WCCM)
10th European Congress on Computational Methods in Applied Sciences
and Engineering (ECCOMAS)

19–24 July 2026, Munich, Germany

Foreword



On behalf of the Executive Committee of ECCOMAS, it is my pleasure to emphasize the importance of the Special Technology Sessions (STS) at the ECCOMAS Congress / World Congress for Computational Mechanics 2026 in Munich and the important role of the Industry Interest Technical Committee (IITC) in strengthening the interaction between computational science and industry.

For nearly three decades, the STS have provided a unique forum where researchers, technology developers and industrial leaders meet to discuss emerging computational methodologies, industrial challenges and future innovation pathways. Since their introduction at the ECCOMAS Congress in Paris in 1996,

the STS have evolved into a highly valued component of ECCOMAS conferences, promoting dialogue across disciplines, sectors and communities. This year's STS takes place at a particularly important moment for computational science and engineering. Artificial Intelligence, data-enhanced modelling and Digital Twin technologies are rapidly transforming the design, monitoring and operation of complex engineering systems by combining computational methods with operational data, sensing technologies and machine learning. At the same time, these developments highlight the growing importance of close collaboration between academia and industry. Advanced predictive methods and Digital Twins depend on access to industrial data, realistic operational environments and continuous validation against physical systems, while combining industrial experience with scientific rigor and methodological innovation. Together, they enable trustworthy and scalable computational technologies addressing major challenges related to energy, mobility, manufacturing, infrastructure and sustainability.

The establishment of the ECCOMAS Industry Interest Technical Committee (IITC) marks an important strategic step for ECCOMAS. By giving industrial and application-oriented perspectives an improved permanent institutional framework within the Association, the IITC strengthens opportunities for cross-disciplinary collaboration, dissemination and strategic dialogue, reflecting the growing recognition that industrial engagement is increasingly central to the future development and impact of computational science.

The members of the ECCOMAS Executive Committee would like to express their sincere gratitude to the four key persons behind the development of the STS, the Industry Interest Group and now the IITC: Jacques Periaux, Tero Tuovinen, Gabriel Bugada, and Dietrich Knoerzer. Their long-term vision and dedication have created an enduring bridge between scientific excellence and industrial relevance within the ECCOMAS community. The Executive Committee thanks also to the Chairmen of WCCM-ECCOMAS Congress 2026: Wolfgang A. Wall, Alexander Popp, Marek Behr, and Ekkehard Ramm for integrating the nearly 150 STS papers in the large Congress programme in Munich.

As the new President of ECCOMAS following the Congress, I look forward to a close and fruitful collaboration with the IITC and to further strengthening the interaction between ECCOMAS and industry in the years ahead.

Trond Kvamsdal

Preface

30 years of STS

The WCCM–ECCOMAS Congress 2026 in Munich continues a long tradition of bringing together scientific excellence, advanced computational methods and industrially relevant applications. Since their introduction at the ECCOMAS Congress in Paris in 1996, the Special Technology Sessions (STS) have provided a dedicated forum where academic researchers, industrial experts, research organisations and technology developers can discuss computational advances in close connection with practical engineering challenges.

This Book of Abstracts reflects that continuing mission. The contributions collected here show how computational science and engineering are increasingly shaped by demanding industrial and societal questions. Sustainable aviation, climate-neutral transport, energy systems, advanced manufacturing, digital engineering, optimisation, multiphysics modelling, data-driven workflows, digital twins and artificial-intelligence-enabled methods form an interconnected landscape in which new methods must be validated, transferred and applied in realistic environments.

The development of the STS has always been closely linked to the broader ECCOMAS ambition of strengthening cooperation between academia and industry. Over the years, the sessions have become a recognised dissemination channel for technological advances, collaborative European research projects and industrial experience in the use of computational methods. Aeronautics has played a particularly strong role in this tradition, while the scope of the STS has expanded toward transport, energy, industrial technologies, digitalisation and other application-driven fields.

A further step was taken in 2015, when the ECCOMAS Managing Board established the Industry Interest Group (IIG). The IIG gave a clearer organisational form to activities that had already matured through the STS. It supported the industrial interface of ECCOMAS conferences, encouraged technology-oriented dissemination and helped keep industrial questions visible within the broader scientific programme. It also contributed to a wider ecosystem of thematic conferences and workshops addressing multiphysics, multiscale methods, big data, transport, digitalisation and modern engineering design challenges.

The establishment of the ECCOMAS Industry Interest Technical Committee (IITC) marks the next natural step in this evolution. The IITC gives the industrial dimension of ECCOMAS a permanent place within the Technical Committee structure of the Association. This is more than an administrative change. It recognises that the dialogue between academia and industry is an integral part of the scientific and strategic mission of ECCOMAS, and it provides continuity, representation and visibility for industrial and application-oriented perspectives.

The cross-disciplinary character of the IITC is especially important. Many of the most urgent challenges facing European industry do not fit within a single scientific domain. Sustainable transport, digital certification, trustworthy artificial intelligence, data governance

in simulation-intensive processes, climate and energy targets, and the integration of sustainability into design workflows require cooperation across computational fluid dynamics, structural mechanics, applied mathematics, scientific computing and industrial practice. The IITC supports this cooperation by connecting scientific domains more systematically to industrial priorities and innovation pathways.

Within this framework, the STS remain a central instrument. They provide visibility for topics of direct technological relevance and create a forum in which research results can be discussed together with industrial constraints, validation requirements and implementation needs. The Munich congress demonstrates the strength of this tradition: the STS programme of WCCM–ECCOMAS 2026 brings together nearly 150 papers in 18 Special Technology Sessions. This broad participation confirms the continuing need for forums in which industrial questions and methodological advances can be discussed side by side.

The abstracts collected in this volume therefore represent more than individual contributions. Together, they illustrate a shared effort to transform scientific progress into technological, economic and societal impact. We warmly thank all authors, organisers, session chairs, reviewers, contributors and supporting organisations who have made this STS programme possible. Their work continues a tradition that began in 1996 and has grown into a mature and influential component of the ECCOMAS conference ecosystem.

We hope that this Book of Abstracts will serve not only as a record of the STS contributions presented in Munich, but also as an invitation to further cooperation. The challenges ahead require scientific depth, industrial realism and a willingness to work across boundaries. The STS, supported by the new IITC framework, offer a strong basis for that work and a powerful bridge between research excellence and industrial innovation in Europe and beyond.

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Jacques Periaux, CIMNE–ECCOMAS
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Gabriel Buggeda, CIMNE–UPC

Programme

WCCM-ECCOMAS Congress 2026, Munich, 19–24 July 2026					Status: 24/06/2026	
Schedule of the Special Technology Sessions						
Time	Sunday 19th July	Monday 20th July	Tuesday 21st July	Wednesday 22nd July	Thursday 23rd July	Friday 24th July
8:00–8:30		Registration	Registration			
8:30–9:15		Opening and Awards Ceremony <i>(9:00–9:30)</i>	Plenary Lectures	Plenary Lectures	Plenary Lectures	Registration
9:15–9:45		Opening Lectures	Coffee Break			
9:45–11:15		Coffee Break	STS 400 <i>(NM-2)</i> STS 397A <i>(NM-4)</i>	STS 422A <i>(NM-2)</i> STS 415 <i>(NM-4)</i>	STS 405A <i>(NM-2)</i> STS 417 <i>(NM-4)</i>	Parallel Sessions
11:15–11:30			Short Break			
11:30–13:00		STS 404 <i>(NM-2)</i>	STS 103A <i>(NM-2)</i> STS 397B <i>(NM-4)</i>	STS 422B <i>(NM-2)</i> STS 424A <i>(NM-4)</i>	STS 405B <i>(NM-2)</i> STS 418 <i>(NM-4)</i>	Parallel Sessions
13:00–14:00	Lunch Break					
14:00–14:45		STS 407 <i>(NM-2)</i>	Plenary Lectures	Plenary Lectures	CFCE Opening Parallel Sessions	Plenary Lectures
14:45–15:00			Short Break			
15:00–16:30		STS 421A <i>(NM-2)</i> STS 413A <i>(NM-4)</i>	STS 103B/420A <i>(NM-2)</i> STS 397C <i>(NM-4)</i>	STS 422C <i>(NM-2)</i> STS 424B <i>(NM-4)</i>	STS 425A <i>(NM-2)</i> STS 399A <i>(NM-4)</i>	Parallel Sessions
16:30–17:00	Congress Pre-Registration 16:30–20:00			Coffee Break		Farewell Coffee/ Drinks at Marketplace
17:00–18:30	Ice-breaking and Welcome Reception	STS 421B <i>(NM-2)</i> STS 413B <i>(NM-4)</i>	STS 420B <i>(NM-2)</i> STS 414 <i>(NM-4)</i>	STS 412 <i>(NM-2)</i> STS 424C <i>(NM-4)</i>	STS 425B <i>(NM-2)</i> STS 399B <i>(NM-4)</i>	
19:00–20:00						
20:00–22:00					Congress Banquet	

Rooms: NM-2 = Salzburg, NM-4 = Hamburg.

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STS103 - Multifunctional Moveables for High-Aspect Ratio Laminar Wing

Main Organizer: Prof. Jochen Wild (DLR German Aerospace Center, Germany)

Chaired by: Prof. Jochen Wild (DLR German Aerospace Center, Germany),
Dr. Jos VANKAN (NLR, Netherlands)

Part	Date	Time	Room
STS103A	Tue 21.07.2026	11:30–13:00	NM - 2 (Salzburg)
Joint	Tue 21.07.2026	15:00–16:30	NM - 2 (Salzburg)
STS103B– STS420A			

Two aerodynamic technology streams promise a break-through in minimizing the energy consumption of flight: laminar wing technology and the significant increase of the aspect ratio of the wing. Both technologies require a significant change of the architecture of wing moveables for high-lift and flight control. At the leading edge, slats are no longer compatible with laminar wing technology, and classical flaps are no longer sufficient to provide sufficient load and deformation control due to the high slenderness and limited space for control actuation. The aim of the proposed session is to collect contributions from aerodynamics, aeroelastics and systems - as e.g. represented by the German Federal Aviation Research Programme project ULTIMATE - to the solution of the specific topics of integrating novel controls into high-aspect ratio laminar wings by simulating aerodynamics, aeroelastics, flight and system behaviors.

STS 103-1

**Challenges of High-Lift System Integration into Laminar Wings
– a Review**

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Abstract

The feasibility of laminar flow control technology for future wing is bound to the development and integration of a high-lift system that complies with the requirements on smooth surfaces to enable maintaining the laminar boundary layer flow. The high-lift system must be able to achieve a lift generating capability sufficiently close to established systems. A shortfall would lead to requiring larger wing area jeopardizing the benefit of drag and fuel burn reduction.

Krueger flaps are currently the mostly discussed high-lift system concept at the leading edge of a laminar transport aircraft wing. They offer a double functionality. Beside the capability to delay wing stall, this device is favoured for its option to prevent the wing surface contamination by dirt or insects in low altitude flight.

At the trailing edge system, a call for multi-functionality is driven by thoughts to use a slight trailing edge deflection to trim the boundary layer development towards an improved stability for laminar flow in the sense of variable camber. The duality of the design has for long time driven research in multifunctional moveables that are a multi-disciplinary design topic between aerodynamics, systems and structures.

This keynote introducing the STS103 is aiming to review research activities of the past two decades in national and European projects to mature the high-lift system integration into the different types of laminar wings – may it be Natural Laminar Flow or Hybrid Laminar Flow Control – with views on aerodynamical, structural and system aspects.

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STS 103-2

Aerodynamic Aspects of Krüger Flap Operations

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Abstract

Krueger flaps have gained increased investigation in recent years. Their ability to avoid disturbance of laminar flow on the wing upper surface and prolong the onset of separation make them the high-lift system of choice for laminar-flow wings. Stored in the cavity under the wing, they deploy against the flow, extending into the airstream. Thereby modifying the wing camber, allowing delay of flow separation and increasing the lift-coefficient. They also act as shielding devices for the wing leading-edge in fully deflected position against contaminants and insects.

The aim of this work is to present the results of study of flow physics surrounding such Krueger-panel high-lift devices mounted on the leading edge of laminar wing transport aircraft. This effort is derived from the German national project ‘ULTIMATE’ [1]. Here, the Krueger flaps are mounted in distributed configuration across the wing and deploy in sequential manner. An innovative design is discussed in detail, incorporating multiple Krueger panels with folding bullnose. The underlying wing layout, Kinematics and system design is derived from the results obtained during earlier European project UHURA [2]. The design assumes the same cruising speed as today’s turbulent wing designs, allowing valid comparisons. Such is another important objective to enable fuel savings upto 10% as compared to today’s aircrafts.

During this study, High-fidelity numerical simulations were carried out to capture the flow physics around the Krueger panels. An extensive test-matrix covering numerous sequential configurations during operations and speeds are considered. The CFD results are partially validated against experimental wind-tunnel results obtained from project partners. Critical failure cases are established and evaluated considering the Krueger panels jammed in unfavourable positions. The aerodynamic analysis evaluates the achievement of handling-quality requirements, including for failure cases, to ensure compact kinematics and system design. The progress-so-far is discussed, with insights into future goals.

Acknowledgement

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STS 103-3

Pretension Control Architecture for raised Krueger Flaps on Laminar Airfoils

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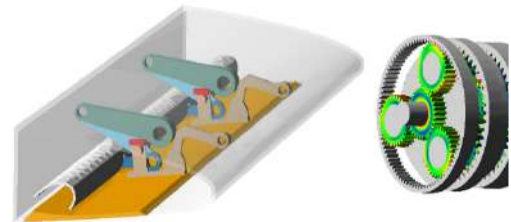
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Abstract

Laminarization of airfoils offers substantial potential for improving aerodynamic performance and represents a key area of research in the optimization of modern commercial aircraft [1]. However, a persistent challenge is contamination of the wing's leading edge, which induces turbulence wedges preventing maintained laminar flow [2]. The raised bull-nose Krueger Flap provides a viable solution to this by shielding the leading edge and thus protecting the wing from contamination.

It has been identified, that the Krueger Flap is subjected to aerodynamic suction forces in certain flight conditions, which cause inadvertent movement of the flap, due to the compliance of the kinematics. A potential solution to this issue is pretensioning the kinematics, to counteract the aerodynamic forces.

For the purpose of developing a first design of the pretension control architecture, a simulative assessment of a suitable control architecture is presented. This is done using a co-simulation framework, consisting of an FMI coupling between *MATLAB Simulink* and *MSC Adams*. The sub-model part in *Simulink/Simscape* presents the actuation system, serving as simulation master. It contains customized modelling elements in *Simscape* representing the physical behaviour. Two multibody systems implemented in *Adams* function as simulation slaves and are included as separate FMUs. The first FMU captures a fully flexible representation of the kinematics and Krueger Flap. The second contains a geared rotary actuator equipped with flexible spur gears and contact simulation between the intermeshing teeth, allowing compliance and backlash effects to be represented. This method of analysing the actuation system of slats at the wing's leading edge has already been used [3] and was adapted in the present work.



The aim of the virtual testing environment is to compare different control strategies and evaluate a final control architecture. Furthermore, selected failure conditions are simulated, for evaluation of the control architecture in a degraded system state.

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STS 103-4

Multi-Fidelity Maneuver and Gust Loads Analyses of a High Aspect Ratio Jet Transport with Laminar Wings

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ABSTRACT

A high aspect ratio wing jet transport (*ULTIMATE-NLF*) with a laminar wing was designed for the project *ULTIMATE* funded by the German Federal Aeronautical Research Programme (LuFo). The design of the wing features both a high aspect ratio (15.6) as well as an innovative laminar airfoil layout with Crossflow Attenuated Natural Laminar Flow (CATNLF). A particular challenge is the structural design and optimization of the highly flexible wing due to the impact of aeroelastic effects, which must be considered throughout the whole design process. Conventional transport aircraft loads and sizing processes are based on potential aerodynamic methods (VLM, DLM) to compute several hundreds of loads cases in a reasonable time. However, these methods are not able to account for nonlinear aerodynamic effects (mainly flow separation at high load factors and large gust gradients), which appear in transonic flight conditions and show a significant impact in the loads [1]. The structural optimization of the *ULTIMATE-NLF* has already been presented in previous works [2]. So far, only potential aerodynamic methods (MSC Nastran SOL144 and SOL146) were applied for the calculation of all steady and unsteady loads. In this work we present an approach for the structural optimization of the wing of the *ULTIMATE-NLF* configuration that computes relevant load cases (steady and quasi-steady maneuver as well as gust loads) by high fidelity aerodynamic methods (RANS and URANS) coupled with flight mechanics and structural dynamics. In addition, we investigate the differences of the loads between a fully turbulent flow assumption as well as free transition modeling (using the LST/ e^N approach).

The outer shape of the *ULTIMATE-NLF* configuration is shown in Figure 1 together with the results of a steady CFD analysis that highlights the CATNLF design for the cruise flight [2]. The dimensioning gust loads (computed by DLM), which appear at VC (loads design cruising speed) at an altitude of approximately 6000 m and for gust gradients of 60 m are also plotted. The maneuver and gust loads will be computed by RANS and URANS, respectively, to construct the loads envelope for the structural optimization process.

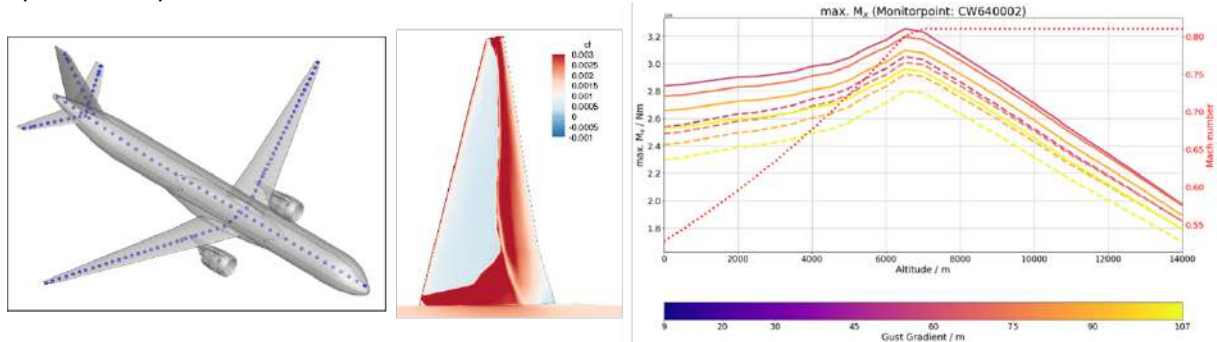


Figure 1: Outer shape of the *ULTIMATE-NLF* configuration (left). Skin friction coefficient computed by RANS with free transition modeling for the design shape and cruise flight conditions highlights the large NLF region (right). Wing root bending moment for a range of altitudes and gust gradients at VC (right).

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STS 103-5

Flight Simulator Investigation of Static Load Alleviation for Transport Aircraft

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Abstract

Load alleviation methods allow lighter wing structures and are therefore essential for increasing efficiency in fuel consumption and reducing the environmental impact of aviation. This paper presents a simulation-based methodology to evaluate static load alleviation strategies for a high aspect ratio aircraft aimed at reducing root bending moment (RBM), while considering the resulting drag increase. For that, a pilot-in-the-loop environment using the research flight simulator Simulator for Educational Projects and Highly Innovative Research (SEPHIR) at Technische Universität Berlin has been employed. The goal was to assess the effect of pre-defined control surface pre-settings (PS) on RBM, drag, and comfort under realistic flight conditions and pilot inputs. The flight mechanics of a virtual Airbus A320-like aircraft with high aspect-ratio wings, developed in MATLAB/Simulink, was integrated into the modular simulation architecture of SEPHIR. A UDP-based real-time communication interface was used between the simulation model and the flight simulator, ensuring synchronized pilot inputs, consistent visual feedback, and continuous data acquisition for post-simulation evaluation. The study considered cruise and landing flight phases. For the cruise flight, four maneuvers were accomplished in compliance with CS-25 certification load cases: (1) climb with a +2.5 g load factor (maneuver load), (2) level flight with turbulence using the von Kármán turbulence model from the MATLAB/Simulink Aerospace Toolbox (gust loads), (3) descent with a -1.0 g load factor under moderate turbulence (combined maneuver and gust load), and (4) a coordinated turn with a 30° bank angle at +1.67 g. For the landing configuration, the RNAV (GPS) Z approach was implemented, including 1-cosine discrete gusts to represent CS-25 maneuver and gust load conditions. The simulation flight test campaign was performed by qualified test pilots using the direct law (assisted manual control) of the SEPHIR flight simulator. Three pre-settings (PS1–PS3) for the control surfaces, as well as a clean configuration, were tested. PS1 was defined and optimized to achieve maximum load alleviation. PS2 penalizes drag increase and performs weighted load alleviation. PS3 uses only five instead of eight control surfaces. Evaluation metrics included RBM, which was computed in post-processing using the vortex lattice method via Athena Vortex Lattice (AVL) routines, along with the drag coefficient and ride comfort parameters, both directly recorded during the simulation. On average, pilots considered that flying qualities had not been considerably affected by the passive load alleviation functions.

STS 103-6

Aerodynamic Design of an HLFC Wing for a Long-Range Transport Aircraft

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Abstract

To achieve the environmental targets defined in Flightpath 2050 [1], significant reductions in fuel consumption and emissions are required. In this context, aerodynamic design plays a central role by reducing drag and improving fuel efficiency. Among various concepts, delaying the laminar–turbulent transition offers substantial drag reduction potential. For long-range transport aircraft, Hybrid Laminar Flow Control (HLFC) [2], combining natural-laminar-flow airfoil design with active boundary-layer suction, represents a viable solution. The present work focuses on the numerical aerodynamic design and analysis of a long-range passenger aircraft to be equipped with an HLFC system within the German LuFo project MUVE. The reference configuration is based on the fully-turbulent high-aspect-ratio wing developed in the INTELWI project [3]. The design point corresponds to cruise conditions at $M_\infty = 0.83$, lift coefficient $C_L = 0.5$, Reynolds number $Re = 4.7 \times 10^7$, and an altitude of $h = 10668 \text{ m}$. HLFC application is restricted to the outer wing section, for both upper and lower surfaces, using leading-edge suction panels combined with tailored airfoil modifications. Airfoil geometries and suction distributions are optimized at selected spanwise stations using the in-house 2.75D HLFC design tool conFLOW [4], which couples a conical-flow solver with boundary-layer and linear stability methods within a Bayesian optimization framework to minimize drag at low computational cost. The optimized airfoils are subsequently integrated into the wing geometry, and twist optimization is performed using coupled CFD–structural simulations with TAU and IFLS, a fluid–structure interaction environment developed at the Institute of Aircraft Design and Lightweight Structures, TU Braunschweig. The aerodynamic performance of the HLFC-equipped wing is evaluated and compared with that of the baseline configuration.

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STS 103-7

Design and Optimisation of a multifunctional Aircraft Wing Leading Edge System: Aerostructural Layout for combined High Lift, Load Alleviation and Hybrid Laminar Flow Control

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Abstract

Leading edge systems of long-haul aircraft wings extend the operational envelope in terms of flight speed, range, and fuel efficiency, while also enhancing flight safety by providing protection against external loads and harsh environmental conditions. Accordingly, leading edge concepts combining the functions of high lift, gust and manoeuvre load alleviation (GLA and MLA) and active drag reduction based on hybrid laminar flow control (HLFC) are being investigated, along with secondary functions such as protection against icing, bird strikes, insect contamination and lightning strikes. In previous research, at least partial combinations of these different leading edge functions have already been demonstrated [1] but a fully integrated multifunctional solution has not yet been realised. The present work addresses the computational, aerostructural design and optimisation of a multifunctional leading edge system (MFLES).

Based on general system requirements, three distinct concepts are derived: a fully morphing droop nose, as well as inward and outward semi-morphing droop noses. A multidisciplinary optimisation framework is applied to achieve optimal shape adaptation of a laminar transonic airfoil (2D). Airfoil geometry parameters and MFLES deflection angles for take-off conditions are optimised using a low-fidelity aerodynamics tool, targeting enhanced lift characteristics, improved low-speed aerodynamic efficiency, and delayed flow separation. Structural characteristics are evaluated using the Chained Beam Constraint Model [2] and Finite Element Analysis, aiming to minimise deformation power consumption (for both high lift and GLA/MLA) and structural mass, while identifying favourable kinematic actuation point locations. The sensitivity of the results to key design parameters is analysed, including implications for kinematics, actuation and HLFC system layout. On this basis, the most suitable droop nose concept among the three is selected.

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STS397 - Hydrogen - Industrial Questions

Main Organizer: Mr. Tero Tuovinen (JAMK University of Applied Sciences, Finland)

Chaired by:

STS397A and STS397C:

Mr. Tero Tuovinen (JAMK University of Applied Sciences, Finland), Prof. Matti Kurki (JAMK University of Applied Sciences, Finland);

STS397B:

Prof. Matti Kurki (JAMK University of Applied Sciences, Finland), Mr. Tero Tuovinen (JAMK University of Applied Sciences, Finland)

Part	Date	Time	Room
STS397A	Tue 21.07.2026	09:45–11:15	NM - 4 (Hamburg)
STS397B	Tue 21.07.2026	11:30–13:00	NM - 4 (Hamburg)
STS397C	Tue 21.07.2026	15:00–16:30	NM - 4 (Hamburg)

This Special Technology Session addresses critical industrial challenges around hydrogen deployment by bridging computational mechanics, measurements, and techno-economic reasoning. We invite contributions that quantify where hydrogen is technically and economically justified across heavy industry and transport, and that demonstrate validated models capable of guiding design and operations. Target topics include multiphysics modelling of electrolyzers and the operation of fuel cells; Hydrogen storage and transport; hydrogen effects on materials (embrittlement, fatigue, fracture); dispersion, combustion, and safety; as well as plant- and network-scale simulations integrating electricity markets and heat recovery. The session also emphasizes value network analysis across supply chains—linking component performance, reliability, and maintenance to system cost, lifecycle impacts, and its risks.

STS 397-1

Perspectives to the Value Chain and Hydrogen Price Creation Using Wind Power

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Abstract

This presentation examines how green hydrogen price is created along a wind-power-to-hydrogen value chain, with a focus on electrolyser-based production (AWE and PEM) and the surrounding electrical and process infrastructure in Finland. A simplified system is assumed where wind power is the primary electricity source, while oxygen is treated as a secondary output that can be stored or transferred elsewhere. Using hour-averaged Finnish Meteorological Institute wind data from 2024 (scaled to 100 m), a 9 MW wind turbine example yields an annual average power of 3.1 MW and approximately 24.5 GWh of electricity ($\approx 35\%$ efficiency), forming the basis for hourly hydrogen production modelling.

Two operational principles are compared: (1) steady hydrogen production, where grid electricity is purchased during low wind and surplus wind power is sold during high wind; and (2) dynamic wind-following production, enabled especially by PEM electrolysers with low minimum load ($\approx 10\%$), but requiring storage capacity to ensure continuous deliveries. The analysis uses an Excel-based cost model where CAPEX includes loan share, interest, and payback assumptions, and OPEX is treated as a percentage of CAPEX.

Results highlight that electrolyser investment cost dominates hydrogen economics and varies widely by market: “inside China” system prices can be a fraction of EU levels, though export prices rise due to higher equipment costs and Western EPC requirements. Hydrogen costs also depend strongly on non-electrolyser factors such as time efficiency/availability, financing interest rate, and especially the share of self-produced versus market electricity - driving illustrative outcomes from ~ 3.5 €/kg in favourable conditions to ~ 4.6 €/kg in less favourable ones. Overall, hydrogen price creation is a dynamic system-level problem shaped by operational strategy, infrastructure losses, financing, and electricity sourcing as much as electrolyser efficiency itself.

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STS 397-2

Modelling, Simulation, Optimisation and Scaling of a (Real) Hydrogen Production Plant with Hydrogen Storage and Distribution for (Regional) Sector Coupling (Mobility, Electricity, Heat)

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Abstract

Hydrogen in the mobility sector offers great opportunities to achieve the decarbonization goals and to reduce local emissions. In particular, public transportation, with its high daily mileage and its services both within cities and across regions, offers the best conditions.

In the state-funded research project “H2FLEX”, the interoperability of hydrogen across different sectors like heat, electricity and mobility is focused. The universities of applied sciences in Esslingen, Reutlingen and Ulm jointly perform the research within various work packages.

One of these work packages deals with modelling, simulation, optimization and evaluation of the hydrogen hub “Hy.Waiblingen”, which produces green hydrogen with PEM electrolysis and is further equipped with low-, medium- and high-pressure storage and a hydrogen fueling station with dispensers for passenger cars and heavy-duty transportation. Furthermore, the hydrogen hub can refill up to two hydrogen trailers and can also be supplied with an external hydrogen trailer for additional fueling capacity.

The main focus is the supply of fuel-cell electric buses of dedicated bus lines of the local county.

The study goal is to model the existing hydrogen hub and simulate its behaviour for different demand scenarios. To ensure the model accuracy, the expected hub behaviour will be validated with real hub measurement data and adapted accordingly.

The simulation models answer various questions like:

- Ideal hub operation conditions for different fueling scenarios for fueling frequencies, time windows and amount of buses,
- Hub performance limitations under different circumstances,
- Hub resilience in case of downtime of hub subsystems,
- Possible multi-megawatt scaling and hub extensions for higher hydrogen supply demands,
- Waste-heat discovery potential to serve existing and new district heating networks.

STS 397-3

Mission-Aware Thermomechanical Modelling of Multi-State Hydrogen Storage Systems for Aviation

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Abstract

Aircraft-integrated hydrogen storage systems are tightly coupled, multi-component, multi-physics systems in which thermodynamic behaviour, structural sizing, and control logic interact across disparate time and energy scales. Beyond conventional single-tank concepts, multi-state architectures combining tanks operating at different pressures and temperatures offer a means to exploit complementary advantages of compressed, cryogenic, and cryo-compressed hydrogen storage. At early stages of aircraft design, where architectural decisions remain fluid, computationally efficient and physics-consistent tools are required to explore these interactions and screen candidate system layouts.

This work introduces a modular thermomechanical modelling framework for early-stage design-space exploration and preliminary sizing of multi-tank hydrogen storage systems for aviation, developed within the Horizon Europe TRIATHLON project [1]. Mission requirements are prescribed as a time history of hydrogen mass flow demand, governing the thermodynamic response and the resulting structural loads. Each tank is modelled as a thermodynamic control volume governed by a system of differential-algebraic equations resolving mass and energy conservation and transient heat transfer, adapted from generalized hydrogen storage models in the literature [2]. Tank-level thermodynamics are coupled to a filament-wound netting formulation for first-order structural sizing [3], enabling estimation of tank geometry, mass, and thermal inertia. System-level behaviour emerges through energy-consistent inter-tank coupling laws, allowing arbitrary network topologies, valve-based interactions, and simple control strategies.

The framework is demonstrated on a representative two-tank storage architecture interacting with an aircraft powerplant, such as a fuel cell or gas turbine. It enables simulation-driven sizing and simple optimisation of tank volumes, operating pressures, and thermal management strategies under mission constraints. By prioritising architectural insight over component-level detail, the framework supports informed decision-making and system-level optimisation for hydrogen-powered aircraft.

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STS 397-4

Electrolyzer Simulation-Based Multi-Objective Optimization

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Abstract

Hydrogen production via electrolysis is considered as a clean energy-conversion technology and optimizing the electrolyzer performance is one of the central tasks in the hydrogen production. In this article, a simulation-based multi-objective optimization approach will be developed to enhance the electrolyzer performance. To accurately model the multi-physics characteristics of electrolyzer, a 3-dimensional CFD model will be built with the open-source platform OpenFOAM, where the temperature, pressure, and gas generation profiles inside the cell will be studied by coupling the electrochemical and thermal model. Subsequently, a multi-objective optimization design will be used to optimize the structural variables such as membrane thickness, and operational variables such as water flow rate of the cell. Parameters will be estimated using the experimental data from a high-accuracy model. The study is expected to provide valuable insights into the trade-offs among energy efficiency, capital cost, and gas production rate, and to offer practical guidelines for the design and operation of high-performance electrolyzers.

STS 397-5

Mission-Optimized Multi-State Hydrogen Storage, Transport and Conditioning Systems for Aviation

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Abstract

Modern aircraft are highly optimised systems with a high degree of functional integration, e.g. storing kerosene in the wing. The change from kerosene to hydrogen as fuel will thus have a profound impact on overall aircraft design. Many studies on hydrogen-powered aviation are centered around the use of liquid hydrogen (LH2) [1] and subcooled hydrogen (sLH2) as fuel [2] focusing on the optimality of hydrogen storage alone in terms of gravimetric and volumetric energy efficiency. This narrow focus leads to challenges in terms of transport and conditioning and will lead to suboptimal performance of the aircraft as a whole. Studying a multi-state architecture combining tanks operating at different pressures and temperatures will be instrumental in identifying what a globally optimised hydrogen-powered aircraft may look like.

As part of the Horizon Europe TRIATHLON project [3] a modular thermomechanical modelling framework for design-space exploration and preliminary sizing of multi-tank hydrogen storage systems for aviation has been developed. The framework can be used to explore candidate configurations in a physics-consistent and computationally efficient way. Each tank is modelled as a thermodynamic control volume governed by a system of differential equations adapted from generalized hydrogen storage models in the literature [4], and coupled to a filament-wound netting formulation for first-order structural sizing [5]. This allows estimation of tank geometry, mass and thermal inertia. Energy-consistent inner-tank coupling laws enable the modelling of arbitrary multi-state hydrogen storage systems through valve-based interactions, and simple control strategies. The time-history of hydrogen mass flow demand for a mission is used as input for the analysis.

Multi-state configurations presented in this work are optimised for a given aircraft configuration and mission using the modular thermomechanical framework. The results are compared to an optimised single tank sLH2 configuration.

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STS 397-6

Advancing Green Hydrogen Technologies for Sustainable Industrial Applications: Insights from the gH2ADDVA Project

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Abstract

Green hydrogen technologies play a pivotal role in the transition toward low-carbon industrial solutions. The gH2ADDVA project focuses on developing clean, environmentally friendly energy production methods, novel material technologies, and AI-based tools for value chain modeling. The project strengthens Finland's energy self-sufficiency and industrial networks while addressing rising energy costs.

The main objectives include:

- (1) Efficient electrolysis and bio-based hydrogen production, storage, and utilization methods;
- (2) Advanced material solutions for renewable energy and hydrogen storage;
- (3) AI-driven approaches for digital twins and value chain optimization;
- (4) Regional RDI and industrial collaboration in hydrogen technologies.

The research combines techno-economic analyses, laboratory testing, and computational modeling. Key results include:

- Preliminary studies on biomass-based hydrogen production and its economic feasibility;
- Development of new material and surface technologies for hydrogen storage, including ALD coatings and fatigue-resistance testing;
- Optimization of electrolytic surfaces and sensor systems for safe hydrogen use;
- Digital implementation of hydrogen value chains using AI methods such as semantic analysis, LLMs, and Retrieval-Augmented Generation.

These findings contribute to cost-effective and safe hydrogen integration in industrial processes, supporting SMEs in Central Finland and reinforcing the region's position in national and EU-level hydrogen clusters. The project demonstrates how multidisciplinary research—spanning physics, bioeconomy, and computational sciences—can accelerate the adoption of green hydrogen technologies and foster sustainable industrial renewal.

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STS 397-7

Power-to-X-to-Power Energy Systems for Renewable Energy Storage and Conversion

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Abstract

Power-to-X-to-Power energy systems can serve as storage and sector-coupling solutions for the transition from fossil fuels to renewable energy [1, 2]. The process uses green hydrogen, which can be produced from wind and solar power via water electrolysis. Within a chemical reactor, hydrogen reacts with carbon dioxide under high pressure and temperature to form methane or methanol. The methane or methanol are stored and can be converted into heat and power when needed. Such a system can be used for seasonal energy storage and mastering dark doldrums.

This work introduces a Power-to-X-to-Power energy system demonstrator, which has been developed to optimize the operation of the individual components and the overall system. The demonstrator is based on a methane synthesis reactor and an oxyfuel combustion process [3]. The oxyfuel combustion is realized in a 20-kW combined heat and power gas engine with a CO₂ separation unit. The CH₄/O₂ mixture is diluted with 50 mol-% of CO₂ to keep the temperature in the combustion chamber below 2000°C. The methane synthesis reactor uses Ni/Al₂O₃ catalysts and operates at 350°C and up to 20 bar of pressure. A maximum of 80 l/min at STP of methane can be produced by the reactor.

In parallel, a digital twin of the energy system demonstrator is being developed [4]. The Python, ESTECO SpA and LOGEsoft software packages are utilized for the development. Low-fidelity and high-fidelity simulations based on detailed chemistry are performed for the methane synthesis reactor, the oxyfuel gas engine, and the CO₂ separation unit. The results are used to generate metamodels, which are incorporated into the digital twin. Subsequently, the digital twin is used to perform a genetic optimization of the energy system. Round-trip efficiencies of 42–48% could be achieved by optimizing the operating parameters, recycling O₂ and CO₂ and reusing waste heat.

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STS 397-8

Numerical Investigation of Operating Condition Effects on Void Fraction, Flow Distribution, and Current Distribution in an Alkaline Electrolyzer Stack

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Abstract

Commercial AWEs are commonly manufactured with a bipolar stack configuration, where the cells are electrically connected in series. The outer electrodes, known as endplates, are supplied with the power supply, while the intermediate electrodes, known as bipolar electrodes, act as an anode on one side and a cathode on the other. However, one inherent limitation with this configuration that restricts the further scaling of AWE systems is the stray current, driven by high potential difference between the cells that causes ionic current to pass through channels and manifolds [1].

Stray currents are electrical currents that divert from the intended electrolytic pathway within the electrical system of the stack and instead flow through the channels and manifolds, as shown in Figure 1. This geometric configuration leads to nonuniform current-potential distributions, resulting in decreased current efficiency [2].



Figure 1: Visual representation of ionic current streamlines (stray currents) in channels and manifolds

This paper presents a reliable numerical method, based on the finite element formulation, to investigate the hydrodynamic and electrical performance of the stack. A three-dimensional (3D) multiphysics model of a 12-cell non-zero gap AWE stack has been built up in COMSOL incorporating an electrochemical model and an Euler-Eulerian k-epsilon turbulence model. Subsequently, the influence of different stack voltages on stray currents and gas volume fraction was examined.

The numerical results revealed that the share of stray currents decreased and effective current increased at higher stack voltages, leading to higher Faradaic efficiency. Increasing the voltage (current) leads to higher gas production, consequently causing an increase in electrical resistance of channels and manifolds. This increased resistance will reduce the stray current, thereby enhancing the current efficiency of the stack.

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STS 397-9

Transient Thermo-Mechanical Stress During Cryogenic Tank Filling

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Abstract

The decarbonization of commercial aviation requires the adoption of climate-neutral propulsion systems, with liquid hydrogen (LH2) emerging as a leading candidate fuel. However, storing LH2 at cryogenic temperatures imposes severe thermo-mechanical loads on the containment structures, particularly during ground operations such as filling [1]. When a cryogenic liquid enters a tank that is initially at ambient temperature, steep and non-uniform temperature gradients develop in the wall, which can induce substantial transient thermal stresses [2]. Understanding these stresses is important for the safe design and operation of future aviation LH2 tanks.

This study presents a finite element model to predict the transient stress evolution in cryogenic tanks during filling. The model represents a horizontal 2 m long, 0.66 m diameter, 316L stainless-steel cylinder with torispherical heads, based on the demonstrator under development in the Horizon Europe project ALRIGH2T [3]. An elastic-plastic, temperature-dependent material model was developed from in-house cryogenic tests supplemented with literature data. The coupled transient thermal-mechanical numerical models were implemented in LS-DYNA®. Experiments with liquid nitrogen (LN2), measuring distributed wall temperatures and induced strains throughout the filling process are foreseen as an initial validation step.

The simulations show that pronounced local temperature gradients form near the moving liquid level, where each point on the wall undergoes a tension-compression stress cycle as the interface passes, with the maximum stresses occurring at the liquid height. Given the limited availability of literature data on stress fields in the inner tank of double-walled vacuum-insulated vessels, the results provide new insight into their thermo-mechanical behaviour under realistic operational transients.

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STS 397-10

Optimization of a Monolithic Membrane Reactor with Coupled Reforming and Diffusive Hydrogen Combustion

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Abstract

This work investigates an intensified membrane reactor with a monolithic square-channel configuration using three-dimensional computational fluid dynamics (CFD), with particular emphasis on steam methane reforming on the permeate side coupled with hydrogen–air combustion on the retentate side under a laminar diffusive flame regime. The proposed configuration enables direct thermal interaction between the reforming and combustion zones, allowing autothermal operation while maintaining a compact reactor layout. Hydrogen selectively permeates through the membrane, influencing local species distributions on the permeate side and enhancing reforming activity, while the permeated hydrogen sustains diffusive combustion on the retentate side without the need for premixing. The CFD model resolves the coupled behaviour of fluid flow, heat transfer, species transport, chemical reactions, and membrane permeation, and includes detailed SMR kinetics, a reduced H₂–air combustion mechanism suitable for laminar diffusion flames, and a NO_x formation sub-model to account for emission characteristics. Radiative heat transfer is incorporated to capture the high-temperature thermal interactions within the monolithic structure. A systematic parametric study is carried out to examine the influence of reactor length and key operating parameters, including inlet temperature, operating pressure, steam-to-carbon ratio, flow configuration (co-current and counter-current), and combustion-side equivalence ratio. The analysis focuses on hydrogen production, methane conversion, membrane hydrogen flux, temperature fields, flame structure, and NO_x emissions. Based on the obtained results, optimal operating ranges are identified that ensure stable diffusive combustion, improved reforming performance, and controlled emission levels. The findings provide practical insight into the coupled thermal and chemical behaviour of membrane-assisted reforming systems with diffusive combustion and offer design and operating guidance for compact, autothermal membrane reactors relevant to hydrogen production and integrated energy applications.

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STS 397-11

Raven: A Local AI System for Navigating Scientific Literature, Applied to Hydrogen Production Research

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Abstract

The volume of scientific publications has grown rapidly in recent years [1], making it increasingly difficult for researchers to maintain an overview of the state of the art. For example, a Web of Science search for ‘hydrogen production’ alone returns over 100,000 results. When building a computational model of a hydrogen value chain, identifying which mathematical models and methods from the literature are best suited for the task is a substantial effort. Similar challenges arise with patent databases and in-house, proprietary document collections — and in such cases, privacy may preclude cloud services.

To address this, we introduce Raven [2], an open-source AI system for navigating large scientific literature collections. Raven is a 100% local, privacy-first tool that runs entirely on a single workstation with an NVIDIA GPU. The system uses open-weight, pretrained AI and ML models throughout.

Raven consists of two core applications. First, Visualizer performs topic discovery on a BibTeX citation database. It computes semantic embeddings [3] of titles and abstracts, clusters similar entries with HDBSCAN [4], and projects the result into a 2D map with t-SNE [5]. This enables rapid, interactive exploration of the topical structure of a large literature collection. Secondly, Librarian is a conversational search and analysis tool using a local large language model (LLM). It employs hybrid keyword-semantic retrieval-augmented generation (RAG) [6] to ground the LLM’s answers in the dataset. We demonstrate Raven on a dataset containing the metadata of approximately 12,000 hydrogen production studies from Web of Science. Topic analysis with Visualizer reveals major research clusters including photocatalysis, biological fermentation, and steam reforming. From a computational mechanics perspective, numerical modeling studies in this dataset are few, and they appear scattered across all topic areas rather than forming a distinct cluster.

We then use Librarian to explore individual areas in more detail, with an eye toward subprocesses in a hydrogen value chain. As an example, we consider photovoltaic hydrogen production. Given variable solar irradiance, what modeling approaches are relevant — for example, for cell efficiency, electrolyzer dynamics, or storage?

Raven is open-source software, available at [2]. As locally hostable open-weight LLMs continue to improve, we expect the utility of local AI tools for scientific work to increase correspondingly.

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STS 397-12

Parametric Design of Cryogenic Tanks and Heat Exchangers Using CFD Simulations

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Abstract

The aviation sector is increasingly exploring electrified propulsion architecture based on cryogenic liquid hydrogen (LH₂) due to LH₂'s high power density. A major engineering challenge in this transition is designing lightweight, efficient storage tanks that provide adequate thermal insulation to limit boil-off while maintaining competitive gravimetric performance and meeting aircraft integration constraints. As experimental testing with cryogenic fluids is extremely costly, numerical modeling has become a cornerstone for the design and analysis of LH₂ storage systems [1], and certification procedures based on numerical tests are also being considered.

Low-order numerical models provide fast and reliable feedback during early design stages, supporting tank pre-sizing, insulation thickness selection, scalability assessments [2], and system-level analyses such as cool-down, filling, and operational phases. However, higher-fidelity simulations are essential for refining these analyses and validating or calibrating reduced-order approaches. In particular, detailed CFD analyses are required to accurately characterize heat transfer phenomena, such as heat fluxes and convective coefficients, associated with internal heat exchangers used for temperature control. Furthermore, three-dimensional parametric simulations are necessary to capture the effects of structural elements, including supports and thermal bridges, which can significantly influence overall thermal performance.

This work presents a set of parametric CFD-based methodologies developed using open-source meshing and simulation tools. The proposed approaches are applied to (i) the analysis and optimization of internal tube heat exchangers within LH₂ storage tanks, and (ii) the optimization of support structures and thermal bridge placement to minimize parasitic heat loads. The results highlight the role of high-fidelity parametric simulations in enabling the design of innovative LH₂ storage concepts and in strengthening the reliability of low-order modeling frameworks.

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STS 397-13

From Low Reactivity to Stable Flames: A Numerical Study of Hydrogen-Enhanced Ammonia Combustion in Swirl Burners

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Abstract

A comprehensive numerical analysis is presented to quantify the influence of hydrogen (H₂) enrichment on the combustion characteristics and nitrogen oxides (NO_x) formation of premixed ammonia-air (NH₃/Air) flames stabilized in a swirl gas turbine combustor. Simulations were carried out for hydrogen volume fractions of 0, 5, 30, 40, and 50%, equivalence ratios of 0.85, 1.0, and 1.2, and reactant inlet temperatures ranging from 400 to 600 K. The addition of hydrogen substantially enhances flame reactivity and thermal intensity. For pure ammonia, the peak flame temperature is limited to 1958 K, whereas increasing the hydrogen fraction to 50% raises the maximum temperature to 2253 K. This enhancement is accompanied by a more compact flame structure, characterized by shorter flame lengths and a reaction zone located closer to the burner exit.

Moreover, as the mixture inlet temperature increases, the chemistry is accelerated, which is evidenced by the increase in the Da number, recording 287 at 66 K compared to 117 at 400 K. The equivalence ratio and the hydrogen addition are key pillars in nitrogen oxide (NO_x) formation. For the same operating conditions, the total NO_x (NO+NO₂+N₂O) emissions increase from 1800 ppm for pure ammonia/air flame to 7500 ppm for 50% hydrogen fraction. The peak NO_x emission is observed under fuel-lean operating conditions. The peak NO_x concentration of 8243 ppm is recorded at an equivalence ratio of 0.85 compared to the NO_x concentration of 3797 ppm at an equivalence ratio of 1.2 (rich conditions). Overall, the results demonstrate that hydrogen-enhanced ammonia combustion can deliver stable, high-intensity flames suitable for gas turbine operation, while also revealing the inherent trade-off between improved combustion performance and increased NO_x formation.

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STS 397-14

Experimental and Numerical Investigation of Hydrogen-Enriched Gasoline Combustion in an Optical Constant-Volume Combustion Chamber

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ABSTRACT

This study presents a combined experimental and numerical investigation of the combustion characteristics of hydrogen-enriched gasoline blends in an optical constant-volume combustion chamber (CVCC). The analysis focuses on flame propagation speed, ignition delay, mass fraction burned (MFB), combustion duration, peak chamber pressure, pressure rise rate, heat release characteristics, and post-combustion species formation under controlled thermodynamic conditions. Hydrogen energy share (HES), defined as the ratio of hydrogen chemical energy to the total fuel energy supplied, was varied from 0% to 40%. Experiments were conducted at elevated initial temperature and pressure.

Flame evolution was visualized using high-speed shadowgraph imaging, while transient chamber pressure was measured using a high-precision pressure transducer. Flame propagation behavior was quantified through post-processing of the captured images using the PIVLab technique. Complementary three-dimensional unsteady Reynolds-averaged Navier-Stokes (URANS) simulations were performed in double precision using ANSYS Fluent 2024 R2 to replicate the CVCC combustion process. The governing continuity, momentum, energy, and species transport equations were solved using the finite volume method.

A coupled pressure-based solver was employed to capture compressibility effects, while turbulence closure was achieved using the realizable k-epsilon model. Spatial gradients were evaluated using the least-squares cell-based method, and a first-order implicit upwind scheme was applied for temporal discretization. Combustion chemistry for hydrogen-gasoline blends was modeled using a reduced chemical kinetic mechanism, while a single-step global reaction model was employed for pure gasoline cases. Spark ignition and initial conditions were matched to the experimental configuration.

Model validation was achieved through comparison of simulated flame propagation and pressure histories with experimental measurements, showing good agreement across all HES conditions. Both experimental and numerical results indicate that increasing HES significantly accelerates combustion. At 40% HES, earlier MFB phasing and shorter combustion duration were observed, along with increases in peak chamber pressure and maximum pressure rise. The peak heat release rate increased by up to 14.6%. Post-combustion species analysis revealed notable reductions in CO₂, CO, and HC with the increasing hydrogen energy share.

STS 397-15

Probabilistic Fatigue Crack Growth Assessment of Hydrogen Pipelines

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ABSTRACT

Hydrogen is expected to play a central role in achieving net-zero emission targets, particularly in hard-to-electrify sectors such as high-temperature industry, seasonal energy storage, and long-distance heavy transport [1]. In this context, many countries are planning to repurpose existing natural gas pipelines for hydrogen service, alongside the construction of new hydrogen-dedicated infrastructure. However, the safe and reliable operation of hydrogen pipelines presents significant material and structural integrity challenges.

As the smallest atom, hydrogen readily enters and diffuses into engineering materials, including pipeline steels. This interaction degrades the mechanical response of the material, leading to reduced fracture toughness and accelerated fatigue crack growth. From an engineering perspective, these effects necessitate rigorous fracture-mechanics assessments to define safe operating conditions for hydrogen pipelines [2]. Two key material inputs for such assessments are fracture toughness and fatigue crack growth behaviour. Unfortunately, these properties are expensive and difficult to measure experimentally under hydrogen environments. As a result, many existing assessments rely on so-called master curves that are assumed to be conservative [2]. However, the degree of conservatism is often unknown and may be excessively restrictive, leading to inefficient or overly pessimistic design and lifetime predictions.

In this study, a comprehensive database of fracture-mechanics properties of pipeline steels under hydrogen exposure, compiled from the literature, is systematically analysed. Based on this dataset, probabilistic surrogate models are developed for fracture toughness and fatigue crack growth rate. These models describe the fracture-mechanics behaviour of pipeline steels as functions of steel grade, hydrogen pressure, stress intensity factor range, loading ratio, loading frequency, and the desired level of conservatism. The developed probabilistic framework is then integrated into the fracture assessment procedures of ASME B31.12 to predict the allowable lifetime of an exemplary hydrogen pipeline for any specified level of conservatism. The resulting predictions are compared with and discussed alongside those obtained using conventional master-curve approach.

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STS399 - Advances in Scale-Resolving Simulation for Turbomachinery

Main Organizer: Dr. Oriol Lehmkuhl (Barcelona Supercomputing Center (BSC), Spain)

Part	Date	Time	Room
STS399A	Thu 23.07.2026	15:00–16:30	NM - 4 (Hamburg)
STS399B	Thu 23.07.2026	17:00–18:30	NM - 4 (Hamburg)

STS 399-1

GLASs: a GPU-accelerated Linear Algebra framework for exascale problems in physics and engineering

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1 Background and motivation

Iterative solvers for linear algebra problems have long played a key role in HPC applications, both related to solving linear systems arising from numerical discretization, and as part of finding eigenpairs of large physical systems. Many libraries exist today that provide highly optimized implementations of these algorithms on homogeneous distributed systems, with PETSc [1] being the most prominent library in use. However, the rise of GPU-based systems creates a space for new developments in this area, as this type of hardware presents unique performance and implementation challenges, such as:

- Limited memory capacity and high data transfer costs between host and device
- Poor support for FP64 operations compared to reduced precision formats
- Communication overheads in multi-GPU systems

On top of that, older libraries often present challenges when integrating with legacy codes, especially those written in Fortran, which is still widely used in the scientific computing community. This creates a need for new libraries that can address these challenges while providing an easy-to-use interface for client codes.

2 Objectives

We aim to present GLASs [2] (GPU Library for Accelerated Solvers) as a lightweight, modular framework for implementing iterative solvers for large linear algebra problems on distributed GPU-accelerated systems. Its main design features are:

- Easy to use templated class-based C++ interface, with Fortran bindings for easy integration with legacy codes
- Lightweight client-library interaction through lambda expression arguments for solver operations
- Custom BLAS-like independent modules for implementing compute-intensive operations
- Options for performing mixed-precision computations, including NVIDIA's bfloat16 half precision format
- Easy switching between different communication backends, including NCCL
- Communication calls performed on device data, enabling the use of GPUDirect RDMA where available

3 Methods

As shown in Figure 1, GLASs provides both a simple API for client-library interface and a set of solver families for linear systems and, in the future, eigenpair problems. By employing templated objects and separating the solver structure from the actual compute-intensive kernels, the library allows for easy integration and high modularity, as well as ease of optimization for different hardware architectures.

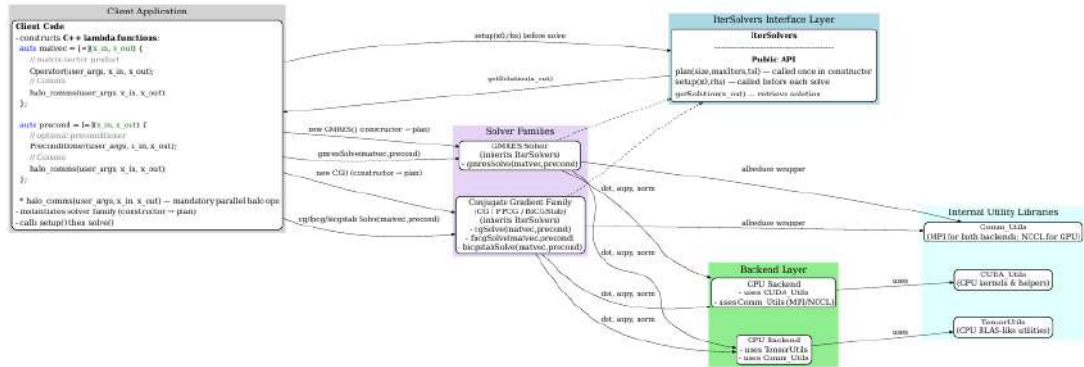


Figure 1: Visual representation of the high-level GLASs architecture.

4 Results

A preview of the library capabilities is presented using a simple test case: solving a tridiagonal linear system using the FPCG [3] solver on a multi-GPU system (MareNostrum 5). Scalability results are shown in Figures 2a and 2b, respectively.

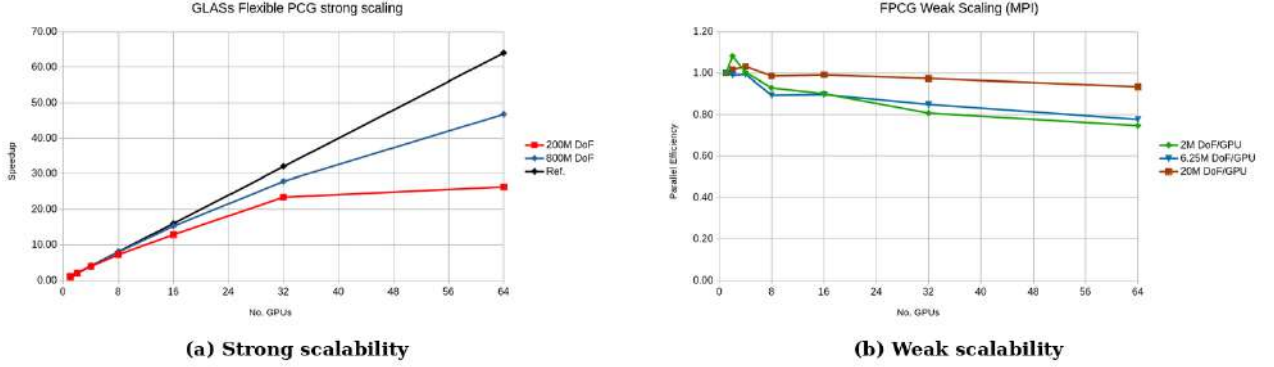


Figure 2: Scalability up to 64 H100 GPUs for the FPCG solver: (a) strong scaling with 200M and 800M unknowns; (b) weak scaling with 2M, 6.25M and 20M unknowns per GPU.

5 Conclusions

This abstract introduces the design philosophy and initial implementation of GLASs, as well as provides justification for its creation and adoption. The scalability results presented demonstrate the potential of the library for performing at exascale levels even at this early stage.

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STS 399-2

Wall-Modeled Large Eddy Simulation of Transonic Buffet over the OAT15A Airfoil: Spanwise Extent Effects on Flow Dynamics

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Abstract

The transonic buffet phenomenon over the OAT15A supercritical airfoil is investigated under high Reynolds number conditions ($Re_c = 3.0 \times 10^6$, $M_\infty = 0.73$) using wall-modeled large eddy simulation (WMLES). Following the methodology originally proposed by Kawai and Fukushima [1], WMLES is employed to alleviate the stringent near-wall resolution requirements of wall-resolved LES, enabling larger time steps and a significant reduction in computational cost while retaining the essential unsteady flow physics. The numerical framework is based on a continuous Galerkin spectral element method (CG-SEM) [2], which further reduces the degrees of freedom while preserving the high-order accuracy required for large eddy simulations.

A central focus of the present study is the assessment of spanwise domain extent and resolution effects on the predicted transonic buffet dynamics. The results demonstrate that spanwise modeling has a pronounced influence on shock-wave/boundary-layer interactions, shock-induced separation, and the development of coherent turbulent structures. In contrast to the results reported by Kawai and Fukushima [1], the present simulations exhibit different buffet characteristics and spanwise flow organization. These discrepancies are consistent with observations previously discussed by Haas and Housman [3], highlighting the sensitivity of transonic buffet predictions to three-dimensional effects.

The findings underline the importance of adequate spanwise representation in WMLES [4] of transonic buffet and demonstrate that the combination of WMLES and CG-SEM provides an efficient and robust framework for the simulation of unsteady transonic flows over realistic airfoil geometries.

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STS 399-3

Towards a Spectral Element Framework for Tetrahedral Meshes Using Entropy Stable Two-Point Flux Formulations

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Abstract

High order spectral element methods based on summation by parts operators and split form discretizations have become a cornerstone for the development of robust and low dissipation solvers for incompressible and compressible flows. The SOD2D framework was originally conceived as a three dimensional spectral element code on unstructured hexahedral meshes, with a strong emphasis on energy consistent formulations, entropy stability and the systematic use of two point numerical fluxes [1].

In the context of the mini symposium on advances in scale-resolving simulation for turbomachinery, this contribution presents the extension of SOD2D towards fully unstructured tetrahedral meshes using a nodal spectral element formulation on simplicial elements. The proposed approach leverages recent developments in tensor product spectral element operators with the summation by parts property on curved triangles and tetrahedra [2], enabling the construction of metric consistent discretizations that preserve the mimetic and stability properties of the original hexahedral framework.

For both incompressible and compressible governing equations, we formulate a unified SEM scheme based on split forms and symmetric two-point fluxes that ensure discrete conservation and entropy stability at the semi discrete level. Attention is devoted to the design of low dissipation stabilisation mechanisms that act selectively on the antisymmetric part of the numerical flux, allowing the method to remain essentially non dissipative in smooth regions while providing sufficient robustness near under resolved gradients and discontinuities.

The resulting tetrahedral spectral element solver is assessed on a series of benchmark problems, including vortex dominated incompressible flows and shock containing compressible configurations. Numerical results demonstrate that the proposed methodology achieves stability and accuracy levels comparable to structured element implementations, while significantly enhancing geometric flexibility. This work contributes to bridging the gap between entropy stable high order formulations and practical simulations on complex industrial geometries within a unified spectral element framework.

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STS 399-4

Filling the Gaps: Video Inpainting for Fluid Flow Reconstruction

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Abstract

Access to reliable and complete experimental data is essential for understanding fluid dynamics phenomena. However, due to experimental limitations, the data obtained are often limited or incomplete, exhibiting gaps, missing entries, and other imperfections that hinder their analysis. As a result, the development of methods for repairing and/or augmenting experimental data is of great interest [1, 2]. From a data-driven perspective, this reconstruction task can be seen within the paradigm of image inpainting.

In the machine learning and deep learning literature, image inpainting refers to the process of filling missing regions of an image with synthetically generated content that is consistent with the observed data. Successful inpainting requires the reconstructed pixels to preserve both local and global characteristics of the original image, including colour distributions, shapes, textures, and semantic structures. When extended to time-resolved data (i.e. videos), this paradigm becomes video inpainting, which further imposes the requirement of temporal coherence across consecutive frames.

Similarly, repairing a gappy dataset of a fluid flow requires to preserve fluid structures and temporal coherence. Therefore, the use of video inpainting techniques seems adequate. In this work, we employ the Spatial-Temporal Transformer Network (STTN) [3] to address the reconstruction of incomplete fluid flow data. The STTN leverages a transformer-based architecture to model long-range spatio-temporal dependencies, enabling coherent reconstruction across missing regions. We demonstrate that this approach yields improved pointwise accuracy and better preservation of spectral content compared to classic reconstruction methods, highlighting its potential for the repair and augmentation of experimental fluid flow data.

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STS 399-5

Experimental and Numerical Design of a High-Pressure Reciprocating Compressor

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Abstract

Providing high-pressure compressed gas streams is a desired capability in various applications related to energy storage, transportation, propulsion, and petrochemistry. Oil-free reciprocating piston compressors are commonly employed as boosters across various platforms and over a wide range of flow rates and pressures due to their inherently flexible design [1]. However, modeling such reciprocating compressors becomes crucial for high delivery pressures since experimentation on new designs is costly. Because of numerous parameters that affect the throughput and operation pressure, the design space is very wide and therefore robust, capable, and reliable modeling approaches are required for rational development of high-pressure boosters. Although a few comprehensive numerical studies on high-pressure reciprocating compressors are available in literature, experimental validation of numerical predictions is rather rare [2-3].

In this study, a multidimensional modeling framework was developed for a high-pressure reciprocating compressor, consisting of both a 0-D mathematical model and a CFD multiphysics model with a deforming mesh by using commercial software. Recognizing that compressor accuracy relies heavily on specific sub-physics, the two most important ones, (i) check valve dynamics and (ii) heat dissipation, were investigated separately [4-5]. To develop a semi-empirical check valve model and to determine the necessary flow coefficients, experimental and CFD investigations were conducted. Similarly, to determine accurate heat transfer coefficients for ambient heat exchange, experimental methods were developed, and they were cross-validated with computational thermal analysis. The integrated compressor models were then compared with experimental data obtained with a commercial booster pump capable of operating pressures up to 750 bar. The comparison indicates that while the CFD model offers detailed resolution of internal pressure and temperature fields, the lumped mathematical model successfully captures the macroscopic behavior. We demonstrate that both models provide critical information regarding discharge pressures and mass flow rates, offering a validated toolset for both rapid prototyping and detailed design.

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STS 399-6

Elasticity-Based r-Adaptation for High-Order Spectral Element Methods

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Abstract

We present a high-order mesh r-adaptation strategy based on a linear elasticity formulation within a continuous Galerkin spectral element method (CG-SEM) framework. The approach enables solution-driven mesh redistribution while preserving high-order accuracy and mesh validity.

The computational mesh is modeled as an elastic solid [4], and nodal positions are obtained by solving a linear elasticity problem. A spatially varying elasticity tensor derived from solution features concentrates nodes in regions of interest while smoothly redistributing them elsewhere.

Mesh motion is incorporated within the CG-SEM framework using an Arbitrary Lagrangian-Eulerian (ALE) formulation. The resulting mesh velocity enters the convective operator, and the geometric mapping is updated by enforcing the discrete Geometric Conservation Law (DGCL). This ensures exact free-stream preservation and prevents spurious source terms, allowing conservation and high-order accuracy to be maintained on moving meshes [2, 3].

The methodology is implemented in the GPU-accelerated compressible flow solver SOD2D [1] using OpenACC. Since redistribution does not alter element connectivity, the method is well suited for GPU-accelerated high-order discretizations where remeshing would incur efficiency and scalability penalties.

The methodology is applied to compressible flow problems in the transonic and supersonic regimes, where the mesh is dynamically adapted to concentrate resolution across shock waves. The increased resolution reduces numerical dissipation and improves solution accuracy. Results show that elasticity-based r-adaptation can follow shock motion and deformation in unsteady simulations, concentrating nodes along the shock front while preserving mesh quality, and high throughput on GPU architectures.

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STS 399-7

Communication-Hiding Strategies for Enhanced Parallel Performance of the CFD Solver SOD2D

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Abstract

SOD2D is a high-order computational fluid dynamics (CFD) solver designed for large-scale simulations of both compressible and incompressible flows on modern high-performance computing systems [1]. The code follows a performance-portable approach based on OpenACC, enabling efficient execution on both GPU- and CPU-based architectures. Prior work has analysed the parallel performance and scalability of SOD2D across a range of workloads, highlighting near-ideal weak scaling and very good strong scaling trends while also identifying communication costs as a limiting factor at high concurrencies [2]. Recent developments have further focused on preparing SOD2D for exascale-class platforms, achieving excellent parallel efficiencies on leadership systems with up to thousands of compute nodes.

Although the code exhibits good parallel performance, profiling analyses indicate that inter-partition communication becomes a dominant cost at large concurrencies, both in strong- and weak-scaling regimes. In the current implementation, the evaluation of spatial operators and the execution of MPI halo exchanges are performed sequentially, which prevents overlapping communication with computation and limits scalability as the communication-to-computation ratio increases.

This work presents a redesigned operator-evaluation workflow aimed at hiding communication costs through asynchronous execution. The computational domain is partitioned into MPI-boundary elements and interior elements. Operator kernels associated with boundary elements are evaluated first, after which non-blocking MPI halo exchanges are immediately initiated. While communication progresses, the remaining interior-element computations are executed concurrently on the target architecture.

Performance results demonstrate that this communication-hiding strategy leads to improved parallel efficiency and speedup across a wide range of core and accelerator counts. The proposed approach enhances both strong- and weak-scaling behaviour, contributing to the sustained scalability of high-order CFD solvers on current and future exascale systems.

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STS 399-8

Characterization of the Transonic Flow in a Diffusive Passage

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Abstract

In this work, a transonic diffuser is investigated, representative of future advanced high work low pressure turbines and diffusive high pressure turbines suitable for rotating detonation engines. We perform Large Eddy Simulations (LES) to reproduce the flow observed in a wind tunnel experiment. The numerical results are first validated against pressure measurements obtained on the bottom wall of the test section, which features a hump-like geometry. The flow dynamics are then characterized using Proper Orthogonal Decomposition (POD) applied to the CFD solution.

Two inlet Mach numbers, 0.31 and 0.40, are investigated, corresponding to Reynolds numbers of 2.67×10^5 and 3.60×10^5 , respectively, based on the hump height. The computational domain consists of a spanwise extrusion of the midplane geometry, assuming an approximately two-dimensional flow. A structured mesh is employed, with average dimensionless spacings of $\Delta y^+ \approx 2$, $\Delta x^+ \approx 90$, and $\Delta z^+ \approx 50$. The simulations are carried out using SOD2D, a high-order, low-dissipation spectral element method solver.

This study represents a first step toward high-fidelity simulations of transonic diffusers. To the authors' knowledge, previous numerical studies of this configuration usually employ second-order URANS solvers.

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STS 399-9

Conforming Adaptive Hexahedral Mesh Refinement for Spectral-Element Simulation of Turbulent Flows

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Abstract

Efficiency is a primary objective in engineering, and aerodynamics is no exception. This is particularly critical in the transportation sector, where reducing aerodynamic drag directly contributes to lower energy consumption. Addressing this challenge requires reliable and accurate numerical tools capable of supporting design optimization processes. In this context, Computational Fluid Dynamics (CFD) plays a central role, especially when combined with accelerated computing technologies such as Graphics Processing Units (GPU).

SOD2D [1, 2] is a GPU-accelerated solver based on a spectral formulation of the Continuous Galerkin Method (CG-SEM). The methodology benefits significantly from the use of high-order spectral hexahedral elements, which allow for efficient operator evaluation and improved exploitation of fine-grained parallelism on modern GPU architectures. However, the requirement of fully hexahedral meshes poses substantial challenges for mesh generation, as the automatic generation of unstructured full-hexahedral grids remains an open and active area of research.

A common strategy to alleviate this limitation is to permit non-conforming interfaces between elements [3, 4], which relaxes meshing constraints at the cost of additional numerical treatment at inter-element boundaries. Alternatively, a widely adopted workaround consists of generating tetrahedral meshes, which are subsequently partitioned into hexahedral elements.

In this work, we propose a mesh refinement technique that exploits the duality between tetrahedral and hexahedral discretizations to overcome the limitations associated with unstructured hexahedral mesh generation. The proposed approach enables systematic mesh refinement while preserving conforming hexahedral elements, thereby avoiding the need for non-conforming interfaces. This strategy is particularly well suited for high-order spectral element methods, where mesh regularity and element quality are critical for numerical accuracy and performance.

The proposed methodology aims to combine the geometric flexibility of tetrahedral meshes with the computational efficiency of spectral hexahedral discretizations, providing a promising pathway for high-fidelity, GPU-accelerated aerodynamic simulations in complex industrial configurations.

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STS 399-10

Assessment of Numerical Approaches for the Prediction of Large-Scale Flow Structures on Separated Flows Using Resolvent Analysis

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Abstract

Flow separation is a ubiquitous phenomenon present in several aeronautical applications, such as low-pressure turbines (LPT) and Micro Aerial Vehicle wings, and is associated with detrimental effects on aerodynamics and performance. These effects are ultimately dominated by the large-scale coherent turbulent structures formed in the separated shear layer. Understanding the physics underlying the formation of these large-scale structures can be exploited towards their efficient manipulation, with the ultimate objective of informing flow control strategies that reduce the negative impact of flow separation. Large Eddy Simulations (LES) are today capable of accurately predicting the flow dynamics for cases of industrial interest, but their computational cost prevents their use in fast-return design cycles or to inform flow control strategies. As an alternative, linear instability equations can obtain predictive information on the dominant coherent structures, with reasonable fidelity in terms of spatial structure and frequency content, at a small fraction of the computational cost associated with LES. Resolvent analysis [1] is one formulation of the linearized equations in the frequency domain, in which the impact of non-linear interactions and external excitation are recast as an endogenous forcing term. The analysis then consists in computing, for each frequency, the forcing term that leads to an optimal response in terms of energy amplification, allowed by the linearized equations over the mean flow.

In this work, we employ resolvent analysis to model the most energetic flow structures formed on the separated flow over a wall-mounted bump geometry that reproduces the pressure gradient distributions present in a LPT blade [2]. The formation of coherent structures in this flow is governed by the convective amplification of the pre-existing flow disturbances by the intense mean flow shear [3], making it a good test case to assess different numerical approaches for conducting resolvent analysis. In particular, we compare matrix-forming approaches based on different manners of defining the linearized equations, i.e. linearized analytical equations and a numerical Jacobian typically used in implicit solvers, and alternatives based on the time-marching of the equations.

Acknowledgements This research has been carried out under project TRANSDIFFUSE, funded by European Research Council Synergies Grant Agreement No. 101167322, project STALSUnS, funded by European Union's Horizon Europe research and innovation programme under the Marie Skłodowska-Curie grant agreement no. 101063992, and project MIADDTRANS (PID2024-157642MB-I00) funded by MCIN/AEI/10.13039/501100011033.

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STS 399-11

Assessment of Wall-Modeled LES for Film-Cooling Flows on Nozzle Guide Vanes

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Abstract

Accurate prediction of film-cooling performance remains a major challenge in turbomachinery. The interaction of turbulent boundary layers, strong pressure gradients, and jet-crossflow mixing generates a wide range of spatial and temporal scales that are not reliably captured by (unsteady) Reynolds-averaged Navier–Stokes (RANS/URANS) methods. While large-eddy simulation (LES) offers the fidelity required to resolve these multi-scale phenomena, wall-resolved LES (WRLES) of realistic turbine components remains prohibitively expensive for routine design workflows. Bridging the gap between predictive accuracy and computational feasibility requires a systematic assessment of wall-modeling strategies in configurations representative of gas-turbine cooling.

This work presents a hierarchy of high-fidelity simulations of the canonical 7-7-7 fan-shaped film-cooling hole configuration [1], progressively increasing the complexity to mimic conditions encountered in turbine vanes. First, a baseline WRLES of the flat-plate 7-7-7 configuration is performed to establish a reference database for jet-in-crossflow and near-wall heat transfer [1]. The study is then extended to curved surfaces, introducing streamwise pressure gradients that influence coolant jet attachment, mixing, and effectiveness. Finally, the methodology is applied to a generic nozzle guide vane (NGV) profile section equipped with cooling-holes, thereby providing a step toward application-relevant geometries.

The WRLES will serve as a baseline. Established wall-modeling approaches based on RANS and Detached Eddy Simulations will be compared with the reference simulations to assess their limitations. The comparison will focus on adiabatic film-cooling effectiveness, heat-transfer coefficients, and near-wall turbulence statistics. By systematically quantifying the deviations between wall-modeled approaches and WRLES, this study aims to identify the physical mechanisms responsible for model breakdown in film-cooling flows. The resulting high-fidelity dataset provides a foundation for assessing alternative near-wall scalings and turbulence-closure assumptions in strongly non-equilibrium boundary layers, thereby informing future developments in wall modeling for turbomachinery applications.

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STS 399-12

Development of Scale-Resolving Simulation Capabilities for Turbomachine Blade Design

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Abstract

The ambitious environmental objectives assigned to the aeronautical industry in the upcoming years require radical innovation in aircraft propulsion, including groundbreaking engine architectures and usage of alternative fuels. As a result, the upcoming generation of aircraft engines will face more varied and demanding flow conditions, that challenge the capabilities of current RANS-based CFD tools. In this context, aerodynamic and aerothermal design methodologies integrating Scale-Resolving Simulation (SRS) methods, i.e. Large-Eddy Simulation (LES) and Direct Numerical Simulation (DNS), can significantly contribute to overcome the current barriers.

In this talk, we will present continued efforts at Cenaero to develop an SRS capability applicable to realistic turbomachine flows. The developments are driven by two main aspects. The first one is the need for acceptable turnaround time, that is addressed by high-order Discontinuous Galerkin spatial discretizations efficiently running on large-scale GPU-based supercomputers. Time integration methods, appropriate mesh generation and methodological improvements are also crucial in reducing the computational time required to reach statistically converged SRS solutions. The second aspect is the ability to correlate SRS results with experimental data for (cross-)validation, involving both the physical representativeness of the simulation (in particular inflow turbulence) and the representation of real-world secondary effects not directly modeled by the simulation setup (e.g. streamtube contraction effects in cascade flows). Examples of applications highlighting the benefits of SRS over RANS will be given. Nevertheless, we will emphasize that SRS should not be considered as a drop-in replacement for RANS in engine design processes because of its computational cost. Consequently, a significant part of the talk will be dedicated to multi-fidelity strategies for the integration of SRS in shape optimization methodologies, including the use of LES and DNS results to benchmark, calibrate and improve turbulence models on a case-specific basis with the help of Machine Learning (ML) techniques.

STS400 - CFD for ONERA, DLR and Airbus – Advanced Features of CODA for future CFD I

Main Organizer: Ms. Cornelia Grabe (DLR)

Chaired by: Ms. Cornelia Grabe (DLR), Dr. Stephanie PERON (ONERA, France)

Part	Date	Time	Room
STS400A	Tue 21.07.2026	09:45–11:15	NM - 2 (Salzburg)

We propose a Special Technology Session on the joint CFD-code developed by Airbus, ONERA and DLR and, in particular, we will present and demonstrate the advanced features of CODA compared to legacy methods.

STS 400-1

CODA Technical Overview and Applications: Current Status and Future Challenges

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Abstract

Airbus, DLR and ONERA will give an introduction and overview of their collaborative and common CFD solver “CODA” [1-3].

In this overview talk we will address the following aspects:

- Background: Why do we need CODA?
- Collaboration between Airbus, DLR & ONERA
- Technical Overview of CODA: Architecture and Ingredients
- Current real life applications of CODA in Airbus
- Future challenges in Airbus

The future challenges will focus on the development of future aircraft configurations.

Specific challenges in CODA will be addressed in the following talks of this STS.

For further information please contact

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STS 400-2

Advances in High-Order Discontinuous Galerkin Methods in the CODA Flow Solver

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Abstract

This work presents recent advances made in the flow solver CODA¹ (CFD solver jointly developed by ONERA, DLR and Airbus) as regards its high-order spatial discretization, namely based on modal Discontinuous Galerkin and nodal, entropy stable DGSEM schemes. We present the high-order DG and DGSEM shock capturing strategy employed in CODA, as well as several applications, including an inviscid forward-facing step at Mach 3, a viscous shock-wall interaction, and the supersonic Taylor-Green vortex flow. These tests are carried out using various mesh topologies and polynomial degrees, which demonstrate the robustness, flexibility and accuracy of CODA for such applications. The interest of the DG method is also demonstrated in a more applied cruising-condition CRM configuration using RANS modeling (see Figure 1). In this case, a significant improvement in the drag coefficient prediction are observed when increasing the order of accuracy or polynomial degree of the DG approximation. Using DGSEM, we demonstrate the capability to perform a wall-modelled LES of the subsonic flow around a rudimentary landing gear geometry (illustrated in Figure 2) placed inside a wind tunnel, employing meshes generated in a highly automatic manner. We assess accuracy in the mean and standard deviation of the pressure coefficient along the wheel's circumference and find an overall good match with experimental results.

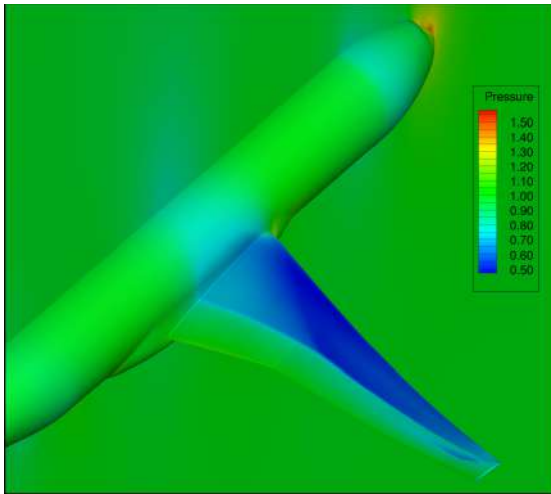


Figure 1: Pressure contours over CRM geometry: DG p_2 transonic RANS simulation

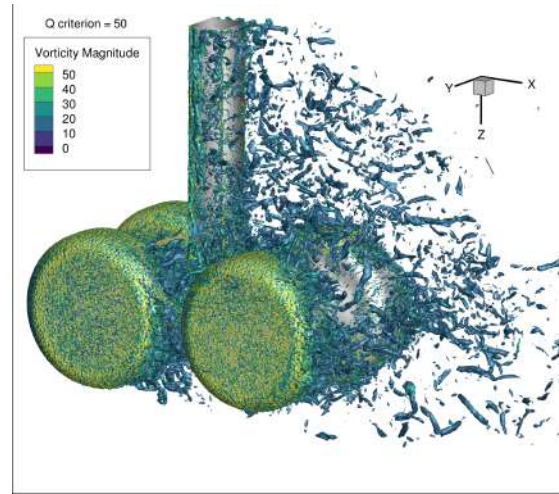


Figure 2: Instantaneous flow around a rudimentary landing gear (p_3 , 22M DOFs/eqn)

¹CODA is the computational fluid dynamics (CFD) software being developed as part of a collaboration between the French Aerospace Lab ONERA, the German Aerospace Center (DLR), Airbus, and their European research partners. CODA is jointly owned by ONERA, DLR and Airbus.

STS 400-3

Implementation of Non-Reflecting Boundary Conditions for Steady Blade Row Coupling in CODA

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Keywords: High Performance Computing, Non-Reflecting Boundary Conditions, Blade Row Coupling, Fluid Mechanics

Abstract

The integration of aeroengines with open fan architectures remains one of the most challenging tasks in the design of next generation aircraft. Tackling such a design problem can only be achieved by the coherent endeavor of various disciplines. In this regard, CODA (CFD Onera DLR Airbus) is being developed by the German Aerospace Center (DLR), the French Aerospace Lab (ONERA) and Airbus as a next generation CFD solver, with both aircraft and aeroengine fan design capabilities and optimized for modern HPC architectures [1].

The accurate simulation of flows across the aeroengine fans requires the correct treatment of the boundary conditions, which are particularly challenging due to physical complications and geometrical constraints originating from the problem's nature. A pivotal approximation in the coupling of the adjacent blade row domains in relative motion with respect to each other, is the mixing plane boundary condition. Despite the unsteady nature of flows through cascades of rotating and stationary blades, the mixing plane approach - accounting only for the time-mean interactions between the blade rows - has proven beneficial as an efficient method for steady computation of the flows within compressor and turbine stages. One crucial aspect that must be taken into account while formulating the mixing plane boundary condition arises from the fact that the artificial boundary is inevitably located close to the field of interest. Therefore, in order to avoid spurious reflections emerging at the boundary and corrupting the solution, the mixing plane method must be combined with non-reflecting boundary conditions [2]. In this work, the existing one-dimensional non-reflecting boundary conditions are enhanced through a more advanced, state-of-the-art alternative. In particular, we present the implementation of the new variant of the mixing plane boundary condition in CODA, examine issues impacting stability and efficiency, and discuss the accuracy improvements achieved through its use.

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STS 400-4

Grid Adaptation in the Context of DG and FV

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Abstract

High-fidelity computations are expensive, but required to simulate complex aircraft configurations for all flight regimes. Adaptive methods improve the accuracy-to-effort ratio by concentrating high flow resolution on regions where it is needed, which are identified by reliable refinement indicators.

This presentation considers a residual-based indicator that accounts for the error on all flow features regardless of their influence on the boundary integral values [1]. Alternatively, an adjoint-based indicator for discontinuous Galerkin methods is used for goal-oriented adaptive computations. Also, this work presents first extensions of it to the finite volume method. The indicators are combined with a hierarchical h-adaptation, using FSAdaptationNG. In case of DG, they additionally guide local polynomial enrichment for hp-adaptation. These methods are integrated in the CFD software by ONERA, DLR and Airbus (CODA)¹ [3] and demonstrate superior accuracy for given computational efforts compared to fixed-grid computations and state-of-the-art adaptive methods.

This work also features metric-based mesh adaptation where the metric field is computed from an accurate Hessian of the Mach number, using the optimal metric formulation from the multiscale error estimator theory [2]. This Hessian, that is computed from the Discontinuous Galerkin formulation, is then rescaled using aforementioned state-of-the-art DG error estimators for higher-order computations. The methods have been validated and applied to configurations of increasing complexity, using the remesher Tucanos [4] and the flow solver CODA [3]. The results demonstrate similar or superior accuracy compared to a variety of state-of-the-art adaptive and non-adaptive flow solvers.

¹ CODA is the computational fluid dynamics (CFD) software being developed as part of a collaboration between the French Aerospace Lab ONERA, the German Aerospace Center (DLR), Airbus, and their European research partners. CODA is jointly owned by ONERA, DLR and Airbus.

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STS 400-5

**Implementation of an Immersed Boundary Method in the CFD Software by
ONERA, DLR and AIRBUS**

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Abstract

This paper discusses the implementation of a direct-forcing Immersed Boundary Method (IBM) in the CFD software by ONERA, DLR and AIRBUS¹ to solve the compressible Reynolds-Averaged Navier-Stokes (RANS) equations around geometrically complex geometries. Developed in close collaboration between ONERA and DLR, this method explicitly forces the flow solution at the integration points located near the immersed boundaries using Immersed Boundary Conditions (IBCs).

As the mesh does not need to conform to the obstacles within the flow to handle intricate geometries, the current approach uses Cartesian meshes to simplify and automate the mesh generation process. Both the Cartesian mesh generation and the specific IBM pre-processing to locate the integration and donor points are handled via Cassiopee (CFD Advanced Set of Services in an Open Python Environment) modules. Unlike other IBM implementations, unstructured AMR-type meshes are favored over structured octree-based grids to reduce the final number of cells by multiple orders of magnitude and to leverage the unstructured architecture of CODA.

A collection of offsets defined from the immersed boundary (surface edges or surface meshes, depending on the simulation dimension) is then used to determine the different levels of refinement. Recent improvements brought to the mesh adaptation tool algorithm have significantly increased the efficiency of the mesh generation and have overcome prior memory limitations. The solution at integration points located on the immersed boundaries is computed using the weakly imposed boundary condition formulation in CODA, adapted for the IBM approach. Wall functions are applied to avoid Cartesian cells with $y^+ = 1$ near the walls, which would be too prohibitive in terms of cell count for high Reynolds number simulations.

RANS simulations are compared against body-fitted wall-resolved solutions, as well as other Cartesian IBM solutions, in order to assess the accuracy, the robustness and the performance of this IBM methodology, especially in terms of skin pressure and skin friction coefficients. To that end, various academic 2D and 3D test cases have been envisioned and thoroughly tested. The conclusions and details of these validations can be found in a companion paper.

¹ CODA, being developed as part of a collaboration between the French Aerospace Lab ONERA, the German Aerospace Center (DLR), Airbus, and their European research partners. CODA is jointly owned by ONERA, DLR and Airbus.

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STS 400-6

**Applications of the New CFD Software by ONERA, DLR,
Airbus (CODA) and Its Algorithmic Differentiation
Framework in Aero-Structure Optimization: Status and
Way Forward**

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Abstract

Multidisciplinary analysis and optimization (MDAO) capabilities based on high-fidelity methods for aerodynamics and structural mechanics are essential for the design of appropriate next-generation aircraft. Optimization problems for industrially relevant use cases typically contain a vast number of design parameters and constraints in all disciplines being involved. That requires for reasons of efficiency the use of gradient-based methods that rely on the presence of accurate intra- and interdisciplinary gradients. With the aim of fulfilling these requirements, as well as for other motivating reasons, the next generation of CFD software is being developed by ONERA, DLR and AIRBUS (CODA) [1, 2]. One of the outstanding features of CODA, especially for its use in the context of optimization, is its algorithmic differentiation (AD) capability [3]. It enables exact differentiation in forward and reverse (adjoint) mode for all available discretizations and turbulence models. Furthermore, the DLR and its partners are continuously developing a gradient-based MDAO suite in multidisciplinary feasibility formulation (MDF) applying RANS-based computational fluid dynamics (CFD) solvers. The FlowSimulator environment, which is being jointly developed by DLR, ONERA and AIRBUS and is specifically tailored for the simulation of CFD-based multidisciplinary applications on HPC systems [4], is applied as an overarching software integration framework for the elements of the MDAO suite.

This paper provides an overview of the current optimization capabilities using the CODA AD framework in combination with the LAGRANGE optimization framework from AIRBUS Defence and Space [5]. A fully coupled aero-structural gradient computation is presented to utilize the duality of calculating the coupled gradients using forward differentiation and adjoint mode. Optimizations are carried out which show that the use of forward differentiation and the adjoint method lead to identical designs. For obtaining designs that are free of local flow separation at the design point and in areas around it, as required in industrial design, flow feature-based constraints were developed. By means of forward differentiation, the constraints were efficiently integrated into the optimization process and the capability was demonstrated in the shape optimization of an high aspect ratio wing. It is shown that the optimized wing with the applied flow constraints under off-design conditions results in a wing that is completely free of flow separation, thereby fulfilling all imposed requirements, with only an insignificant increase in drag in cruise flight. The methods are demonstrated on the industrially relevant benchmark test case DLR-F25, featuring a flexible high-aspect ratio wing [6] with a large number of design variables reflecting aerodynamic shape and structural properties.

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STS404 - New Digitalized Methods and Tools for New Challenges in Green Aerospace Engineering and Scientific Computation

Main Organizer: Prof. Jacques Periaux (cimne, Spain)

Part	Date	Time	Room
STS404A	Mon 20.07.2026	11:30–13:00	NM - 2 (Salzburg)

Everybody knows the importance of reducing the risks of climate change. Reducing CO₂ emissions and noise levels in aviation remains today and tomorrow a great challenge. Innovations in Research and Industry are crucial towards reaching climate neutrality for aviation and modern Transport by 2050. Now, halfway to the target, scientists and engineers are delivering results for a greener aviation in the fields of propulsion systems (1), aerostructures (2), aerodynamics (3) and disruptive aircraft configurations (4). These innovative technologies are candidates for integration into modern transport systems within the next two decades. A critical question for sustaining growth in the aviation sector is: are the current digital methods and tools in development including Artificial Intelligence (AI) sufficiently advanced for mastering new numerical methods and tools to provide solutions to new challenges contributing to a decarbonated environment? This STS (two hours format) will consist of Keynote lectures presenting innovative numerical solutions contributing to first priority challenges in climate neutrality in the fields of (1), (2), (3) and (4).

STS 404-1

Robust Optimization Techniques for Uncertain Aerospace Environments

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Abstract

The pursuit of climate-neutral aviation demands optimization methods that remain reliable under real-world uncertainty and the highly nonlinear physics of modern aircraft design. This keynote presents two complementary data-driven optimization strategies for robust aerodynamic design. First, we introduce a Distributionally Robust Optimization (DRO) framework that constructs ambiguity sets from operational and environmental data. By optimizing for the worst-case expected performance, DRO provides a statistically principled way to formalize the trade-off between performance and resilience to distributional shifts for real-world engineering. Second, we enhance gradient-based, high-fidelity design optimization by embedding learned design knowledge. Using generative diffusion models, we learn a smooth manifold of physically realistic shapes from existing designs and enforce it as an optimization constraint. Central to the method is the backpropagation of adjoint-computed shape gradients through this generative model to the latent space. This ensures the optimization remains within aerodynamically plausible regions, thereby eliminating trial-and-error tuning and ensuring greater robustness to initialization and optimizer choices. We will outline algorithmic components, integration with CFD and adjoint workflows, and representative transonic aerodynamic results that illustrate improved robustness compared to conventional approaches.

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STS 404-2

Incremental MDO Framework for Sizing and Optimisation of H₂-Fuelled Electric Power Train in General Aviation Propeller Aircraft

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Abstract

Achieving Net Zero aviation objectives demands a fundamental rethinking of aircraft propulsion architectures [1]. The design of electric powertrains, where strong couplings between propulsion, electrical and thermal management systems are inadequately captured by conventional sequential sizing approaches represents the key technological challenge. In such architectures, Balance of Plant (BoP) components become critical design drivers, as cooling requirements directly impact aerodynamic drag and auxiliary power demand, with a straight penalty on propulsive efficiency [2].

The objective of this work is to develop an integrated, physics-based sizing and Multidisciplinary Design Optimisation (MDO) framework for H₂-fuelled electric power trains in general aviation propeller aircraft, capable of considering these couplings at the conceptual design phase. A novel holistic optimisation environment is developed where fuel cell, electric motor, propeller, air intake, and thermal management system are simultaneously sized within a unified framework leveraging consistent physical models. This tool is implemented in OpenMDAO, enabling tight coupling between disciplinary models and efficient gradient-based optimisation.

The fuel cell system is modelled using Proton Exchange Membrane Fuel Cell (PEMFC) polarisation curve and electrochemical constitutive equations, computing stack voltage, thermal balance, reactant mass flows, and also sizing ancillary elements. BoP power consumption is explicitly calculated and included within the overall power balance. Thermal management system includes the sizing of heat exchangers and their cooling air path. The air intake is modelled and optimised using a one-dimensional formulation based on compressible flow relations, combining Rayleigh, Fanno and isentropic flow effects while estimating pressure losses induced by the heat exchanger and external drag.

The methodology follows an incremental development strategy, with individual components validated prior to integration into the MDO framework. A Single-Design-Point optimisation is used for baseline sizing and extended to a Multi-Design-Point formulation to ensure constraint fulfilment across the flight envelope, avoiding infeasible or inefficient designs [3]. The resulting framework will provide a consistent foundation for the preliminary sizing of H₂-electric powerplants, supporting the development of viable hybrid-electric aircraft aligned with long-term sustainability objectives.

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STS 404-3

Shakedown-driven Design of Reusable Spacecraft Structures via Topology Optimization and Physics-Informed Machine Learning

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Abstract

To meet the stringent requirements of safety, lightweight, and reusability for future crewed spacecraft, conventional elastic limit-based design approaches are becoming obsolete. To this end, this study proposes employing elastic shakedown as a more advanced design criterion and develops a comprehensive framework for designing complex aerospace components.

Specifically, we focus on two representative structures: the integrally stiffened cabin body and lightweight brackets. To evaluate these structures, a shakedown analysis algorithm for shell elements with drilling degree of freedom is developed, providing the basis for a subsequent shakedown-based optimization of stiffened panel. Furthermore, a shakedown-oriented topology optimization algorithm is established to allow for the synergistic design of stiffener layouts and material distribution, ensuring structural integrity under cyclic loading while minimizing mass.

The proposed methodology is validated through both numerical simulations and shakedown experiments, and in addition to the conventional numerical optimization techniques for solving the shakedown problem, we also discuss how to combine Graph Neural Networks (GNN) with Physics-Informed Neural Networks (PINN) to achieve a more efficient shakedown analysis. This research provides a robust and efficient path for the lightweight design of next-generation reusable space structures, shifting the design paradigm from conservative elastic limits to more realistic cyclic plasticity boundaries.

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STS 404-4

Operator learning method with adaptive activation function for high speed shock tube problems and airfoil flows

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Abstract

To accurately capture sharp features like shock and expansion waves in high-speed compressible flows, we introduce the OL-AAF (operator learning method with adaptive activation function), a novel framework designed to learn solution operators for parametric governing equations for high speed shock tube problems and airfoil flows. The primary novelty of the neural network lies in a layer-wise gated bridge branch that establishes interaction information channels between the latent representations of neural networks. By utilizing learnable gating parameters to adaptively modulate coupled hidden features at every layer, the architecture's representational capacity is markedly increased. The approximation ability of the network is also improved by an adaptive Z-shape-ReLU activation function in the basis function network's terminal layers. Through the simultaneous optimization of its positive-axis slope and truncation threshold, Z-shape-ReLU counteracts the numerical 'blurring' typical of SiLU or other activation functions, ensuring high-fidelity approximations of strong discontinuities. Validated against high-speed shock tube and airfoil flow datasets, the OL-AAF framework outperforms DeepONet in shock-position accuracy and displays strong generalization. This study gains a robust architectural template for high-speed, data-driven aerodynamic prediction. To address discrepancies in physical equations, an enhanced fine-tuning module integrated with physical constraints is proposed. Physical equation residuals are calculated via a point-based query strategy to enable efficient gradient computation, which are then mapped into the latent feature space for iterative refinement. The fine-tuning workflow adopts a self-supervised learning paradigm, ensuring adherence to physical consistency without compromising the core characteristics of the generated fields. Experimental results demonstrate that this physics-informed fine-tuning framework achieves a substantial reduction in physical inaccuracies.

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STS405 - Advances in Simulation Technologies Towards Next-Generation Aircraft Design

Main Organizer: Dr. Yoshiaki Abe (Tohoku University, Japan)

Part	Date	Time	Room
STS405A	Thu 23.07.2026	09:45–11:15	NM - 2 (Salzburg)
STS405B	Thu 23.07.2026	11:30–13:00	NM - 2 (Salzburg)

As the aerospace industry strives for unprecedented levels of efficiency, sustainability, and performance, traditional design and testing methodologies are proving insufficient. This session will highlight the latest breakthroughs in high-fidelity simulations and Multidisciplinary Design Optimization (MDO), which are now seamlessly integrated to create highly accurate and predictive digital twins of aircraft systems. We will explore how these simulations are enabling engineers to rapidly iterate on complex designs, from novel aerodynamic configurations and lightweight composite structures to advanced propulsion systems. The session welcomes presentations and discussions on a range of topics, including: 1) High-order schemes for fluid dynamics: e.g., finite-difference/element, Discontinuous Galerkin (DG), and Flux Reconstruction (FR) methods for more accurate and efficient CFD; 2) Aeroelastic analysis: e.g., with a focus on high-aspect-ratio and flexible wings, which are critical for enhancing aerodynamic efficiency; 3) High-fidelity structural analysis: e.g., material and geometrical nonlinear analysis to better predict the behavior of complex structures under various situations; 4) Multi-physics simulation: Covering complex interactions such as fluid-structure interaction (FSI) and combustion science, essential for integrated system analysis; 5) Data-driven methods: Utilizing reduced-order models (ROMs) and machine learning to accelerate the design cycle and manage massive datasets. Discussions will also address computational resource challenges and data-management needs in large-scale simulations. Designed for researchers and professionals at the intersection of aerospace engineering and computational science, this STS highlights the shift from physical prototyping toward virtual design paradigms—paving the way for innovative, sustainable aircraft development.

STS 405-1

Preliminary Structural Design of a Truss-Braced Wing for Modular Wing Aircraft

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Abstract

The truss-braced wing (TBW) is a promising configuration for enabling high-aspect-ratio wings while alleviating wing-root bending loads through alternative axial load paths. Existing literature shows that structural modeling of truss-braced wings is largely dominated by two extremes: (i) numerical beambased multidisciplinary design optimization frameworks, which are computationally efficient but analytically opaque, and (ii) high-fidelity finite-element models, which are accurate but computationally intensive. What remains largely absent is a lightweight, parametrized analytical structural model that captures bending–torsion coupling and enables a transparent structural assessment of different truss configurations during the conceptual and preliminary design phases. This work addresses this gap by developing a fully parametrized structural framework for a modular truss-braced wing based on geometrically exact beam theory.

The wing–truss system is modeled using a geometrically exact Simo–Reissner bending–torsion beam formulation, capturing coupled axial force, shear force, bending moment, and torsional moment while explicitly representing the truss as a discrete load-carrying member. Realistic spanwise aerodynamic and mass distributions are applied under representative maneuvering load cases.

A parametric study is performed to investigate the influence of truss attachment location in both the spanwise and chordwise directions, quantifying how truss placement governs internal load redistribution along the wing. Subsequently, wingbox structural sizing is carried out using both the Simo–Reissner beam formulation and detailed finite-element analyses in MSC Nastran, yielding consistent thickness and mass trends. In addition, the truss is structurally sized under axial load and buckling constraints, and its aerodynamic performance is evaluated through the associated drag contribution.

The proposed framework provides a physically transparent and computationally efficient tool for conceptual and preliminary TBW design, supporting aero-structural trade-off studies prior to higher-fidelity numerical analyses.

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STS 405-2

Analysis and Wind Tunnel Experiment for High Aspect Ratio Wing Dynamics under Fuselage Vibration

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Abstract

High Altitude Platform Station (HAPS) planes have lightweight, high-aspect-ratio wings used for flying at high altitudes and providing internet connections in places where internet access is scarce. However, because of these wing characteristics, the wings can easily undergo large dynamic deformation that may lead to structural failure. Therefore, past research [1], [2] has conducted wind tunnel experiments to analyze wing dynamics under aeroelastic effects. However, fuselage vibrations, which can occur in flying planes operating in unsteady wind environments, have not been often considered.

Therefore, in this research, we conducted fuselage vibration experiments and simulations of a plane model with flexible high-aspect-ratio wings made of polyethylene terephthalate (PET). A Magnetic Suspension and Balancing System (MSBS) capable of six-degree-of-freedom (6DOF) control was used to float and vibrate the plane model at different frequencies. In addition, we developed a numerical model of the high-aspect-ratio wing based on a nonlinear finite element method called the absolute nodal coordinate formulation (ANCF). Fuselage vibration was considered in the simulation by applying sinusoidal displacement to the numerical wing model. The displacement of the flexible wing was measured during both the vibration experiments and simulations and was subsequently compared.

The root mean square (RMS) deflection of the wing, calculated after centering the vibration waveform about the x-axis, showed good agreement between the experiment and the simulation.

To the best of the authors' knowledge, this is the first research to use the MSBS wind tunnel for the research of high-aspect-ratio wing dynamics. The obtained experimental data will be useful for validating numerical models of high-aspect-ratio wings.

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STS 405A-3

Multibody Dynamics of Tethered Aerial Vehicle Using Arbitrary Lagrangian–Eulerian Absolute Nodal Coordinate Formulation with Rigid-Flexible Coupling

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ABSTRACT

Tethered structures have widely appeared in mechanical components due to their flexibility and lightweight characteristics. In aerospace engineering, aerial vehicles employ tethers as crucial components for towing, refueling, and exploration missions. Tethered structures form flexible multibody systems, and their dynamic motion can significantly influence the overall system behavior [1,2]. This study focuses on the transient dynamics of a tether attached to an aerial vehicle during deployment and retrieval processes. A numerical dynamic model is established by combining variable-length flexible cable model based on an arbitrary Lagrangian-Eulerian absolute nodal coordinate formulation (ALE-ANCF) with a rigid-body attitude model described using Euler parameters. Torsional effects in the cable are newly incorporated, and their dynamic influence on both the cable motion and the attitude of the rigid body is investigated. In conventional ALE-ANCF approaches, elements are inserted or removed when their lengths exceed prescribed thresholds, which can occur the numerical disturbances. To enhance numerical stability, a co-moving node strategy is proposed, in which adjacent nodes are advanced in tandem with node deletion. Numerical results demonstrate that the proposed method effectively captures the dynamic behavior of the tether and the aerial vehicle.

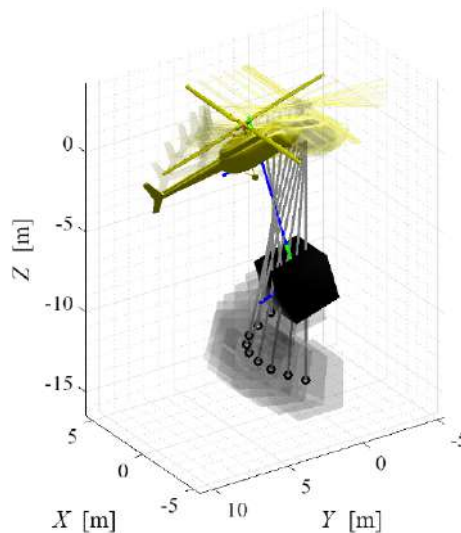


Figure 1: Dynamic motion of the aerial vehicle and container retrieved by the tether.

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STS 405-4

Simulating Unsteady Base Flow Around an Axisymmetric Bluff Body with Strut Interference Using High-Order ILES

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Abstract

The unsteady base flow around an axisymmetric bluff body at a Reynolds number of 3.2×10^5 is simulated using a high-order implicit large eddy simulation (ILES) approach. Accurate prediction of bluff-body base flow is challenging due to massive flow separation and unsteady turbulent structures in the near-wake region, which are not adequately captured by conventional Reynolds-averaged Navier-Stokes (RANS) methods. High-fidelity numerical schemes with low numerical dissipation are therefore required to resolve such flows. In this study, ILES of the separated base flow is performed using the high-order flux-reconstruction solver PyFR [1]. The results are validated against wind-tunnel experiments [2] through comparisons of the base pressure coefficient and near-wake velocity fields. Simulations including a support strut are also conducted to assess aerodynamic interference effects associated with wind-tunnel mounting. In the presentation, we will explore in detail the effects of the support strut on the base pressure distribution and the resulting unsteady wake flow structures.

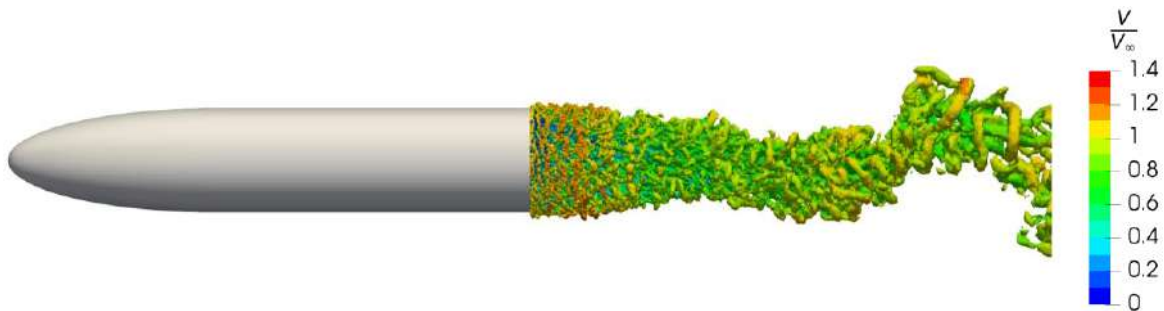


Figure 1: Axisymmetric body and iso- Q surface contoured by velocity magnitude.

Acknowledgement

This research is supported by the National Research Foundation of Korea (NFR) grant funded by the Korea government (MSIT) (No. RS-2023-00282764).

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STS 405-5

Multidisciplinary Conceptual Design and Analysis of Ammonia-Fueled Composite Aircraft

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Abstract

Ammonia has emerged as a promising carbon-free energy carrier for sustainable aviation due to its high hydrogen density and well-established production, transportation, and storage infrastructure. However, the adoption of ammonia as an aviation fuel introduces significant challenges related to propulsion efficiency, fuel storage integration, and airframe structural design. This study proposes a multidisciplinary conceptual design and analysis framework for ammonia-fueled composite aircraft, integrating aerodynamics, structural mechanics, and fuel system considerations within a unified design environment.

At the conceptual design stage, candidate aircraft configurations are generated and evaluated through coupled aerodynamic analyses and propulsion performance models representative of ammonia-based power systems. The composite wing planform is designed and optimized based on the wing area required to satisfy mission range constraints. A multi-objective Bayesian optimization framework, combined with two-way coupled aeroelastic analysis and structural sizing, is employed to simultaneously minimize aerodynamic drag and structural weight, thereby enhancing overall aerodynamic efficiency.

For each optimized wing configuration, the composite fuselage is subsequently sized to ensure structural safety and integrity. The influence of wing planform parameters, particularly wingspan, on total airframe structural weight is systematically investigated. In parallel, a conventional kerosene-fueled aircraft is analyzed as a reference case to quantify the impacts of ammonia fuel storage requirements on airframe weight, load distribution, and overall aircraft efficiency. Key performance metrics, including lift-to-drag ratio, structural weight, and mission feasibility, are evaluated to identify viable design trends and multidisciplinary trade-offs. The results provide valuable insights into the conceptual design of next-generation ammonia-fueled composite aircraft and offer guidance for future sustainable aviation development.

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STS 405-6

On the Implementation and Analysis of a Domain-Coupling Algorithm in CODA

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Abstract

To fully realise the combined potential of next generation aircraft and engine technologies an integrated multiphysics design approach is essential. In this context the German Aerospace Center (DLR), the French Aerospace Lab (ONERA) and Airbus are currently developing CODA (CFD ONERA DLR Airbus), a next-generation CFD solver for aircraft and turbomachinery design, devised to be able to fully exploit current and future HPC architectures [1].

Beyond robust and efficient numerical discretization schemes, the efficient and accurate simulation of modern propulsion systems requires a number of specific numerical boundary conditions. In the context of time-accurate simulations, one such essential boundary condition is that which is used to couple adjacent domains (i.e. blade rows) in a time-accurate and conservative manner. The focus of this paper is therefore the implementation and analysis of a domain-coupling algorithm in CODA that is tailored to the physics of blade-row-interactions. The approach implemented is based on a temporal and spatial Fourier decomposition of the flow field along the interface boundaries and allows, when combined with phase-shifted periodic boundary conditions, the simulation of stages with arbitrary blade-count ratios using only a single passage per blade row. A challenge that arises due to the use of temporal Fourier data in conventional time-domain simulations is that these data are not immediately available, but rather must be computed iteratively from the available instantaneous flow data. To mitigate potential stability issues that this may cause we therefore investigate in detail the impact of the formulation of the boundary condition using characteristic variables and compare the results with alternative approaches. To verify the approach a number of test cases are presented, ranging from the advection of a harmonic entropy wave in a simple duct to the URANS simulation of a fan-stage.

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STS 405-7

Multidisciplinary Analysis and Optimization of a Regional Aircraft with Higher Fidelity Models

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Abstract

The evolution of climate change sets new design paradigms for the aeronautic industry. The imperative to reduce CO2 emissions necessitates the development of disruptive aircraft configurations. For regional flights, one exploration is to implement to the classical tube and wing aircraft, innovative powertrain solutions such as the hybrid one. While this innovation is actively studied in the research world, its uptake is still slow in the industrial one. Indeed, although hybrid electric propulsion appears as a great asset in the fleet decarbonization [1, 2], the maturity of such technologies, and their modelisation in preliminary design in the literature, does not bring confidence to the industrials to develop such aircraft. To bridge this crucial gap, this work proposes a robust, high-fidelity Multidisciplinary Design Analysis and Optimization (MDAO) framework tailored for the conceptual design of hybrid-electric regional aircraft.

The methodology centers on implementing a parallel hybrid power chain on a reference regional commuter (the ATR-72). Using the FAST-OAD framework developed by ISAE-SUPAERO and ONERA [3], the objective is to perform high-fidelity MDAO to identify optimal configurations maximizing CO2 emissions reduction potential across a reference design mission profile. A critical requirement for this MDAO loop is the improvement of numerical confidence, particularly concerning coupled disciplinary trade-offs and uncertainty propagation.

This work focuses first on improving the fidelity of the reference model built based on the ATR-72. Crucially, the approach investigates replacing traditional semi-empirical disciplinary models (aerodynamics, propulsion) with data-driven meta-models trained directly on available experimental flight test data. As the available dataset was not built for surrogate modeling, the effectiveness of this approach relies on a strategic decision regarding the number of meta-models required, balancing accuracy against computational costs. Specifically the Kriging technique [4] is deployed as the primary surrogate modeling method to construct high-fidelity models for both the engine and the propeller. These models are built from datasets provided by each ATR-72's manufacturer. A key aspect of this Kriging model is the methodological management of the experimental datasets, which are numerous but often poorly distributed. Furthermore, the hybrid chain components (batteries, electric motors, and management systems) will be modeled with high fidelity beyond simple empirical equations implementation and efficiency assumptions. This methodological calibration work aims to establish an accurate and validated digital twin, thereby providing the necessary numerical reliability to confidently assess the environmental gains of the hybrid powertrain implementation.

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STS 405-8

Conservation in Load and Displacement Transfer Methods for Fluid-Structure Interaction

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Abstract

In fluid-structure interaction (FSI) analysis, load and displacement transfer methods that exchange physical quantities between fluid and structural meshes play a crucial role in ensuring computational accuracy and numerical stability. Inappropriate transfer procedures may lead to violations of conservation laws related to force and energy, resulting in a degradation of the overall accuracy and numerical stability of coupled analyses.

In this study, we propose the load and displacement transfer method that improves transfer accuracy while preserving the total load, moment, and work between the fluid and structure. In the proposed method, a basic transfer matrix is first constructed using Radial Basis Function (RBF) interpolation based on the correspondence between the fluid and structural meshes. The target structure is then divided into multiple regions, and small-scale transfer matrices are constructed for each region. These matrices are subsequently assembled to improve computational efficiency and numerical stability. Next, stepwise conservation corrections are applied to the constructed transfer matrices. First, a correction is introduced to preserve the total load, followed by a correction to ensure conservation of the total moment. Finally, a correction is applied to preserve the total work, resulting in load and displacement transfer matrices that satisfy physical consistency. Although the displacement transfer matrix and the load transfer matrix are defined independently, both are designed to simultaneously satisfy the conservation conditions of force, moment, and work, which constitutes a key feature of the proposed method.

Through simple transfer tests, it is demonstrated that the proposed method achieves highly accurate displacement transfer from the structure to the fluid and load transfer from the fluid to the structure. In particular, a significant improvement in transfer accuracy compared with conventional methods is confirmed even when there is a large difference in mesh resolution between the fluid and structural domains.

The proposed load and displacement transfer method provides a versatile and robust data exchange framework that achieves both conservation and high transfer accuracy. It is shown that the method enables stable and accurate FSI analyses using non-matching meshes and is expected to contribute to the advancement of large-scale and practical FSI simulations, including aeroelastic and multiphysics analyses.

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STS 405-9

Aerothermal Investigation of Throat Leakage Cooling in a Faceted Supersonic Variable Nozzle

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Abstract

The thermal management of variable-geometry supersonic exhaust nozzles is critical for structural integrity and infrared signature reduction [1]. Early NASA tests [2] on variable two-dimensional convergent-divergent nozzles revealed that, while cooling flows provide necessary thermal protection in exhaust nozzles, the integration of cooling mechanisms often results in thrust penalties. To mitigate such losses, we analyze a leakage cooling model that replicates a cooling strategy used in modern aircraft engines. The primary objective is to computationally investigate complex coolant-induced flow physics, including flow separation and shock wave-shear layer interaction.

The computational domain models the internal flow path of a 12-sided faceted nozzle based on contemporary aircraft engines. To simulate realistic operating conditions, coolant air at 500 K was injected through leakage slits located at the convergent flap and the throat hinge under a Nozzle Pressure Ratio (NPR) of 3.5.

The results from preliminary steady RANS simulations demonstrate that throat leakage injection effectively forms a film cooling layer on the faceted divergent flaps. Notably, the flap wall temperature was significantly reduced by over 200 K. However, the cooling flow was observed to intensify the shock wave-shear layer interaction, particularly around the nozzle corners at the exit, suggesting the formation of anisotropic turbulence structures. To further analyze these phenomena, Detached Eddy Simulation (DES) is to be performed and the detailed findings are to be discussed.

Acknowledgement

This research was supported by Hanwha Aerospace through the project 'Supersonic Nozzle Analysis and Design Technology', and by the KISTI Supercomputing Center [KSC-2023-CRE-0546].

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STS 405-10

AEROELASTIC DESIGN OF HIGH-ASPECT-RATIO WINGS FOR HIGH ALTITUDE PLATFORM STATION

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ABSTRACT

High Altitude Platform Stations (HAPS) operating in the stratosphere are being developed for various applications, such as atmospheric observation, telecommunication, and surface surveillance. To fulfill these long-endurance missions at high altitude where meteorological effects are limited, high-aspect-ratio wings are required to enhance aerodynamic efficiency. Generally, such wings are more deformable than low-aspect-ratio wings designed for the same lift and area.

However, such flexible wings not only affect the aerodynamic performance in cruise but also increase susceptibility to dynamic aeroelastic issues such as flutter. Therefore, it is essential to design HAPS wings considering aeroelastic effects. In previous research, Kennedy et al. [1] conducted aeroelastic design optimization of high-aspect-ratio wings made of aluminum or composites, in the transonic regime; however, they only addressed static aeroelastic effects, neglecting dynamic aeroelastic phenomena such as flutter. More recently, Jonsson et al. [2] performed design optimization of high-aspect-ratio wings considering the flutter constraint and nonlinear geometric effects. Nevertheless, their study utilized a low-fidelity aerodynamic model based on the potential flow unsteady airfoil theory, which cannot capture viscous and compressibility effects.

In this study, we perform aeroelastic design of high-aspect-ratio wings for HAPS in the subsonic regime, considering both static and dynamic aeroelastic effects. We employ a high-fidelity fluid-structure interaction (FSI) analysis based on computational fluid dynamics (CFD) and computational structural dynamics (CSD) for the static aeroelastic sizing process. For dynamic aeroelastic analysis, we utilize a coupling method between CFD and modal-based CSD.

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STS 405-11

ROBUST TRAJECTORY OPTIMIZATION FOR A MARS AIRPLANE WITH A DEPLOYABLE MEMBRANE WING

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ABSTRACT

Deployable membrane wings enable compact packaging of Mars airplanes inside an entry capsule, but their aeroelastic deformation can lead to unexpected shape changes during flight. Moreover, Martian flights are strongly influenced by wind disturbances. This study presents a robust trajectory optimization framework for a membrane-wing Mars airplane. Aerodynamic loads are evaluated through coupled computational fluid dynamics and membrane-structure simulations, and the resulting forces are integrated into a flight-aerodynamics coupled trajectory simulation. The vehicle is released vertically from a Mars entry capsule and transitions to an exploration flight via a pitch-up maneuver.

We formulate a robust multiobjective optimization problem to simultaneously maximize flight duration and downrange distance. The search is performed using NSGA-II. Uncertainties are quantified using polynomial chaos expansion (PCE), considering two sources: (i) uncertainty in membrane displacement and (ii) uncertainty in wind disturbance. Robust optimization is conducted by maximizing the mean values of the objectives predicted by the PCE-based uncertainty model.

The obtained Pareto-optimal set reveals the trade-off between endurance and range, and a maximum-range solution is identified. The results indicate that uncertainty associated with membrane displacement primarily affects the pitch-up maneuver, whereas wind disturbance significantly influences the final flight range. These findings highlight the necessity of incorporating aeroelastic and environmental uncertainties in trajectory design for deployable-wing Mars aircraft.

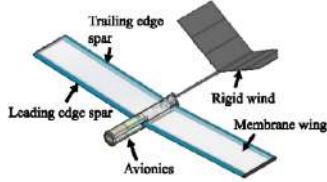


Figure 1: Deployable membrane-wing Mars airplane.

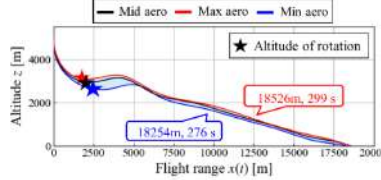


Figure 2: Robust trajectory under the uncertainty of the wing's displacement.

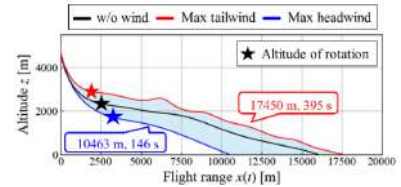


Figure 3: Robust trajectory under the uncertainty of the wind disturbance.

Acknowledgement

This work was supported by JSPS KAKENHI Grant Number 24K01083.

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STS 405-12

On the Multiphysics Modelling and Simulation of Morphing Air-Launched and Air-Retrieved UAVs

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Abstract

Air-launched effects and air-retrieved effects are novel types of unmanned aerial vehicles (UAV). Air-launched effects are small, morphing UAVs that are tube launched from a carrier aircraft. Air-retrieved effects are UAVs that are retrieved in-air, for example using a tether, akin to aerial refuelling. The launch and retrieval of these UAVs is accompanied with highly dynamic loading. Furthermore, they are characterised by a strong coupling between the aerodynamics, structural dynamics and flight dynamics. These necessitate sophisticated coupled simulations in order to assess their operational envelopes.

In this work, a variety of physical models is coupled to analyse the launch and retrieval of these systems. We utilise an unsteady vortex lattice model for the aerodynamic simulation, where the wake is tracked through a vortex particle method. Co-rotational beam models are used for the structural modelling of the lifting surfaces. The flight dynamics are modelled through the Newton-Euler equations derived for an aircraft with morphing lifting surfaces. For the retrieval operation, the structural dynamics of the tether are modelled through a rigid link cable model. These models are coupled through a custom co-simulation framework that allows for a hierarchical coupling integration.

Numerical simulations are performed to examine the operational envelopes for the safe launch and retrieval of such systems. Particular attention is paid to the aeroelastic stability & flight dynamic stability. In case of aerial retrieval, the risk of hose whip is examined in detail. The aim of this study is to gain insight into key design & operational parameters driving the safety of these systems. In turns, this gives key insights into the design of next-generation aerospace systems.

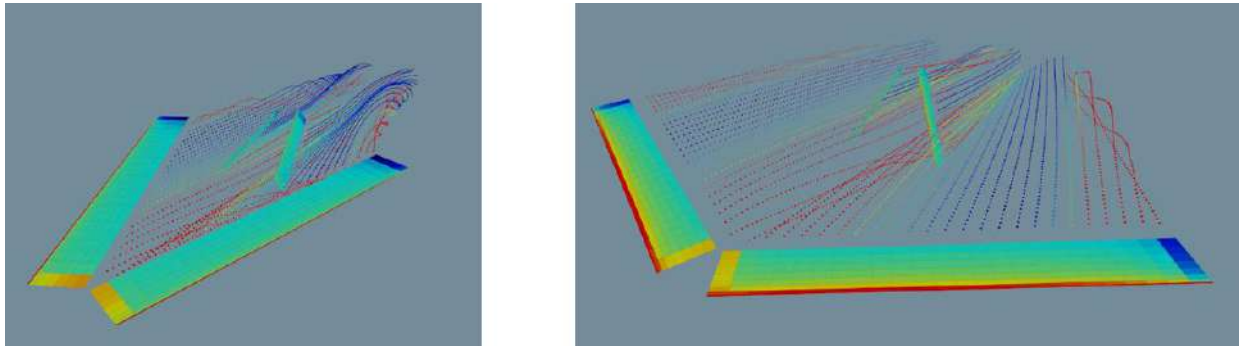


Figure 1: Snapshots of a morphing UAS during its launch phase.

STS407 - Additive Manufacturing in Industry: Open Challenges and Future Perspective

Main Organizer: Dr. Massimo Carraturo (University of Pavia, Italy)

Chaired by:

Dr. Massimo Carraturo (University of Pavia, Italy), Prof. Ferdinando Auricchio (Universita' di Pavia, Italy)

Part	Date	Time	Room
STS407A	Mon 20.07.2026	14:00–14:45	NM - 2 (Salzburg)

Additive Manufacturing (AM) technologies are undergoing exponential growth in many engineering fields, from aerospace to biomedical applications, from fashion to the food industry. AM technologies promise to revolutionize the world of manufacturing due to their capability to produce close-to-freeform components with structural and mechanical properties close to or even superior to those obtained using traditional manufacturing processes. In fact, thanks to the recent advancements in many AM technologies, manufacturing constraints are dramatically reduced, and the designer can finally focus on the intended application of the part rather than on its manufacturability. However, a widespread adoption of AM in many industrial sectors is yet hindered by the low reproducibility and standardization of the process. Therefore, the present Symposium aims at presenting and discussing the most recent efforts in the world of industry towards a deeper control and understanding of AM processes. The Symposium is meant to host contributions from industry, and it addresses, but is not limited to, the following topics:

- Standards and certification
- Process modelling
- Material modelling
- Metrology and sensing techniques
- Uncertainty quantification
- Benchmarking and Validation
- Oil and Gas applications
- Energy applications
- Valves and pumps

STS 407-1

Parametric Study of Surface Roughness in Laser Powder Bed Fusion of Ti-6Al-4V

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Abstract

This paper reports an experimental investigation of the surface roughness of Ti-6Al-4V components fabricated by laser powder bed fusion. A process window is defined and used to design an experimental plan. Test coupons were produced on a OneClick system at multiple conditions spanning the process window. Surface roughness measurements were performed using a 4D Keyence digital microscope and evaluated in accordance with ASTM standards. A parametric analysis, together with comparisons to existing literature, identifies an appropriate cutoff value of 0.8 and a magnification of 300× for Ra measurements. The results indicate that surface roughness is more strongly influenced by scanning speed than by laser power. The as-built surface roughness remains relatively stable for scanning speeds between 600 and 1800 mm/s, yielding acceptable Ra values in the range of 1.0 to 1.5.

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STS 407-2

In-Situ Process Monitoring and Ex-Situ Process-Structure-Property Database Implementation for a Wire- Arc Directed Energy Deposition Cell

**Lucinda K. Slattery^{1,*}, Theodore M. Belmont¹, Benjamin M. Bailey², James T. Stinson¹,
and Zackery B. McClelland¹**

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Abstract

A large barrier to the adaptation of additive manufacturing (AM) as replacement for conventional manufacturing is underdeveloped quality assurance practices. To address this and leverage the layer-by-layer fabrication in AM, this work presents the development and implementation of a digital thread pipeline for a Wire Arc Directed Energy Deposition (Wire-Arc DED) system. The pipeline is an open-source and free software stack, co-developed between the University of Maine and U.S. Army Corps of Engineers ERDC. The process agnostic framework is comprised of customizable Robot Operating System in-situ monitoring support and a MongoDB process-structure-property database architecture. For the Wire-Arc DED cell, the in-situ monitoring consists of temporally fused machine data and sensors, including weld properties, thermal camera footage, and interpass temperature measurements, to capture dense datasets during fabrication. This in-situ data is visualized real-time using Foxglove to inform operators of process anomalies. Subsequently, the heterogeneous data is packaged into rosbags and pushed automatically to the database, ensuring data integrity and accessibility for post-analysis. The novel functionality of this framework is its ability to directly link the captured process data to resultant structure and property data. This is fundamental for accelerating quality assurance of additively manufactured parts, as it allows for dense inspection of process data throughout the part's fabrication process, as well as provenance connectivity to relevant historical destructive testing. The pipeline also provides the data necessary for developing and validating traditional and machine learning process models and performance predictions. Through the correlation of specific processing conditions to microstructural and mechanical performance, there is a clear pathway to enable real-time sensor-based structure and property prediction during manufacturing. By integrating an open-source framework into a Wire-Arc DED cell, this research demonstrates a viable pathway to produce digital threads and shows a blueprint for creating more reliable and repeatable AM components and processes.

STS412 - MBSE Technologies In Civil Air Transportation

Main Organizer: Dr. Wen BAI (Chinese Aeronautical Establishment (CAE), China)

Chaired by:

Dr. Lefeng LYU (Chinese Aeronautical Establishment, China), Ms. Yifan Zhang (Tsinghua University, China)

Part	Date	Time	Room
STS412A	Wed 22.07.2026	17:00–18:30	NM - 2 (Salzburg)

The Model Based Systems Engineering (MBSE) technology had been well applied in aviation industry. This STS will focus on recent practices and achievements of MBSE technology in the design of low-altitude air vehicles and low-altitude system of systems. The topics consist of and are not restricted to: Application of MBSE Technology in Design of Low-Altitude Air Vehicle at Conceptual Design Synthesis Stage, Low-Altitude Air Vehicle System Design, Low-Altitude System of Systems Design and Optimization, MBSE-Driven Exploration of Logical Architecture Design Spaces and Trade-off Analysis of Multiple Solutions, and Design Technologies of Low-Altitude Spectrum Monitoring System Based on MBSE.

STS 412-1

Research on Digital Requirements Modeling for Quad-tiltrotor High-Speed Civil Rotorcraft

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Abstract

This study focuses on the development of a digital requirements model for novel quad-tiltrotor configuration high-speed civil rotorcraft, aiming to establish a systematic approach for turning stakeholder needs into conceptual design solutions.

Based on systems engineering principals and model-based system engineering (MBSE) methodologies, this research proposes a forward design process from several specific application scenarios to ensure end-to-end traceability and traceability of requirements. A digital management framework is established to standardize the conceptual design workflow, enabling visual and standardized control over requirement validation and baseline management, which has been applied to the design of a quad-tiltrotor conceptual scheme. This framework guarantees the integrity and correctness of conceptual solutions by aligning user-driven requirements with design outputs. Furthermore, the feasibility of the proposed methodology is validated through the verification of a proof-of-concept vehicle, requirement conformance verification based on the quad-tiltrotor conceptual design scheme, and iterative refinement of the conceptual design process.

This study contributes to the establishment of a centralized digital workflow for civil rotorcraft development, enhancing the efficiency and consistency of requirement-driven design activities in high-speed rotorcraft projects.

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STS 412-2

Design Technology of Low-Altitude Spectrum Monitoring System Based on MBSE

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Abstract

Low-altitude surveillance serves as a crucial safeguard for the safety of low-altitude operations, ensuring the secure and efficient functioning of aircraft in low-altitude airspace. Compared with high-altitude systems, advances in low-altitude aviation are presenting a new landscape characterized by high density, autonomy, and heterogeneity. To establish a low-altitude surveillance technology system with no blind spots, a model-based systems engineering (MBSE) approach is introduced into the design process of low-altitude surveillance systems. Based on the MagicGrid system modeling framework, a model-based design methodology and process are proposed. This includes defining stakeholder requirements, formulating operational schemes for low-altitude surveillance missions, conducting functional and physical decomposition, and performing engineering analyses of performance parameters. The low-altitude spectrum monitoring and positioning system is used as an illustrative example. The requirements, structure, behavior, and parameters of the low-altitude surveillance mission are modeled using SysML. It is concluded that MBSE can enhance the consistency and traceability of design information through system models, providing a valuable reference for the application of MBSE methods in the design of low-altitude surveillance systems.

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STS 412-3

A Minimal Operational Unit-Based Decoupled Optimization Framework for Aerial Emergency-Response System-of-Systems Layout

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Abstract

In low-altitude public aviation, aerial emergency-response SoS design must determine fleet composition and basing under multi-scenario constraints, with decisions that remain explainable and traceable. However, mission-level simulation and SoS fleet-and-basing optimization are tightly coupled: changes in environment, fleet composition, or basing propagate across levels, resulting in expensive nested multi-objective search, limited model reuse, and weak end-to-end traceability [1,2]. We propose a layered decoupling framework that embeds Minimal Operational Units (MOUs) within an RFLP structure [3]. R defines effectiveness and cost evaluation metrics and constraints; F maps mission workflows to executable evaluation models; L standardizes MOUs as parameterized capability packages with defined interfaces; P instantiates a discrete Pareto-optimal mission-level MOU library [4] for SoS-level layout optimization. Layouts are explicit compositions over the library of evaluated MOUs, enabling cross-layer traceability. A forest firefighting case study shows that Pareto-efficient MOUs can be grouped into several patterns (Fig. 1): formations of 4-5 10-tonne-class helicopters deliver the best effectiveness-cost trade-off. In a nationwide application for China with 363 added helicopters (Fig. 2), coverage across priority fire-risk zones (Levels 1-3) improves by up to 39% over the 2025 baseline. Overall, the MOU bridge converts nested mission-SoS optimization into scalable combinatorial search over a finite discrete library, enabling computable, traceable, and engineering-feasible concept generation.

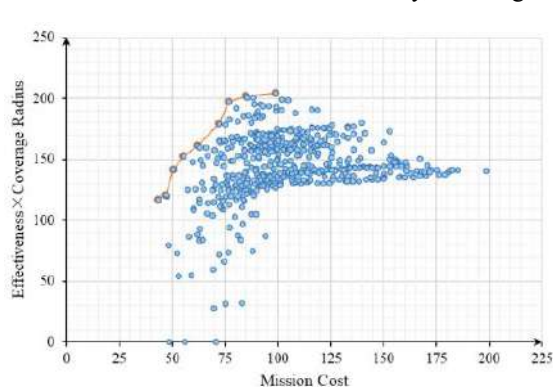


Figure 1 - Effectiveness-cost scatter and Pareto front of mission-level MOU candidates

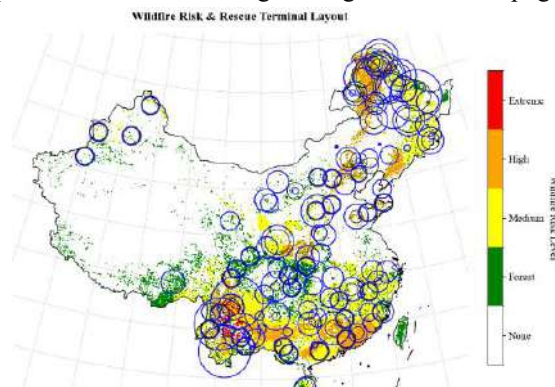


Figure 2 - SoS fleet-and-basing layout optimized by composing MOUs from the candidate library

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STS 412-4

Low-Altitude Air Transportation System Architecture Development Based on UAF

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Abstract

Low-altitude air transportation system is a typical system of systems (SoS) which presents a complex challenge in collaborative evolution of advanced air mobility vehicle technologies and integrated operation of unmanned and manned vehicles in a high density airspace. Low-altitude air transportation includes multiple operating scenarios covering emergency service, cargo and passenger transport with high safety and reliable requirements. Stakeholders and heterogeneous air mobility vehicles require interoperability and interactive collaboration to support SoS ecosystem continuous evolution. The emerging low-altitude air mobility vehicles must coexist and collaborate with current air transportation system, and conform to existing airspace management regulations [1].

The low-altitude air transportation SoS design requires an architecture to provide holistic view and comprehensive understanding of the relationship and interactions between constituent systems. In this paper, a low-altitude air transportation system architecture is proposed based on unified architecture framework (UAF). The framework implements a standardized multi-perspective and hierarchical design method to integrate multiple concerns from strategic vision to technical implementations [2]. This paper defines the SoS vision and strategic phases from trial experimentation to business fleet operation. Unmanned cargo and urban passenger transport scenarios are analysed and key capabilities are identified to direct air mobility vehicle system requirement development. The paper defines the SoS operational architecture and analyses low-altitude operation process with information exchange interactions between air vehicle, vertiport, remote pilot and other operational roles. A trade-off analysis is performed between different physical solution architectures to support vehicle system configuration selection.

Keywords: low-altitude air transportation, system of systems, architecture

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STS 412-5

Research on System Architecture Modelling Method for Civil Rotorcraft Using SysML V2

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Abstract

Model-Based Systems Engineering (MBSE) serves as the primary paradigm to address challenges of increasing complexity in aerospace industry, and the Systems Modelling Language (SysML) is a key technology for implementing MBSE. The next-generation modelling language - SysML V2, with a novel language kernel and architecture, provides effective ways to tackle the major challenges encountered in MBSE application.

Taking the system architecture modelling of a typical civil rotorcraft as the context, the problems encountered using SysML V1 are examined, including insufficient semantic precision, poor model computability, and difficulties in modelling & simulation tools integration. Targetedly, some specific new features of SysML V2 - precise formal semantics, built-in model validation rules and standardized programmatic interfaces - are introduced. The proposed procedure to realize the RFLP process then follows up. For the Requirements (R) level, SysML V2 requirement elements are used to create more precise and parameterized requirements models as the foundation for requirement verification and validation. For the Functional (F) level, SysML V2 behavior elements are used to define formalized and computable functional models, enabling unambiguous allocation and traceability to lower-level logical components. For the Logical (L) level, conceptual structures are constructed using SysML V2 structural elements. For the Physical (P) level, detailed representation of physical components is modelled through SysML V2 structural elements and mathematical expressions, enhancing the integration and interoperability between the physical architecture and multi-disciplinary models.

The proposed system architecture modelling method using SysML V2 effectively improves the accuracy, computability, and interoperability of system architecture models.

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STS 412-6

Safety Assessment Methods of Multi-Modal Complex Avionics Systems Based on MBSA

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Abstract

Unlike the standardized classifications applied to traditional fixed-wing and rotary-wing aircraft, low-altitude aircraft are evolving towards greater flexibility and intelligence in system configuration. A prime example is the Electric Vertical Take-Off and Landing (eVTOL) aircraft, which utilizes pure electric propulsion and achieves runway-independent operations through adaptive control of aerodynamic surfaces. This capability significantly expands potential application scenarios but imposes demanding control requirements on the avionics system across distinct flight phases. Consequently, avionics system architectures are shifting from single-mode to multimodal configurations to accommodate these dynamic needs. Effectively modeling and assessing the safety of such multimodal avionics systems within a Model-Based Systems Engineering (MBSE) framework has thus become a critical focus for both academia and industry.

To address the safety assessment challenges arising from state transitions in multimodal avionics systems, this paper adopts an MBSE methodology. Integrating the forward-design philosophy of civil aviation and employing the Systems Modeling Language (SysML), a digital design chain encompassing requirements, functions, and architecture is established. Following a "black-box opening and hierarchical decomposition" approach, the study develops static architectural models of multimodal avionics systems and dynamic behavioral models under typical flight missions. Furthermore, it extends failure mode analysis across different transition states, creating a coherent modeling pathway from requirements to architecture. This overcomes the limitation of existing methods that often focus on isolated failure modes. The proposed approach is validated through a case study on the avionics state transitions of a tilt-rotor eVTOL aircraft during flight. The research provides a systematic engineering solution for the safety assessment of next-generation low-altitude aircraft.

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STS 412-7

A Compartment-Perspective Methodology for Modeling and Analyzing Complex Aircraft Integration Assembly Processes: An Extended Application of the RFLP Framework

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Abstract

This research tackles the challenges of interlinked aircraft systems and tightly coupled assembly processes through a compartment-perspective modeling approach for assembly process analysis, expanding and adapting the RFLP (Requirements-Functional-Logical-Physical) systems engineering framework.

The key innovation is the novel adaptation of the RFLP framework into assembly process design, creating a comprehensive multi-layered, multi-perspective modeling framework. This framework translates top-level aircraft requirements into detailed compartment installation test sequences. Within the Functional layer, the approach disassembles product requirements into compartmental perspective models, emphasizing the specific functions of physical regions or units. This ensures that local task planning aligns with broader system functional needs. In the Logical layer, the method maps subsystem interfaces and interactions into test sequences, structuring test item dependencies and converting them into executable compartment-level tests. In the Physical layer, it establishes a precise link between compartment logic and components, to generate an assembly information list and test processes. The methodology's feasibility is demonstrated using a typical aircraft compartment example.

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STS413 - eVTOL: Configuration, Simulation and Optimization

Main Organizer: Prof. Ning Zhao (Nanjing University of Aeronautics and Astronautics, China)

Chaired by:

STS413A:

Prof. Ning Qin (University of Sheffield, United Kingdom), Prof. Ning Zhao (Nanjing University of Aeronautics and Astronautics, China);

STS413B:

Prof. Chunling Zhu (Nanjing University of Aeronautics and Astronautics, China), Prof. Ning Qin (University of Sheffield, United Kingdom)

Part	Date	Time	Room
STS413A	Mon 20.07.2026	15:00–16:30	NM - 4 (Hamburg)
STS413B	Mon 20.07.2026	17:00–18:30	NM - 4 (Hamburg)

The topics include but not restricted to: eVTOL configuration, rotor and propulsion system, eVTOL aerodynamic performance, simulation and optimization, eVTOL applications.

STS 413-1

Numerical Study of the Aerodynamic Interaction between Structure Wake and Lift-plus-cruise eVTOL

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Abstract

With the development of vertical take-off and landing (VTOL) vehicles, urban air mobility (UAM) is emerging as a future solution to alleviate traffic congestion in megacities. In urban area, complex terrain, building-induced turbulence wake and wind shear may significantly perturb eVTOL aerodynamic performance. Furthermore, to effectively reduce the congestion, the vertiports must be located in central urban areas, thereby exposing VTOLs to the strong influence of turbulence wake generated by tall buildings during take-off and landing. This paper conducts a numerical study on the coupled flow field between a lift-plus-cruise eVTOL and the wake of the tall buildings by using the Detached Eddy Simulation (DES) method. The hovering and the landing of the eVTOL under the different influence of the wake were numerically simulated. Firstly, the aerodynamic interference of building wake on the lift propellers of the lift-plus-cruise eVTOL during hovering in different regions of the wake was investigated. Secondly, the numerical simulations were conducted on the coupled flow field of the building wake and a eVTOL under different free-stream conditions, and the effects of wake on the aerodynamic performance of the eVTOL under various wind directions were investigated. Finally, the landing process of the eVTOL was numerically simulated to study the influence of the building wake to the eVTOL. The results show that the wake may significantly affect the lift and torque of the eVTOL, thus leading to lift fluctuations and reduced controllability.

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Mission-Level Feasibility Assessment of eVTOL under Coupled Energy and Thermal Constraints

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ABSTRACT

Electric vertical take-off and landing (eVTOL) aircraft are expected to play an important role in future urban transportation systems. However, large-scale and standardized eVTOL operations are fundamentally constrained by limited onboard battery capacity and stringent temperature limits of batteries and electric motors, which are closely related to electric propulsion and thermal management configurations.

To address thermal limitations, extensive research efforts have focused on thermal management systems (TMS) to regulate component temperatures within allowable limits [1]. Nevertheless, the mission-level implications of thermal management have not yet been sufficiently clarified. Even when component temperatures are properly managed, the operation of TMS introduces additional power consumption that may indirectly constrain mission feasibility.

This study presents a mission-level electro-thermal simulation framework to assess eVTOL mission feasibility under simultaneous energy and thermal constraints (Fig. 1).

Mission feasibility is evaluated based on the simultaneous satisfaction of prescribed energy reserve requirements and component temperature limits. Parametric analyses across ambient temperature and mission distance are conducted to identify feasibility envelopes that define admissible operational and configuration-dependent design regions. The results show that thermal constraints, through increased TMS power consumption, could become the dominant factor limiting mission feasibility even when temperature limits are satisfied.

These feasibility envelopes provide practical design and operational insights for configuration selection under different mission and environmental conditions. The proposed framework provides a basis for eVTOL configuration analysis, mission design, and optimization-oriented studies under realistic operating conditions.

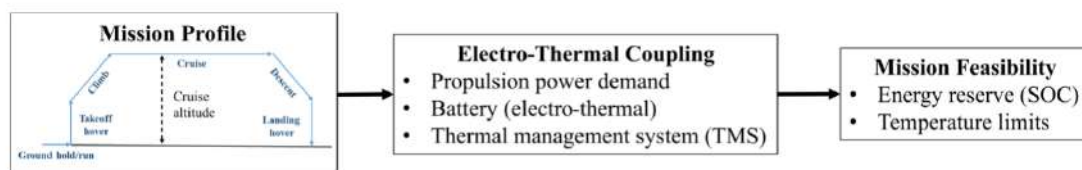


Figure 1: Mission-level electro-thermal simulation framework coupling propulsion power, battery electro-thermal behaviour, and thermal management system operation to assess eVTOL mission feasibility.

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STS 413-3

Optimal Control-Based Operational Characteristic Analysis and Adjustment Scheme Design for Tilting Electric-Driven Ducted Fans

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Abstract

Tilting electric-driven ducted fans, owing to their capability to integrate vertical takeoff and landing with high-speed cruise characteristics, have become core propulsion components for electric vertical takeoff and landing (eVTOL) aircrafts. However, their high coupling with aircraft dynamics causes traditional evaluation methods based on fixed control strategies to fail in reflecting true performance, thereby limiting performance evaluation and further optimization. To address this issue, this study proposes a performance evaluation method based on optimal aircraft/propulsor cooperative control. By dynamically matching flight trajectories with ducted fan control strategies, it optimizes the operational efficiency of the ducted fan during takeoff, tilting, and climb phases, thereby obtaining more reasonable operational characteristics of the ducted fan for analysis and further optimization.

The study analyzes the operational characteristics of the fixed-structure tilting ducted fan and compares the performance enhancement effects of two adjustment schemes: adjustable blade installation angles and adjustable nozzle area. The results show that: under the optimal aircraft/propulsor cooperative control strategy, the ducted fan adiabatic efficiency can be maintained above 85.0% during the takeoff, tilting, and climb phases. When entering the cruise phase, the adiabatic efficiency decreases to 76.5% due to reduced rotational speed. By adjusting the blade installation angles, the ducted fan adiabatic efficiency can reach 85.0% with a 9.9% cruise range increase; whereas the nozzle adjustment scheme enhances the pressure ratio to mitigate the effects of total pressure loss, achieving a 19.5% cruise range improvement while maintaining identical ducted fan adiabatic efficiency (85.0%), demonstrating more significant enhancement effects.

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STS 413-4

Wind-Resilient eVTOL Configuration and Flight Testing

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Abstract

Wind resilience is a pivotal performance metric for electric vertical take-off and landing (eVTOL) aircraft. This paper presents the design, fabrication, and flight testing of a novel eVTOL configuration (designated ETS30), optimized for enhanced performance in high-wind conditions.

The design integrates a force-vectorized thrust control mechanism with a decoupled position-attitude control algorithm to improve wind rejection capabilities. Test results show that the ETS30 achieved stable hovering in an indoor wind tunnel under Stage 7 wind (15 m/s average), with roll, pitch, and yaw angles controlled within 3° and position variation under 0.5 m.

In outdoor flight tests, the aircraft maintained stable position and attitude control when subjected to a 10° pitch step disturbance at 30 m/s airspeed, equivalent to Stage 11 wind conditions. The proposed configuration demonstrates excellent high-wind resilience, showing significant application potential for eVTOL operations in challenging atmospheric environments.

STS 413-5

Mid-Fidelity Analysis of Aerodynamic Interaction in Lift+Cruise VTOL Urban Air Mobility Concept Aircraft

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Abstract

The emerging urban air mobility (UAM) concept relies on distributed electric propulsion systems, where complex aerodynamic interactions among multiple rotors and lifting surfaces critically influence overall performance. This study presents a comprehensive mid-fidelity numerical analysis of the NASA lift+cruise vertical take-off and landing (VTOL) UAM concept aircraft, focusing on rotor-wing-rotor aerodynamic interactions during both hover and transition flight phases. The open-source vortex-based solver DUST [1] is employed to efficiently simulate the three-dimensional flow field, capturing wake evolution and mutual interference effects between lifting rotors and the wing. Numerical simulations are systematically performed to quantify the interactional aerodynamic phenomena and their impact on wing loading and rear rotor efficiency. Validation against high-fidelity CFD results from references [2,3] demonstrates good agreement, confirming the reliability of the mid-fidelity approach. Under hover conditions, wake interactions among the lifting rotors significantly alter the flow field at their tip regions, while the strong downwash streams induce substantial negative lift on the wing, creating a download penalty that must be compensated by increased rotor thrust. During transition conditions, the rear lifting rotors operate in the wake of upstream lifting rotors, resulting in reduced thrust efficiency and increased unsteady loading. These findings elucidate the complex coupling mechanisms in distributed propulsion UAM configurations and provide quantitative insights essential for performance prediction and design optimization.

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Aerodynamic and Hydrodynamic Optimization of a Seaplane: A CFD-Based Study

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ABSTRACT

Seaplane design requires a delicate balance between aerodynamic efficiency for flight and hydrodynamic performance for water takeoff. This study presents a CFD-based optimization of a seaplane configuration, focusing on the coupled aerodynamic and hydrodynamic characteristics during takeoff. The main geometric parameters are listed in Table 1.

The MH114 airfoil is optimized using Isight and Xfoil, achieving a 15% increase in maximum lift-to-drag ratio. As shown in Fig. 1(a), CFD simulations reveal that as the angle of attack increases from -2° to 1° , the lift-to-drag ratio rises steadily, reaching a maximum of 19.1 at 1° angle of attack with a cruise speed of 23 m/s. Beyond this angle, the lift-to-drag ratio gradually decreases, dropping to 18.4 at 3° and 17.1 at 6° . The static margin is 20%, ensuring longitudinal stability, with a stall angle of 16° and a maximum lift coefficient of 2.0.

Self-propulsion simulations using overset mesh and 6-DOF motion reveal that as shown in Fig. 1(b), as speed increases from 3 m/s to 9 m/s, the planing resistance rises progressively, reaching a peak of approximately 150 N at 9 m/s, accounting for 15% of the takeoff weight. Beyond this speed, the resistance decreases rapidly as the hull lifts off the water, dropping to 107 N at 11 m/s and 68 N at 13 m/s. The step creates a pressure drop region that effectively reduces the wetted area. The lift-off pitch angle is 8.2° , which matches the afterbody angle of 7.5° , ensuring a smooth transition from water to air.

Three longitudinal center-of-gravity positions (forward, mid, aft) are evaluated to investigate their effects on planing stability. Results show that the mid-CG configuration achieves the best balance between stable planing attitude and peak resistance.

Table 1 Principal dimensions of the seaplane

	Fuselage				Wing				Hull					
Parameter	Length	Span	Height	Weight	Area	Aspect ratio	Airfoil	Incidence	Length	Beam	Length ratio	Step height	Deadrise	Afterbody angle
Value	4.5 m	7.0 m	1.7 m	100 kg	3.4 m ²	14.4	MH114-008	2°	3.9 m	0.39 m	6:7	0.39 m	20°	7.5°

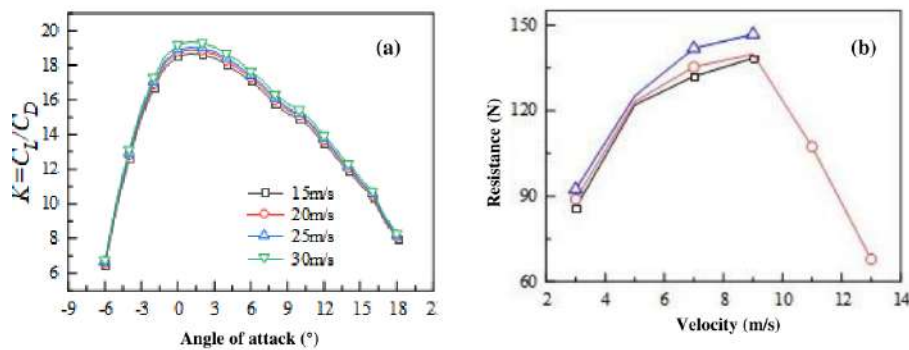


Fig. 1 (a) Lift-to-drag ratio vs. angle of attack (from original report Fig. 22); (b) Water surface planing resistance vs. speed.

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STS 413-7

3D Hybrid Mesh Generation Method Based on Automatic Surface Meshes Generation

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Abstract

A 3D hybrid mesh generation method was developed, which bases on an automatic 3D surface mesh generation method to form the body fitted mesh around the wall. The piecewise linear Morse theory was used to extract geometry features from 3D point clouds data, which includes feature points and feature lines of the geometric surfaces. The surface was then transformed from 3D physical space to 2D parametric space based on Least-Squares Conformal Mapping [1]. Combined with Cross-field [2][3] theory, the 2D geometry was partitioned in the 2D parametric space, and then maps back to the 3D physical space, thus achieving the automation of dividing the surface into multi-block structured meshes. Multi-block structured body fitted mesh are then generated by extruding the surface meshes outward, followed by filling the far-field with unstructured meshes to achieve 3D meshes generation.

The proposed algorithm is validated via spherical and ONERA-M6 wing models, with its mesh generation and numerical simulation results presented in Fig. 1. Block partitioning results show smooth transitions at geometric joints, excellent orthogonality of each block, and high-quality structured meshes. These meshes are applied to simulate viscous flows over supersonic spheres and ONERA-M6 wings, post-processing results clearly capture shock waves, thus verifying mesh reliability.

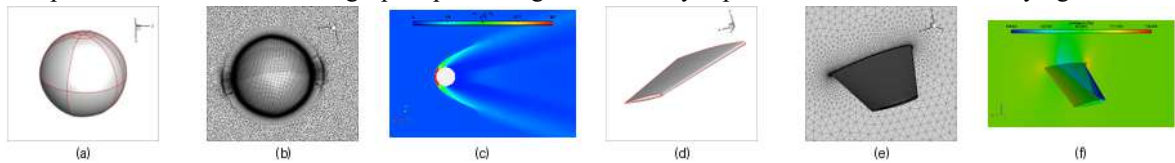


Figure 1. (a), (b), (d) and (e) show the surface block partitioning and mesh generation results; (c) and (f) are the pressure distribution contour plots.

The proposed quadrilateral structural block generation algorithm enables efficient, rapid partitioning of bounded surface blocks with excellent orthogonality. Meanwhile, the body fitted meshes generated by this algorithm feature high automation and superior quality, providing an efficient mesh generation solution for subsequent numerical simulations.

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STS 413-8

Icing Meteorological Parameters and Ice Thickness Prediction Algorithms

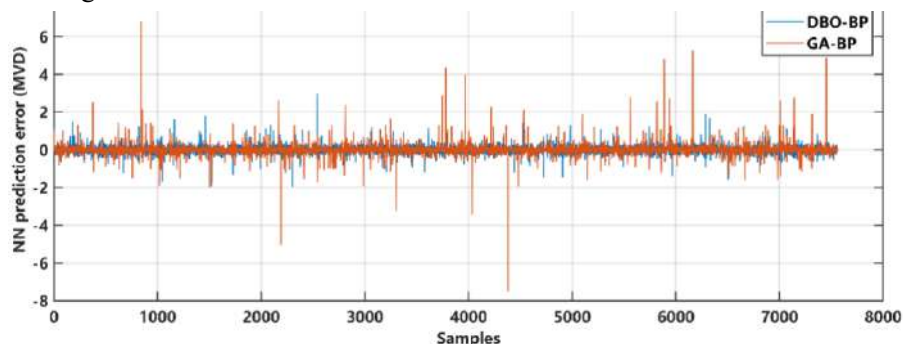
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Abstract

Low-altitude aircraft operate in the airspace below 1,000 meters, and face the risk of icing within the cloud layer range of 0 to 3,000 meters. In particular, the altitude range of 1,500 to 3,000 meters is a common high-incidence area for icing on low-altitude aircraft. According to FAR-25 Appendix C, the median volumetric diameter (MVD) and liquid water content (LWC) are the key meteorological parameters for aircraft icing, but they are difficult to be measured during the flight. An icing meteorological parameter measuring method is thus proposed herein with a device integrated with multiple ultrasonic sensors (specifically designed for ice thickness measurement) and pressure sensors. Based on the pressure sensor mounted on the device, the air speed and direction are calculated. And then an icing meteorological parameter prediction method based on the local ice thickness data collected by the ultrasonic sensors is developed. Validation results demonstrate that the proposed method yields a maximum absolute prediction error of 2.9915 μm , an average neural network prediction error of 0.1359 μm , a maximum relative prediction error of 13.94%, and an average relative error of 0.53%.



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STS 413-9

An Artificial Neural Network-Based Approach for Flow Field in Urban Area

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Abstract

The low-altitude economy refers to a comprehensive economic paradigm on airspace below 3,000 meters, utilizing aerial platforms such as unmanned aerial vehicles (UAVs) and electric vertical take-off and landing (eVTOL) aircraft, with broad applications in transportation, logistics, and inspection. eVTOLs offer advantages including electrification, vertical take-off and landing capability, low noise, and environmental sustainability, positioning them as a key solution for urban air mobility. In urban environments characterized by complex terrain, building-induced turbulence, wind shear, and vortex structures significantly perturb eVTOL aerodynamic performance, leading to lift fluctuations and reduced controllability. Particularly during take-off and landing phases, such flow disturbances increase the risk of instability, thereby imposing more stringent requirements on aerodynamic design and flight control system robustness. This study addresses the influence of vortex structures in complex airflow fields on the aerodynamic performance of aircraft by proposing an artificial neural network-based methodology for predicting such flow field. The investigation focuses on the 3D flow field along the descent trajectory of an aircraft under varying inflow conditions. The input features of the model include the inflow wind angle and velocity, while the output targets are the velocity components in the x, y, and z directions along the descent trajectory. This configuration creates a nonlinear mapping between the inflow conditions and the spatial velocity distribution. The network architecture is fine-tuned, and training parameters are optimized to improve convergence and generalization performance. Results indicate that the model effectively captures spatiotemporal variations in 3D velocity fields and accurately predicts velocity distributions at critical locations in the flow field under diverse conditions, with excellent approximation abilities, particularly in regions where vortex structures dominate. This data-driven approach offers viable potential for aerospace engineering applications.

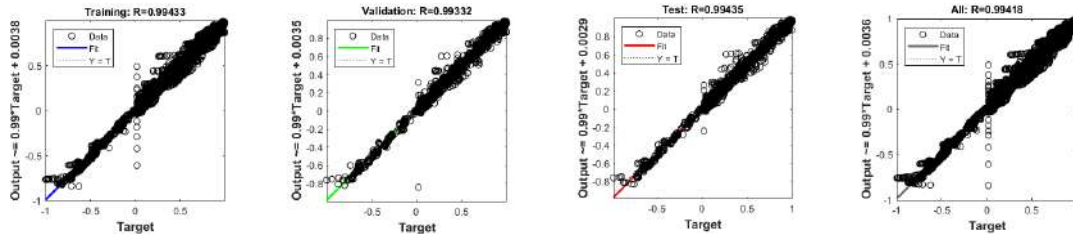


Figure 1. Regression analysis of network performance for training, validation, test, and all datasets.

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STS 413-10

Influence of Turbulent Inflow with Different Atmospheric Stabilities on the Aerodynamic Characteristics of Lift-Cruise eVTOL Rotor System During Transition Phase

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Abstract

Traditional aerodynamic analyses of electric vertical take-off and landing (eVTOL) urban air mobility (UAM) aircraft predominantly assume uniform inflow conditions, neglecting the complex atmospheric environments encountered during actual operations. In fact, atmospheric stability has a significant effect on the temporal and spatial distribution of turbulent inflow, hence further affect the safety, stability, and operational efficiency of the aircraft [1].

Under stable atmospheric conditions, vertical motion is suppressed, leading to generally calm and laminar airflow that is conducive to stable flight control. Conversely, unstable conditions promote thermal convection, generating hazardous phenomena such as turbulence, gusts, and vertical wind shear. These pose substantial risks to eVTOLs, particularly during low-speed, high-power phases like hover and landing. They can cause aircraft attitude instability, increase control system workload and energy consumption, and may exceed operational wind limits, leading to flight cancellations or delays.

This study employs an efficient mid-fidelity coupled vortex method [2] integrated with a turbulent inflow generator to investigate the aerodynamic characteristics of a lift-cruise eVTOL rotor system during transition flight under different atmospheric stabilities. Results indicate that under uniform inflow conditions, aerodynamic loads exhibit steady periodic variations once the rotor wake reaches a fully developed state. However, under unstable atmosphere, increasing turbulence intensity progressively disrupts the organized wake structures, culminating in significant wake deterioration under high-turbulence conditions.

Compared with the uniform flow baseline, turbulent inflow substantially amplifies unsteady load fluctuations. These findings underscore the necessity of incorporating realistic atmospheric turbulence in UAM aerodynamic design process, thereby deepening the understanding of rotor-turbulence interaction physics and informing the development of more robust UAM aircraft.

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STS 413-11

Hydrodynamic Takeoff Performance of a Seaplane: CFD Analysis and Optimization

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Abstract

The water-surface takeoff of a trans-medium vehicle involves a transition from the high-density water phase to the low-density air phase, presenting challenges in terms of high hydrodynamic resistance and pitch instability. Accurate prediction of takeoff performance is critical for vehicle design. In this study, unsteady Reynolds-averaged Navier-Stokes (URANS) simulations are conducted using the Realizable k-epsilon turbulence model and the volume-of-fluid (VOF) method for free-surface capturing [1]. An overset mesh approach is employed to resolve 6-DOF motions under self-propulsion conditions. A thrust model derived from wind tunnel measurements of the ducted propeller is implemented as a velocity-dependent function. Takeoff is defined as the moment when the hull completely loses contact with the water surface (zero wetted area).

Self-propulsion simulations reveal that thrust applied at the propeller location (above the center of gravity) induces a nose-down moment, causing excessive pitch (up to 25°) and preventing acceleration beyond 5 m/s. In contrast, with thrust aligned with the center of gravity, the vehicle successfully accelerates and becomes fully airborne. The typical takeoff sequence is illustrated in Fig. 1. Nine geometric modifications are evaluated under identical thrust input. A 1 cm increase in forward step height achieves takeoff at 17.3 m/s. A V-shaped bottom (2 cm width, 15° deadrise) achieves 16.1 m/s. The surface-piercing hydrofoil configuration achieves the lowest takeoff speed at 9.9 m/s (compared to 20.6 m/s for the baseline), demonstrating a significant improvement in thrust utilization efficiency. Longitudinal moment balance is the key factor governing takeoff success. Thrust misalignment with the center of gravity severely impairs acceleration, while geometric modifications, particularly surface-piercing hydrofoils, substantially improve takeoff efficiency.

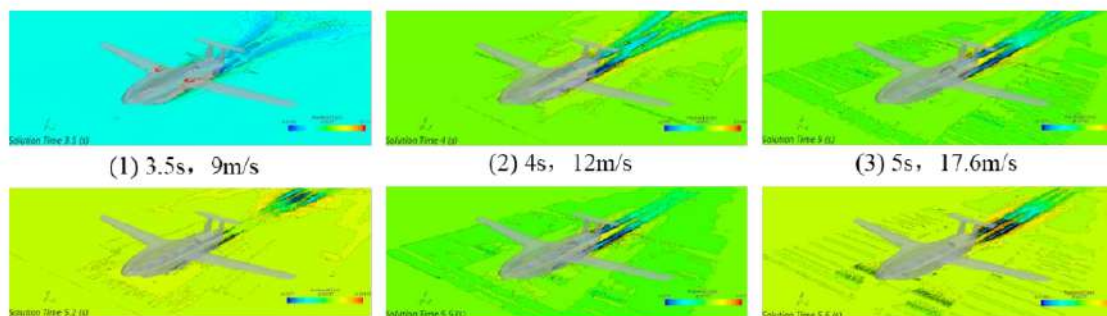


Fig. 1 Self-propulsion takeoff process with thrust aligned with the center of gravity (adapted from the original report). Key stages: (1)-(2) planing state; (3) hull lifts off the water; (4) re-entry; (5) takeoff initiates; (6) fully airborne.

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STS414 - AI for Low-Altitude Economy & UAV

Main Organizer: Prof. Song Fu (Tsinghua University, China)

Chaired by: Prof. Song Fu (Tsinghua University, China), Prof. Hui Li (Harbin Institute of Technology, China)

Part	Date	Time	Room
STS414A	Tue 21.07.2026	17:00–18:30	NM - 4 (Hamburg)

STS 414-1

AI Enabled Psychoacoustic Analysis of Drone Noise for Low-Altitude Economy

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Abstract

The successful implementation of a low-altitude economy (LAE) depends critically on effective noise control, a priority second only to safety [1]. Targeted research in this area is essential to foster the healthy development and widespread adoption of aircraft in this emerging sector. This paper outlines a research initiative to identify key scientific problems and to develop the associated strategies, with a specific focus on drone (and possibly eVTOL) and their operational use cases projected for the Hong Kong and Great Bay Area in the near future.

This work performs classical frequency-domain analysis [2] and AI-enabled psychoacoustic analysis [3] on drone noise compared to musical tones of traditional musical instrument. As noise being a major hindrance to the large-scale adoption of drones, researchers all over the world have been endeavouring to understand the reason behind the high annoyance caused by drone noise and looking for mitigation strategies. In this work, by directly comparing the acoustic characteristics of drone noise with that of traditional musical instrument and utilizing AI technologies, we could hopefully understand the reasons for drone noise problems from a new perspective. In particular, acoustic measurements of a self-made drone have been performed in an anechoic chamber while the musical samples of violin are generated using iPhone GarageBand. The spectrogram and three sound quality metrics were used for comparison, which is conducted with certain AI strategies. More details will be given in the final manuscript.

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STS 414-2

Bridging the Fidelity Gap: Euler to RANS Flow Reconstruction via Physics-Aware Transformers

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Abstract

The emergence of the Low-Altitude Economy, encompassing UAM, eVTOLs, and logistics drones, demands a paradigm shift in aerodynamic design. Unlike traditional aviation, this sector requires rapid iteration of thousands of configurations. However, a critical bottleneck remains: high-fidelity Reynolds-averaged Navier-Stokes (RANS) simulations are prohibitively expensive for such large-scale sweeps, while low-cost Euler solvers fail to capture essential viscous phenomena like flow separation and drag. To resolve this tension, we present a data-driven framework that reconstructs high-fidelity RANS fields directly from low-cost Euler simulations. We propose a physics-aware Transformer architecture as Figure 1 utilizing a "slice-tokenization" strategy, which aggregates grid points into physically correlated tokens to reduce attention complexity. This architecture creates a synergistic mapping: Euler solutions provide global physical priors, while explicit positional encodings and condition modulation guide the precise reconstruction of viscous-dominated regions. Evaluated on transonic supercritical airfoils, our method reduces reconstruction error by up to 48% for streamwise velocity and 25% for pressure compared to baselines. Crucially, the model recovers complex viscous physics, such as shock-boundary layer interactions and no-slip wall conditions, from inviscid inputs. By enabling RANS-level accuracy at near-Euler computational costs, this framework offers a scalable "digital wind tunnel" for the low-altitude economy, significantly accelerating the design and certification of next-generation aerial platforms.

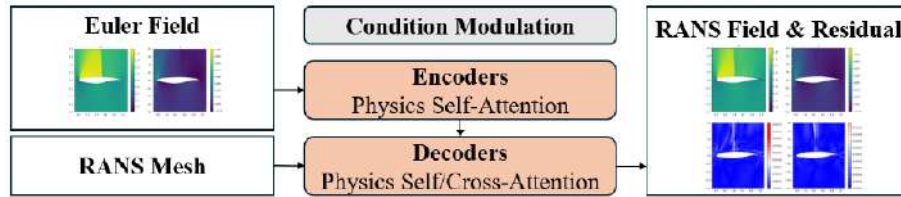


Figure 1: Model architecture

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STS 414-3

Resilient Low-Altitude Logistics: A Multi-Objective Evolutionary Approach for UAV Network Topology Optimization

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Abstract

The rapid expansion of the low-altitude economy presents unprecedented opportunities for logistics but demands highly resilient network architectures. Designing Unmanned Aerial Vehicle (UAV) networks that balance operational efficiency, structural robustness, and construction costs is a complex multi-objective challenge. This paper proposes an AI-driven optimization framework based on the Non-dominated Sorting Genetic Algorithm II (NSGA-II). We introduce a hybrid topology generation mechanism that integrates Minimum Spanning Trees (MST) for backbone connectivity with Voronoi-based partitioning for access networks. The method optimizes three conflicting objectives: global transport efficiency, network robustness (measured by algebraic connectivity), and operational cost. Numerical experiments confirm the algorithm's effectiveness, with the Hypervolume indicator proving mathematical convergence to a diverse set of Pareto-optimal solutions. The results identify critical trade-offs between cost and resilience, providing a scalable, data-driven methodology for the strategic planning of future urban air mobility ecosystems [1, 2, 3].

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STS 414-4

Towards a Unified Data-Driven Turbulence Model Through Multi-Objective Learning

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Abstract

Turbulence remains one of the last unresolved problems of classical physics and a major bottleneck to accurate flow prediction in climate, aerospace, and energy systems. Industrial simulations therefore rely on averaged representations of turbulence, which often struggle to predict flows governed by multiple interacting mechanisms. We present a unified, data-driven turbulence modeling framework designed to learn robustly from sparse, indirect observations across diverse flow regimes [1]. The framework embeds physical consistency into a flexible, frame-invariant closure, automatically selects representative training cases based on similarity of flow-feature distributions, and learns a single, unified model through a multi-objective ensemble strategy [2, 3] that balances competing objectives across flows and quantities of interest. The resulting unified foundation model adapts seamlessly across regimes without manual intervention. It outperforms existing turbulence models across a broad spectrum of canonical flows and maintains improved performance in realistic three-dimensional configurations of industrial relevance, including a generic car and a gas turbine diffuser. When application-specific accuracy is required, the framework further enables specialist models through additive fine-tuning on targeted flow datasets. The results demonstrate the feasibility of a deployable and generalized turbulence modeling approach that unifies multiple flow mechanisms within a single architecture for a broad range of natural and industrial flows.

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STS 414-5

Scenario-Based Risk Modelling for Urban UAV Traffic Management with Bayesian Networks

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Abstract

The rapid expansion of Unmanned Aerial Vehicles (UAVs) and Advanced Air Mobility (AAM) in urban environments poses significant challenges for Unmanned Traffic Management (UTM), particularly in predicting and mitigating safety risks in complex low-altitude airspace. UAV operations are subject to dynamic hazards such as dense traffic, infrastructure obstacles, adverse weather, and off-nominal events including system failures. Under such uncertainties, UTM systems must evaluate and compare the risks of alternative flight routes across different operational scenarios, which is critical for both strategic planning and tactical deconfliction.

Recent studies have demonstrated the value of dynamic risk mapping for AAM systems. For example, Altun et al. [1] showed that risk maps can support contingency management by enabling safer route selection during emergency conditions. However, existing approaches lack probabilistic frameworks capable of integrating heterogeneous uncertainties while simultaneously comparing multiple routing options.

Bayesian Networks (BNs) provide an effective solution by modelling conditional dependencies and supporting probabilistic reasoning under uncertainty. Their ability to combine empirical data with expert knowledge and dynamically update predictions makes them particularly suitable for UTM applications [2].

This study proposes a Bayesian Network-based probabilistic risk assessment framework to evaluate and compare safety risks across alternative UAV routes under varying scenarios. By integrating traffic, system, environmental, and infrastructure factors, the model generates scenario-based risk predictions to support data-driven decision-making. The framework contributes to safer and more adaptive UTM systems through risk-informed routing strategies.

References

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STS415 - Toward The New Materials Science Integrating with Computational and Deep Learning Technologies

Main Organizer: Mr. Tohru Hirano (Daikin Industries, Ltd., Japan)

Chaired by: Mr. Tohru Hirano (Daikin Industries, Ltd., Japan), Dr. Susumu Minami (Kyoto University, Japan)

Part	Date	Time	Room
STS415A	Wed 22.07.2026	09:45–11:15	NM - 4 (Hamburg)

The rapid advancement of computational materials science and the emergence of deep learning technologies are transforming the landscape of materials discovery, design, and optimization. This session focuses on the integration of physics-based simulations, high-throughput computations, and data-driven approaches to accelerate innovation in materials research. A particular emphasis will be placed on modeling of materials microstructures, including their generation, evolution, and optimization, as well as the theoretical modeling of diverse functional materials beyond structural mechanics. These include functionally graded materials (FGMs), thermoelectric materials, metal-organic frameworks (MOFs), and piezoelectric materials, where the interplay between structure and electronic functionality is critical. The related crystal structures modeling and phonon engineering are also depicted. Topics of interest include, but are not limited to:

- Theoretical modeling and design of functional materials such as functionally graded materials (FGM), thermoelectric materials, and metal-organic frameworks (MOFs).
- Microstructure modeling and optimization using mathematical models and AI-assisted techniques
- Applications of deep learning in microstructure-property relationships, defect prediction, and synthesis planning
- Autonomous materials discovery using active learning and reinforcement learning In this session, through interdisciplinary dialogue, we aim to define the next-generation paradigm of materials research empowered by advanced computation and deep learning methodologies.

STS 415-1

**Modeling and Design of Micro- and Nanostructures:
Focusing on Several New Materials Concepts and Machine Learning**

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ABSTRACT

In this presentation, micro- and nanoscale modelling and design of materials and structures are surveyed in view of structural and functional property relationships in Functionally Graded Materials (FGMs), thermo-electric (TE) materials, and Metal-Organic Frameworks (MOFs), through an integrated views of computational methods such as first principles modelling and machine learning (ML).

In FGMs, graded composition, interfaces, and porosity control coupled thermo-mechanical-electrical-diffusive responses, where continuum or Finite-Element Models (FEMs) augmented with data-driven surrogates enable inverse design. In TE materials, multiscale mechanisms of electron and phonon transport - defects, interfaces, and nano structuring - are captured by first-principles with Boltzmann Transport Equation (BTE) or Molecular Dynamics (MD), while Crystal Graph Neural Networks (CGNN) and generative models accelerate prediction of transport coefficients and ZT optimization.

For MOFs, the vast chemical/topological space is tackled by Grand Canonical Monte Carlo (GCMC) simulation and density functional theory (DFT) for adsorption/diffusion, ML models for property prediction, and synthesis-aware generative design with Bayesian optimization, enabling rapid advances in separation, storage, catalysis, and sensing.

We emphasize end-to-end pipelines from first principles to features, ML/DL models, multi-scale FEMs, and device evaluation; physics-informed learning; and active integration with experimental data for reliability. Key challenges include data scarcity and bias, rigorous multiscale coupling, extrapolation and interpretability, and constraints from synthesis feasibility and durability. Also, a roadmap toward autonomous materials design via generative AI is considered under physical constraints, digital twins for design automation, and hierarchical optimization across materials-manufacturing-devices-systems.

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STS 415-2

Online Learning-Accelerated 3D Monte Carlo Simulation for Gate-All-Around Transistors

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Abstract

The development of ultra-scaled semiconductor devices requires device simulators that do not rely on empirical models. The Monte Carlo (MC) simulation is among the most suitable approaches for this purpose. In conventional MC simulation, device characteristics are typically obtained by repeatedly solving the Poisson equation in discrete space and the Boltzmann transport equation in continuous space. To avoid this inefficiency, we have developed a Poisson solver using Physics-Informed Neural Networks (PINNs) [1] to directly compute the electric field from the charge distribution and implemented it in our MC simulator. In this study, we aim to enable accurate predictions even under untrained conditions by introducing an online transfer learning using the variational form of the Poisson equation.

The machine learning model consists of two components (see Fig. 1): one that represents the charge density distribution and another that maps the electron position to the output location. The former employs a Convolutional Neural Network (CNN) to extract features, while the latter represents the electron position using basis functions. By combining these two components, a mesh-free representation of the output function is achieved. This framework is based on the Deep Operator Network (DeepONet) [2], an operator-learning method. For performance evaluation, the constructed model was applied to a Si GAA FET with a gate length of 10 nm and a channel cross section of 5 nm × 5 nm. For the trained device structure, the relative error of the I-V characteristics was 2.3%. For untrained device structure, the prediction was challenging due to non-physical growth and reduction in the number of electrons. Therefore, we introduced online learning with the variational form of the Poisson equation and achieved a relative error of 4.3%, as shown in Fig. 2. The computational speed depends on the mesh resolution; for 13,064 mesh points, approximately 7× acceleration was achieved.

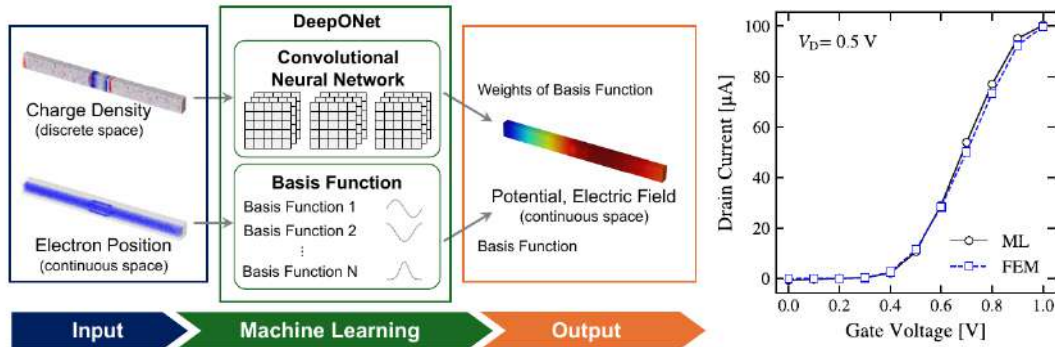


Figure 1 [left]: Proposed machine learning model structure.

Figure 2 [right]: I-V characteristics obtained by machine learning and a conventional FEM-based Monte Carlo simulation for an unseen device structure with online learning. Black open circles indicate the machine-learning results, whereas blue open squares indicate the results of the conventional FEM-based Monte Carlo simulation.

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STS 415-3

Development of a Model Bridging Finite Element Analysis and Infrared Stress Measurement for Spatial Defect Estimation in Complex-Shaped CFRP

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Abstract

In this study, a machine learning-based defect detection framework is proposed to estimate three dimensional (3D) defect spatial information in complex-shaped carbon fiber reinforced plastics (CFRPs) using surface stress distributions obtained from infrared stress measurement [1]. While CFRPs are essential for complex structures like prosthetic legs, detecting internal defects in such curvilinear geometries remains challenging for conventional methods. The proposed method utilizes a graph neural network (GNN) capable of learning from 3D mesh data. A major challenge in this approach is the scarcity of experimental data, which prohibits the direct training of the GNN. To address this, the GNN is trained exclusively using a large dataset generated by homogenization finite element analysis (FEA).

To enable the FEA-trained GNN to process experimental data accurately, we introduce a statistical domain adaptation framework integrating principal component analysis (PCA), partial least squares (PLS), and gaussian process regression (GPR). Specifically, PCA is first applied to the FEA stress distributions to derive their latent variables. Subsequently, PLS is employed to extract features from the experimental infrared images that are statistically correlated with the FEA physics, filtering out noise. Finally, GPR constructs a non-linear mapping function that connects these PLS-extracted experimental latent variables to the PCA-reduced FEA latent variables. This process effectively aligns the experimental input with the simulation-based feature space.

The framework was validated through cross-validation using experimental data from a CFRP prosthetic leg with artificial defects. The results demonstrated that the proposed method successfully predicted the presence and approximate 3D geometry of internal defects from experimental images, effectively overcoming the data scarcity issue.

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STS 415-4

First-principles Study of Strain Engineering for Anomalous Nernst Effect in Iron-based Binary Ferromagnets

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ABSTRACT

The anomalous Nernst effect (ANE), a thermoelectric effect caused by the spontaneous magnetization of materials, has attracted much attention due to the transverse thermoelectric voltage, and it has been reported that the ANE has advantages in terms of thermoelectric device applications[1]. Materials such as Co₂MnGa[2] and Fe₃Ga[3] have been reported as having large ANE originating from the intrinsic contribution, such as topological electronic structure. In addition, it was reported that strain engineering could improve conventional thermoelectric voltage based on the Seebeck effect[4]; therefore, strain engineering could also be a promising approach to improve ANE.

In this study, from the application viewpoint, we focused on the iron-based ferromagnet L12-type Fe₃Ga. We clarified that pristine Fe₃Ga shows large ANE: transverse thermoelectric conductivity reaches about 3 AK⁻¹m⁻¹ around room temperature[5]. This value is comparable to well-known large ANE material[2,3]. Furthermore, we also found that applying the tensile-strain, the sign of ANE is switched; bipolarity of ANE[6] was realized by strain-engineering. We also conducted detailed electronic structure analysis, and we conclude that the key topological electronic structure can be tuned by applying strain loading. Strain engineering for ANE could also be a promising approach to enhance thermoelectric response.

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STS 415-5

Analysis of Low-Energy Localized Phonon Mode in SiGe Alloys and its Impact on Lattice Thermal Conductivity: A Molecular Dynamics Study

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Abstract

The origin of the low-energy localized phonon mode in SiGe alloys was investigated using classical molecular dynamics (MD) simulations. Inelastic X-ray scattering spectra have shown that the peak intensity of this mode is comparable to that of the Ge-Ge optical phonon mode [1]. However, previous MD studies [2] employing SiGe alloy models with randomly arranged atoms failed to reproduce the relative intensity of the localized phonon mode. In this work, we performed MD simulations using SiGe alloy models with controlled Ge cluster sizes.

We found that the intensity of the localized phonon mode increases as the cluster size decreases, and the model containing isolated Ge atoms dispersed in the Si matrix exhibited the maximum intensity. Models containing Ge dimers or trimers simultaneously reproduce sharp localized phonon mode and Ge-Ge optical phonon mode. Considering that both the Ge-Ge optical phonon mode and the localized phonon mode are observed simultaneously, we conclude that Ge dimer or trimer clusters are the most plausible origin of the localized phonon mode. Also, we evaluated the lattice thermal conductivity of SiGe structures containing isolated Ge atoms dispersed in the Si matrix that exhibit the highest localized phonon mode intensity using the Green-Kubo method. Calculations were performed with Ge concentrations of 10%, 20%, and 30%. The thermal conductivity decreased with increasing Ge concentration, showing the lowest value in the model of 30%. The peak intensity of the localized phonon mode increased with Ge concentration and the 30% model exhibited highest value. These results suggest that the localized phonon mode contributes to the reduction in thermal conductivity.

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STS 415-6

Design of Tensor Prediction Models Based on Deep Learning: 2D Case

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Abstract

Heterogeneous materials, characterized by spatially varying mechanical properties, pose significant challenges in modeling and simulation due to their complex behavior. Traditional approaches, such as asymptotic developments and numerical methods (e.g., finite elements or fast Fourier transform - FFT [3]), enable the computation of effective tensors but face computational limitations at high resolutions. This study presents an innovative AI-based methodology [1] to predict first- and second-order homogenization tensors in 2D ($A^{0,0}$, $B^{0,1}$, and $C^{0,0}$) under plane stress conditions, applied to a Representative Volume Element (RVE) not included in the initial database. The studied RVE features a resolution of 256^2 , a mechanical property contrast ranging from 10 to 1000, and a maximum relative error of predicted values below 0.7%. The approach integrates convolutional neural networks (CNNs) [2], trained on a database of 56,000 RVEs generated and simulated via FFT, with Python-based frameworks (TensorFlow/Keras).

The performance of the models is evaluated against reference FFT-based simulations, demonstrating their ability to provide rapid, reliable, and automated predictions of the equivalent mechanical properties of heterogeneous materials. This work highlights the synergy between traditional numerical methods and AI, paving the way for more efficient and scalable solutions in materials science and engineering.

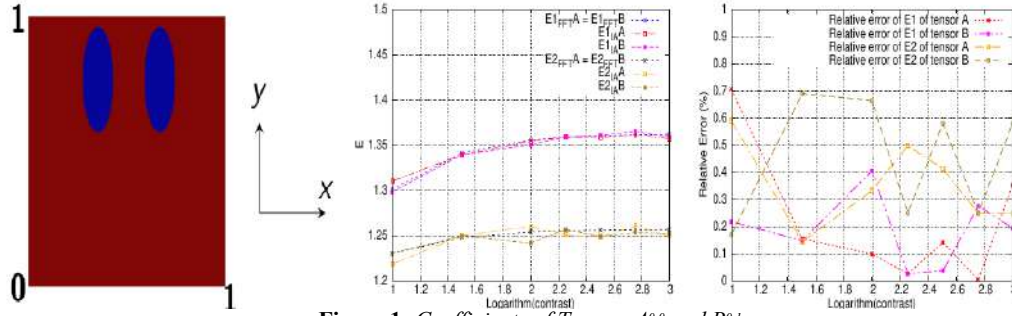


Figure 1: Coefficients of Tensors $A^{0,0}$ and $B^{0,1}$.

C++ without MPI/OpenMP (s)	C++ with MPI/OpenMP (s)	AI Prediction (s)	Gain (C++ with .../AI)
18.10	2.225	0.164	13.57

Table 1: Simulation time.

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STS417 - AI-Machine Learning Methodologies to Accelerate CFD-Based Design and Optimisation

Main Organizer: Prof. Shahrokh Shahpar (Rolls-Royce plc, United Kingdom)

Part	Date	Time	Room
STS417A	Thu 23.07.2026	09:45–11:15	NM - 4 (Hamburg)

Data driven methods under the Artificial Intelligence (AI) umbrella and its associated subset Machine Learning (ML) have seen extensive development in recent years. This is mainly due to a number of powerful opensource codes democratising the use Deep Neural Network (DNN), and increase in computing powers with new GPU and CPU chips. The AI methods although originally developed to replicate the human brain, once trained, are shown to be able to learn highly complex relationships in engineering datasets. The ability to apply the AI methods to physical problems, ranges from analytical, to numerical as well as experimental fluid mechanics. The new AI/ML methods is claimed to cut simulation times from days/hours to near instant and improves efficiency. However, these methods often require a large amount of training data, to produce accurate results for the highly non-linear fluid mechanics problems, nearly all the results published in the literature relating to high-dimensional test cases have used large number of simulations often much higher than even “classical” surrogate models used in the industrial optimisation workflows. In this STS, we would like to review and discuss novel methods that are used to address the aforementioned inefficiencies, aiming to accelerate CFD simulations used to design turbomachinery components like multi-stage Fan, Compressor and Turbine components in a fraction of the cost and time associated with direct design using high-fidelity analysis.

STS 417-1

Development and Application of AI-Machine Learning Methodologies to Accelerate Turbomachinery Flow Analysis

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Abstract

Driven by the need to reduce emissions from aviation, improving efficiency is the central challenge in modern gas turbine design. Applying Machine Learning (ML) techniques in place of direct simulation in the loop is of increasing prominence due to near instant results. However, they have not yet achieved the robustness necessary for industrial application in the turbomachinery field. This work aims to detail a generalisable ML framework applied to a highly-loaded, transonic compressor - NASA Rotor37. The model targets achieving equivalent accuracy of flow structures and extracted performance parameters to steady state simulations for a given physics fluid regime, with less than 200 training data points for 18 varied Engineering Parameters.

Central to the framework is a novel, geometry-agnostic processing technique that bypasses the limitations of traditional blade parameterisation, enabling seamless scalability across diverse topologies. By encoding raw blade geometry and boundary conditions directly into an asymmetric UNET architecture [1], the model performs a complex dimensional mapping to generate precise 2D flow fields. Unlike prevalent works restricted to fixed geometric templates [2], this method leverages physics-informed data preparation to ensure the model remains generalisable and capable of predicting out-of-distribution blade designs.

The model accurately predicts five flow state variables across an off-design blade characteristic, capturing both stall and choked flow behaviours. The R^2 values consistently exceeding 0.99 are achieved for local state variables, while derived isentropic efficiency maintains a mean R^2 of 0.96 across the full off-design location. The proposed methodology exhibits the robustness required for industrial application, accurately predicting off-design performance for a novel geometries containing topological features absent from the training set. When integrated into an optimisation workflow, the framework identifies optimal configurations that closely align with computational fluid dynamics results, reducing computational overhead to near negligible.

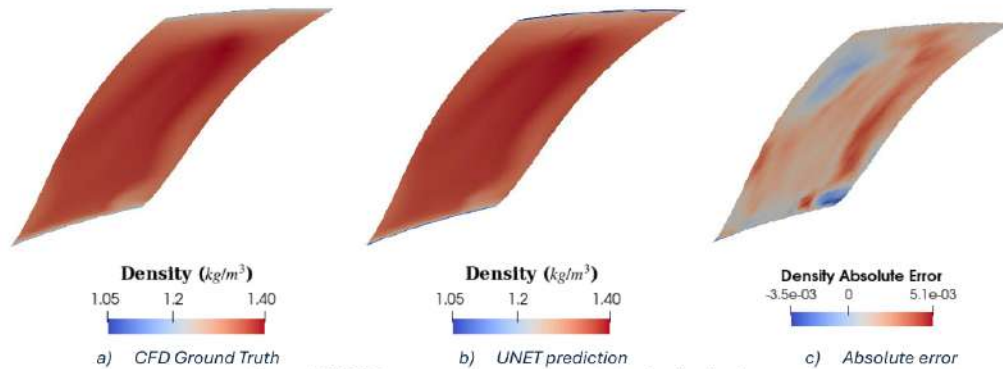


Figure 1: NASA Rotor compressor stage-exit density distribution.

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STS 417-2

Data-driven fine-grained prediction of laminar-turbulent transition in zero-pressure-gradient flat-plate boundary layers

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 and Jie Ren^{**†}

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ABSTRACT

The laminar-to-turbulent transition remains a fundamental and enduring challenge in fluid mechanics. Its complexity arises from the intrinsic nonlinearity and extreme sensitivity to external disturbances. This transition is critical in a wide range of applications, including aerospace, marine engineering, geophysical flows, and energy systems. While the governing physics can be well described by the Navier-Stokes equations, practical prediction efforts often fall short due to the lack of comprehensive models for perturbation initialization and turbulence generation in numerical simulations.

To address the uncertainty introduced by unforeseeable environmental perturbations, we propose a fine-grained predictive framework that accurately predicts the transition location. The framework generates an extensive dataset using nonlinear parabolized stability equations (NPSE). NPSE simulations are performed over a wide range of randomly prescribed initial conditions for the generic zero-pressure-gradient flat-plate boundary-layer flow, resulting in a large dataset that captures the nonlinear evolution of instability waves across three canonical transition pathways (Type-K, -H, and -O).

From a database of 3000 simulation cases, we extract diagnostic quantities (e.g., wall pressure signals and skin-friction coefficients) from each simulation to construct a feature set that links pre-transition flow characteristics to transition onset locations. Machine learning models are systematically evaluated, with ensemble methods - particularly Extreme gradient boosting (XGBoost) - demonstrating exceptional predictive accuracy (mean relative error of approximately 0.001). Compared to methods currently available (e.g., N-factor, transitional turbulence model), this approach accounts for the physical process and achieves transition prediction without relying on any empirical parameters.

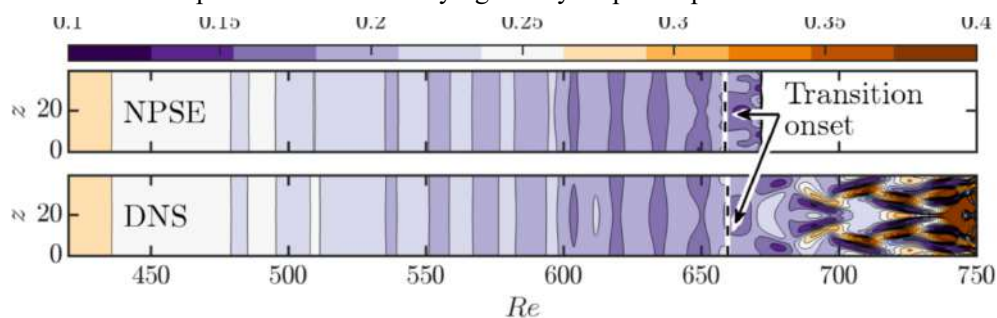


Figure 1: NPSE serves as a tool for identifying transition onset and establishing a reliable dataset for analysis.

STS 417-3

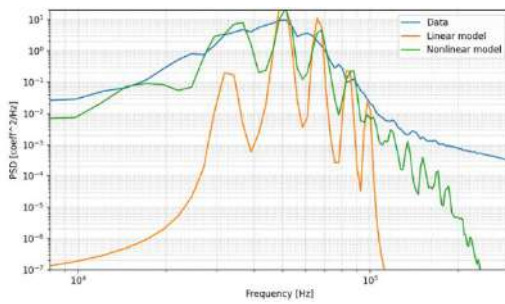
Learning Nonlinear Dynamics of Turbulent Flows for Noise Generation

Dao Zhou and Zhong-Nan Wang[†]

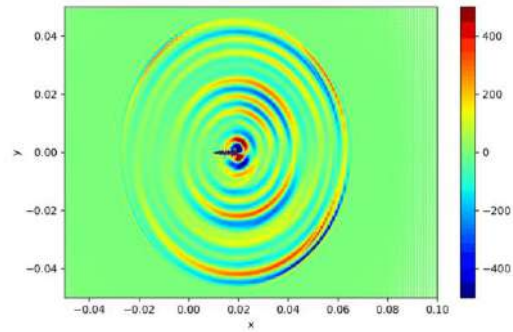
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Abstract

Sound generated by turbulent flows is considered as a major source of environmental noise, which comes as the second threat to health directly after air pollution according to WHO. A typical example is the turbulent jet from aero-engine exhaust, which is the dominant source when an aircraft takes off. The noise generation by turbulence is highly related to the coherent structures [1]. Linear model can produce the on-average dynamical behaviour of the coherent structures, but significantly underpredict the noise radiation. This indicates that nonlinearity plays a key role in generating noise. In this research, we aim to identify the nonlinear interactions of coherent structures that underpins the noise generation by learning a reduced-order model (ROM) from high-fidelity simulation data with the SINDy method. To enhance the accuracy and interpretability of data-driven ROM, the physical constraint has been applied to preserve the energy transfer in the turbulence cascade with a closure model used to account for the interactions with unresolved parts. In addition to modelling the deterministic interactions between coherent structures, an additional forcing is formulated to account for the stochastic effects of fine-scale turbulence. Figure 1a shows that the derived ROM can well represent the nonlinear dynamics for a turbulent mixing layer, compared to a linear model. The acoustic field, shown in Figure 1b, is obtained by solving the Acoustics Perturbation Equation with reduced-order modelled sources, offering insights into the relationship between the nonlinear dynamics of coherent structures and noise generation.



(a) Spectra of the coherent structure by linear and nonlinear ROM



(b) Acoustic pressure calculated by APE with ROM-simulated source

Figure 1: ROM-based prediction of coherent structure dynamics and radiated acoustics

References

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STS 417-4

Inverse Design Using Surrogate-Assisted Score-Based Diffusion Models

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Abstract

Designing aerospace components often requires balancing conflicting objectives including aerodynamic performances under strict industrial constraints such as structural integrity and low noise emissions. Traditional design processes rely on iterative trial-and-error: parameterizing geometries, adjusting variables manually, simulating or testing, and repeating until acceptable performance is achieved. While effective, this approach is resource-intensive, requires significant expertise, and often fails to explore the design space efficiently. Inverse design provides an alternative paradigm by directly generating candidate geometries that satisfy desired performance objectives, bypassing the need for iterative evaluation and modification, particularly when combined with recent advances in generative modeling. Among generative methods, diffusion models stand out for their stability and ability to generate diverse, high-quality samples. Yet their application to realistic, highly constrained optimisation remains limited due to issues such as distribution shift, constraint handling, and sampling efficiency.

In this work, we address these challenges by proposing a score-based diffusion model complemented with tools initially developed within Cenaero's surrogate-based optimisation framework MINAMO. First, constrained problems are reformulated into an aggregated single-objective formulation, which is then used as a conditioning mechanism for the diffusion model. Second, we investigate the mitigation of distribution shift by enriching the initial database through adaptive infill sampling. The methodology is demonstrated on two representative cases.

The first case concerns the aerodynamic design of the ONERA M6 wing under transonic flow conditions. The geometry is parameterized using the Free-Form Deformation method, and an initial database is constructed through a Design of Experiments. The diffusion model is then conditioned to generate input parameters leading to increasing lift-to-drag ratios, illustrating its capability to propose new geometries that outperform existing designs, and thus demonstrating the effectiveness of the score-based inverse design approach. The second case uses a similar methodology to address the constrained design of high-speed propeller blades. Here, the training database for the generative model is augmented with samples obtained from a parallel surrogate-based optimisation. This demonstrates that, while diffusion models can generate promising candidates for inverse design, incorporating new samples from surrogate-based optimisation enhances the generative capacity of the diffusion model and helps mitigate issues related to distribution shift.

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STS418 - Noise Impact and Control of eVTOL

Main Organizer: Mr. Bao Chen (AVIC ARI, China)

Part	Date	Time	Room
STS418A	Thu 23.07.2026	11:30–13:00	NM - 4 (Hamburg)

Cities are important application scenarios for eVTOL, and noise is a crucial factor in determining the environment-friendliness of eVTOL. Firstly, eVTOLs adopt typically a distributed propulsion layout, utilizing various combinations of multiple rotors and tiltrotors to realize flight in different states such as takeoff, transition, cruise and landing. The flow mechanism and noise generation mechanism are complex, and many sound sources pose issues with both external noise and cabin noise; Secondly, eVTOL take off and fly in cities, and the takeoff and landing points are close to residential and commercial areas. Noise of eVTOL does not undergo long-distance attenuation and directly affects the surrounding environment, bringing potential noise pollution. Overall, noise pollution in low altitude environments is one of key factors limiting the large-scale application of eVTOL. This STS will conduct specialized academic exchanges on the numerical simulation methods of eVTOL noise sources and propagation characteristics, experimental verification methods, etc. We look forward to experts and scholars from universities, research institutions, and industries around the world, such as the European Union and China, sharing research results and exploring future technological developments.

STS 418-1

Numerical Investigation on Aerodynamics and Aeroacoustics of Looped Propeller with Gurney Flap

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Abstract

Electric vertical take-off and landing (eVTOL) aircraft are expected to operate over an area of high population density, where propeller noise is a major problem. The loop-type propeller “Loopprop” has been developed for low-noise drone/eVTOL applications [1]. This study investigates the effects of a Gurney flap (GF) on the flow field, aerodynamic performance and aeroacoustics characteristics of a three-blade Loopprop in hover.

The numerical simulations are performed using rFlow3D [2], a rotary-wing CFD solver under development at JAXA, and the aeroacoustics analysis is performed using rNoise [3], an aeroacoustics prediction tool also under development at JAXA. The GF height is set to 2% of the blade chord length [4]. Simulations are performed for both the Loopprop without GF and with GF2% under two conditions: the same rotational speed and the same thrust.

The Loopprop with GF2% increases the thrust coefficient by approximately 36% and improves the Figure of Merit by approximately 5% compared to the Loopprop without GF. These improvements are attributed to an enhanced pressure difference between the suction and pressure sides and delayed/suppressed separation. At the same rotational speed, Loopprop with GF2% increases the Sound Pressure Level (SPL) at the blade-passing frequency by 2-5 dB, while the Overall Sound Pressure Level (OASPL) is almost the same. At the same thrust, Loopprop with GF2% decreases the SPL by 5-10 dB, and the OASPL by 3dB. These results suggest that GF-enabled lift enhancement can be exploited to lower rotational speed at equal thrust, offering simultaneous aerodynamic and acoustic benefits for Loopprop.

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STS 418-2

Scalable Gaussian Beam Tracing with Dynamic Parallelism for City - Scale Urban Aerial Noise Prediction

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Abstract

The Gaussian Beam Tracing (GBT) method effectively addresses the singularity problems of traditional ray tracing in high-frequency acoustic simulations [1]. However, its application in large-scale complex environments is hindered by immense computational costs due to massive ray-surface interactions and beam summation operations. This study proposes a high-performance GPU-accelerated GBT solver that integrates CUDA Dynamic Parallelism with advanced spatial partitioning algorithms [2].

To overcome the performance bottleneck of ray-scene intersection tests, this work investigates three acceleration structures optimized for GPU architectures: Octrees, KD-trees, and Bounding Volume Hierarchies (BVH). Unlike traditional CPU-based Quadtree implementations, we evaluate these 3D structures based on construction overhead, memory access patterns, and thread divergence control. The results indicate that the BVH structure, when combined with dynamic parallelism, minimizes traversal steps and maximizes parallel thread occupancy.

Furthermore, we utilize dynamic parallelism to handle the irregular workloads inherent in the Gaussian Beam Summation (GBS) process, allowing threads to dynamically spawn child kernels for computationally intensive regions. Simulation results in a complex city environment show that the proposed method achieves an overall pipeline acceleration of 112x compared to a single-threaded CPU baseline, with the GBS stage achieving a speedup of up to 817x. This approach enables efficient, high-precision environmental noise assessment.

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STS 418-3

Research on Wind Tunnel Test Validation of Computational Aeroacoustics for Rotor

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Abstract

Rotor noise is a primary noise source of eVTOLs, and many kinds of computational aeroacoustics have been developed. Wind tunnel testing serves as a crucial means for validating rotor noise computation simulation and reduction designs.

In order to supply wind tunnel test data to validate computational aeroacoustics method, research activities on whole-path wind tunnel testing technologies for rotor aerodynamic noise based on an 8-meter-scale large aeroacoustics wind was given in this paper. From the perspective of noise source identification, a 4-meter aperture, 130-channel microphone phased array was developed, along with a rotating sound source identification algorithm based on signal reconstruction. Regarding noise propagation, a low-noise in-flow microphone support structure was designed and a 22-channel scanning U-shaped in-flow microphone array was developed. For near-field noise reception, surface-mounted microphones with embedded installation methods were adopted to achieve acoustic load measurement on aircraft surfaces. In terms of far-field noise reception, a hemispherical far-field noise characterization array was designed to enable high-resolution measurement of noise directivity. A unified data acquisition and processing platform was employed to collect, process, and correct various noise signals.

The BO-105 model was utilized to complete whole-path wind tunnel testing verification covering noise source identification, in-flow acoustic propagation, and near/farfield acoustic reception of rotor noise, achieving a seven-time repeatability accuracy of 0.59dB for far-field directivity measurements.

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STS 418-4

Dual-Biomimetic Conceptual Design of a Blended Wing Body Unmanned Aerial Vehicle Inspired by Eagle and Manta Ray

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Abstract

This paper proposes a mission-driven, dual-biomimetic conceptual design and aerodynamic assessment of a 200 kg-class blended-wing-body unmanned aerial cargo aircraft for regional rapid logistics. The study is motivated by the state of the art in high-efficiency BWB configurations and bio-inspired aerodynamic shaping, where practical deployment is often limited by the coupled challenges of low-speed stall behavior, trim requirements, and insufficient directional stability for tailless BWB platforms. Drawing inspiration from manta rays (smooth wing-body blending and rounded leading-edge characteristics) and eagles (high-aspect-ratio tendency, wingtip devices, and tail-assisted stability augmentation), we establish a traceable mapping from biological traits to engineering geometry features and evaluate their isolated and combined effects.

Parameterized geometries are built in CATIA and evaluated using steady RANS CFD (Spalart–Allmaras). A controlled comparative matrix isolates the incremental effects of the biomimetic wing-body planform, leading-edge radius, winglets, V-tail, and surface smoothing, followed by a twin-engine installation assessment that considers nacelle external drag. The results indicate improved cruise efficiency for the biomimetic planform, increased $C_{L,max}$ and delayed stall for the rounded leading edge, marginal net gains from winglets, and a pronounced improvement in static stability and trim requirements with the V-tail, mainly due to interference-driven wing-body pressure redistribution. Surface smoothing provides the largest drag reduction by lowering pressure drag. The final configuration meets the prescribed mission constraints, demonstrating a practical dual-biomimetic design route for cargo BWB UAVs.

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STS 418-5

A Robust Numerical Method for Rotor-Based Simulations on Unstructured Overset Grids

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Abstract

Rotor flow fields are highly complex and strongly unsteady, posing significant challenges for numerical simulation using traditional grids. While overset unstructured grids can effectively accommodate the rotor's complex motion and geometric features, they often suffer from poor numerical stability and low computational efficiency. To overcome these limitations, this study develops a robust and efficient implicit numerical method for overset unstructured grids based on the exact Jacobian matrix.

The proposed approach integrates a combined hole-cutting strategy based on signed distance fields and distances to physical surfaces with a contribution-cell search algorithm using a Bounding Volume Hierarchy (BVH), enabling fast and automated overset grid assembly. Numerical stability is further enhanced through a compact least-squares reconstruction, while the exact Jacobian matrix is computed via the chain rule to improve accuracy and reversibility, reducing errors in the implicit linear solver. An adaptive CFL scheme is also employed to further increase overall computational efficiency. Validation against representative test cases demonstrates that the proposed implicit method achieves substantial improvements in both convergence and computational efficiency compared with conventional approaches.

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STS 418-6

Multidisciplinary, Multi-point Optimization of Aircraft propellers, Including Aero-acoustic and Structural Constraints

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Abstract

The design of highly efficient propellers is a primary driver for the viability of emerging electric and hybrid-electric aircraft, specifically within the sectors of Urban Air Mobility (UAM) and unmanned aerial vehicles (UAVs). While high-fidelity computational fluid dynamics (CFD) provides significant insight, its prohibitive computational cost renders it impractical for the many-query analyses required in early-stage design optimization. This paper presents a multidisciplinary design optimization (MDO) framework capable of tailoring propeller planforms across multiple flight conditions, including take-off, climb, and cruise.

The methodology integrates a rapid aerodynamic solver based on a vortex filament method and Betz theory with a discrete-frequency aero-acoustic model to predict thickness and loading noise[1]. To ensure physical fidelity and design viability, the framework is enhanced by a structural deformation module. This module accounts for fluid-structure interaction (FSI), capturing the effects of aerodynamic and centrifugal loading on blade twist and bending. The propeller geometry is parameterized using Bezier ` curves, allowing for a flexible design space within a gradient-based optimization environment.

By simultaneously addressing aerodynamic efficiency, acoustic signatures, and structural aeroelasticity, the proposed approach provides a holistic tool for the development of next-generation propulsion systems. The paper details the numerical formulation of the solvers, the integration of the multidisciplinary framework, and provides results from a representative test case demonstrating the trade-offs between performance and noise across a diverse mission profile.

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STS420 - Ultra-Performing Wing Project (UP Wing) on HAR Wing Design and Development for SMR Aircraft

Main Organizer: Dr. Jos VANKAN (NLR, Netherlands)

Chaired by: Joint STS103B–STS420A: Prof. Jochen Wild (DLR German Aerospace Center, Germany), Dr. Jos VANKAN (NLR, Netherlands); STS420B: Dr. Jos VANKAN (NLR, Netherlands), Dr. Bruno Stefes (Airbus Operations GmbH, Germany)

Part	Date	Time	Room
Joint STS103B– STS420A	Tue 21.07.2026	15:00–16:30	NM - 2 (Salzburg)
STS420B	Tue 21.07.2026	17:00–18:30	NM - 2 (Salzburg)

Sustainable aviation is a major challenge that requires technology developments in many different areas. One important area is the reduction of green-house gas emissions, which is directly related to aircraft operations and energy efficiency. One of the key components for improving aircraft efficiency is drag reduction, and increased wing aspect ratio is a key enabler for that. Therefore this STS focuses on technologies for design and development of high aspect ratio wings for short- and medium range aircraft, including design, modelling, analysis, testing, validation, manufacturing and assembly of the technologies involved in advanced high-aspect-ratio wing development.

STS 420-1

Introduction to the Ultra-Performing Wing Project (UP Wing)

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Keywords: *High aspect ratio wings, short- and medium range aircraft, MDO.*

Abstract

Sustainable aviation is a major challenge that requires technology developments in many different areas. One important area is the reduction of green-house gas (GHG) emissions, which is directly related to aircraft operations and energy efficiency. One of the key components for improving aircraft efficiency is drag reduction, and increased wing aspect ratio is a key enabler for that.

Therefore, this STS will focus on technologies for design and development of high aspect ratio (HAR) wings for short- and medium range (SMR) aircraft. This category of aircraft is responsible for a major contribution in aviation GHG emissions and is therefore important to address. At the same time, these aircraft have high-tech wings with advanced aerodynamics, optimized structures and complex integration of primary and secondary flight controls.

In the Clean Aviation UP Wing project (2023-2026, [1]), the relevant enabling wing technologies for improving wing efficiency are being investigated. These multi-disciplinary investigations include aero-elastic design, advanced loads control, multidisciplinary modelling and optimization, innovative computational methods, systems and structural design tools for innovative wing design. In particular, increasing the wing aspect ratio will require special attention for load control, for which combined numerical-experimental investigations are being completed in the UP Wing project.

The STS420 will present papers on the design, modelling, analysis, testing, validation, manufacturing and assembly of all the relevant technologies that are involved in the development of these advanced high-aspect ratio wings.

This paper will present a general introduction of the UP Wing project and an overview of the STS420 program.

Acknowledgement

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STS 420-2

Multidisciplinary Design of a Commercial LH2 Aircraft with Advanced Technologies

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Abstract

The aviation industry is currently facing the challenge of achieving net-zero carbon emissions by 2050, as future regulations would have it. However, conventional "tube-and-wing" architectures are reaching a plateau in efficiency, driving the exploration of disruptive energy sources and airframe configurations. Liquid hydrogen has emerged as a strong contender for sustainable flights, but the requirement for large cryogenic tanks typically leads to "dry wing" configurations (lacking the structural relief of fuel weight) and increased fuselage volume. To counteract these penalties, ultra-high-aspect-ratio wings are being investigated. Specifically, the Strut-Braced Wing (SBW) configuration is a key enabler for these slender wings, providing the necessary structural support to increase span and reduce induced drag without the weight penalty of a standard cantilever design.

For that particular concept, research within the NASA SUGAR framework demonstrated that these configurations could achieve over 50% reduction in energy use when combined with advanced propulsion. Additionally, previous work by the authors found that SBW concepts can outperform current aircrafts with respect to mission block fuel, without a substantial increase in MTOW, ultimately leading to configurations with up to a 15% reduction in mission block fuel [2]. Overall, most studies underscore the need for high-fidelity structural modeling to account for complex phenomena at every scale.

This paper details a comprehensive MDAO study of a commercial LH2 SBW aircraft, building on the framework detailed in previous work [1], which was extended to incorporate two major contributions: i/ advanced composite sizing of both the wing and the strut, with the intent of maximizing the weight savings offered by modern materials; ii/ explicit integration of the propulsion system, with a dedicated analysis of the interaction between the propeller slipstream and the wing aerodynamics. The resulting, new, optimized concept is then compared to a reference A320 type aircraft, as well as the result from previous studies by the authors [2]. Results will give insights into the trade-offs between aerodynamic efficiency and structural weight on the overall performance of the aircraft, as well as demonstrate a significant leap in fuel efficiency.

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STS 420-3

Aerodynamic Design of a Strut-Braced Wing for Overall Aircraft Design in an MDO Strategy

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Abstract

This paper aims at presenting the detailed aerodynamic design of a strut-braced wing (SBW) aircraft configuration powered by LH₂, carried out within the framework of the Clean Aviation ACAP and UPWING projects. In this context, ONERA has established a multidisciplinary design process to explore the design space offered by such a configuration. This paper will focus on the aerodynamic design activities performed within both projects. From a multidisciplinary and multistep design process (where the level of fidelity of the disciplinary modules used in the process was progressively increased) a first configuration at Overall Aircraft Design (OAD) level is defined. This OAD multidisciplinary design strategy based on FAST-OAD [1] will be briefly presented in the final paper. The high-fidelity aerodynamic performance assessment carried out within the OAD design framework is performed using the in-house automatic computation chain PyCaps/EGADS [2]. On the configuration resulting from this process, a refined aerodynamic design phase will be carried out. During this design phase, critical aspects of the aerodynamic design will be addressed, such as the interaction between the strut and the wing, the design of the strut-wing junction, and the transonic airfoil design for both the wing and the strut.

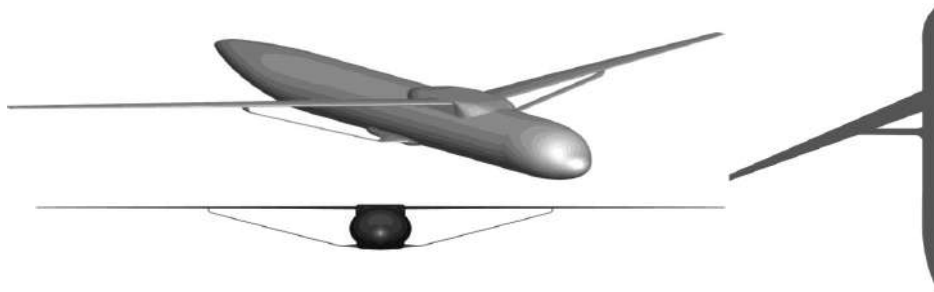


Figure 1 - Aircraft shape resulting from the first OAD design loop

Finally, based on the experience from several European projects on adjoint-based optimisation (MADELEINE [3], NEXTAIR) an adapted optimization process applied to the strut-braced wing configuration will be implemented and applied. The aerodynamic performance of the optimal SBW configuration will be detailed in the final paper using in-house far-field drag method. Such method enables to decompose the total drag into its physical components and identify the benefits provided by the new configuration.

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STS 420-4

Aerodynamic design of an advanced droop nose device for a high aspect ratio wing

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Abstract

Ambitions to reduce the environmental impact of air traffic calls for novel solutions to improve the energy efficiency of large transport aircraft, independent of the propulsion type. A major contributor to aerodynamic drag is induced drag that can directly be approached by the wing aspect ratio as already pointed out by Ludwig Prandtl when formulating the lifting line theory. While glider aircraft achieve glide ratios up to 70 by highly stretched wings [1], current commercial transport jet aircraft operate at glide ratios up to 20.

The DLR-F25 configuration [2] was selected within the Clean Aviation project UP-Wing to address the challenges of distributing and installing multifunctional movable surfaces for aircraft flight control, gust and load alleviation and as high-lift system [3]. It is a single-aisle medium-range aircraft competitive to an A321 size with an aspect ratio increased to 15.6.

The current paper describes aerodynamic design investigations to install an alternative Advanced Droop-Nose Device (ADND) at the outboard part of the wing of the DLR-F25. In consequence of the high stretching of the wing, the cross sectional airfoil size on the outboard wing gets comparatively small. Standard high-lift systems as slat devices no longer fit with their systems into the limited space. The ADND is a variant of a droop-nose device featuring an additional bending panel at the interface to avoid the curvature discontinuity usually imposed [4].

The present contribution will analyze in detail how such a device compares aerodynamically to the standard slat device. It will address the spanwise occupation for providing sufficient high-lift capability and inspect the aspects of the spanwise transition from a slat to the ADND device. The work is based on steady Reynolds-Averaged Navier-Stokes flow simulations of the landing wing/body configuration including engine effects in idle operation and considering different CFD methodologies for the design and analysis phases of the high-lift system.

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STS 420-5

Innovative Lightweight Design through Non-Conventional Composite Laminates

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Keywords: NCSSLs (non-Conventional Stacking Sequence Laminates), Composite Structures, Lightweight Design, Impact Resistance, Compression After Impact, Non-Conventional Laminates, Aerospace Materials.

Abstract

Composite materials are widely used in aerospace thanks to their high strength-to-weight ratio, but traditional symmetric and balanced laminates may limit their full potential.

This research explores Non-Conventional Stacking Sequence Laminates (NCSSLs), an innovative design strategy that breaks symmetry rules to optimize performance. By varying the number and orientation of plies, including bundles with the same fibre orientation and using traditional fibre orientation outer bundles, NCSSLs aim to reduce weight while maintaining impact resistance, particularly Compression After Impact (CAI) strength. Experimental testing combined with numerical simulations has shown that these novel stacking sequences achieve mechanical performance comparable to conventional laminates while enabling potential weight savings.

The results open the door to more efficient composite structures, offering a compelling alternative for applications where every gram counts, such as aerospace and advanced mobility. The project receives funding from the Clean Aviation Joint Undertaking under the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 101101974.

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STS420-6

Numerical Simulation of Droplet Impact Experiments on Structural Surfaces

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ABSTRACT

An important topic in the design of aircraft component surfaces and coatings is their resistance against rain erosion. Rain erosion has been the subject of intensive investigation for some time [e.g. 1–3] and particularly affects components such as the leading edges of wings, horizontal and vertical stabilisers, nose domes, and helicopter rotor blade edges, which are vulnerable to damage from droplet impacts. To predict the rain erosion behaviour of different materials and coatings, ground erosion tests such as the rotating arm test [4] or the Pulsating Jet Erosion Test (PJET) [5] are conducted.

For the development and design of coatings or new materials, a simulation methodology that is capable of predicting the phenomena and mechanisms observed in tests based on an adequate representation of the underlying physics and basic material properties by direct simulation of droplet impacts would be highly desirable. Some efforts have been undertaken in this direction [e.g. 1,6,7], but a simulation methodology which combines multiple impacts with the accurate representation of each droplet impact is not yet available.

We investigated PJET tests on a model aluminum material (Al 1050 H14) with a hardness comparable to common CLAD surfaces, characterized the material in static and dynamic tensile tests and performed numerical simulations in 2D and 3D. We measure the crater depth from the PJET-test for different impact numbers with high precision to obtain a good basis for the validation of the simulations. Additionally, the PJET method has been combined with a methodology to determine the weight loss of the impact craters. Our 2D simulation model with commercial software (ANSYS Autodyn) can predict the crater depth for up to 500 droplet impacts. The 3D multiple impact simulations with specialized numerical codes developed at Fraunhofer EMI show an interdependence of the surface deformation due to droplet impact and the impact pressure.

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STS420-7

Development of a Highly Flexible Wind Tunnel Model with Active Control System for High-Speed Gust Load Alleviation Testing

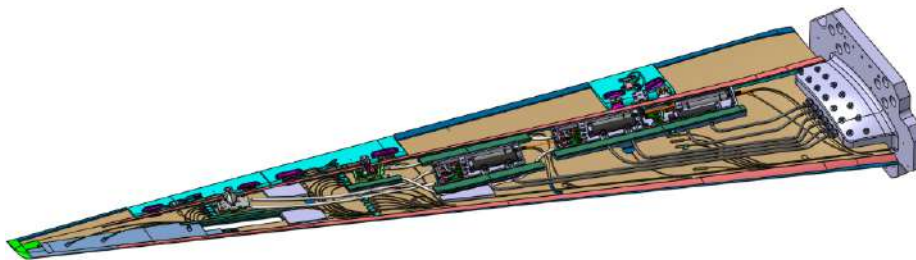
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Abstract

Sustainable aviation is a key objective in reducing the environmental impact of air travel. Reduction of greenhouse gas emissions can be accomplished through increased efficiency in aircraft design. One approach to improving efficiency is the application of High Aspect Ratio (HAR) wings, which offer enhanced aerodynamic performance. However, compared to conventional wing designs, HAR wings experience an increased dynamic response due to external disturbances, resulting in higher wing loads.

The UPWing project “Novel Control Technologies” aims at reducing these wing loads by applying manoeuvre and gust load alleviation technologies. As part of this effort, a wind tunnel model is being developed to investigate different methods for gust load alleviation (GLA) in transonic cruise speed conditions. The model will have 1.47 m semi-span, at a scale factor of 15.3, and utilise fast actuating control surfaces to alleviate the gust loads. This paper, as part of the STS420 programme, will provide an overview of the design and development of the GLA wind tunnel model, focusing on the wing structure itself and the (internal) flap actuation mechanism.



The main challenges associated with the design and development of the GLA wind tunnel model is to create a flexible model that can withstand large bending deformations, equivalent to 17% of the semi-span, while maintaining structural integrity. Additionally, the model must integrate various types of instrumentation, such as Kulites for dynamic pressure measurement, accelerometers, and strain gauges. The design must also accommodate a hydraulic actuation mechanism for each of the three flaps, that is sufficiently fast (compared to the wing eigenfrequency) and able to overcome the moments generated by the control surfaces in transonic test conditions, all within the limited available space inside the wing. Further, these actuation mechanisms should have minimal impact on the stiffness of the wing and not compromise the wing's structural integrity.

Acknowledgement

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STS421 - Technological and Operational Roadmap for Greening of Aviation

Main Organizer: Mr. Luis Campos (Universidade de Lisboa, Portugal)

Chaired by:

STS421A:

Prof. Rosa Maria Arnaldo Valdes (Universidad Politecnica de Madrid, Spain),
Prof. Oleksandr ZAPOROZHETS (Sieć Badawcza Łukasiewicz - Instytut Lotnictwa, Poland);

STS421B:

Mr. Luis Campos (Universidade de Lisboa, Portugal), Ms. Maria Zamarreno Suarez (Universidad Politecnica de Madrid, Spain)

Part	Date	Time	Room
STS421A	Mon 20.07.2026	15:00–16:30	NM - 2 (Salzburg)
STS421B	Mon 20.07.2026	17:00–18:30	NM - 2 (Salzburg)

The session focuses on the more recent results in the fourth and last year of the project EFACA (Environmentally Friendly Aviation for All Classes of Aircraft). After an introductory overview of the EFACA project (Paper 1), it goes into more detail at the five levels of the project: (i) Level 1: Laboratory and test bench demonstration to TRL3 of 3 critical technologies, namely: (Paper 2) A gearbox combining power from a gas turbine and electric motor to drive a 700 HP propeller; (Paper 3) An hydrogen fuel cell with novel phase change cooling to boost efficiency and operability; (Paper 4) A complete liquid hydrogen fuel system, comprising cryogenic storage and transport, vaporizer and combustor; (ii) Level 2: Status and prospects of two technologies: (Paper 5) Advances in battery power for emissions free flight of small aircraft; (Paper 6) Alternative sustainable aviation fuels for carbon neutral flight of large long-range airliners; (iii) Level 3: Preliminary design of two aircraft types: (Paper 7) A propeller regional airliner (PRA) with 1000km range with 80 passengers using hybrid turboelectric propulsion combining turboprop and hydrogen fuel cell in the ATR72-600 class; (Paper 8) A liquid hydrogen fuelled jet liner (LHJ) with 2000km range with 150 passengers in the A 220/320 class; (iv) Level 4: Assessment of the current and future status of (Paper 9) Airport Noise and (Paper 10) Local and Global Emissions of all types (CO₂, NO_x, Sulphur, Particles and Contrails), including the benefits of the 2 EFACA designs: PRA/LHJ compared with current ATR72-600/A320neo; (v) Level 5: Roadmap for greening of aviation (Paper 11), relative to ACARE FlightPath 2050, EU FIT 55 for 2035 and ICAO NetZero 2050 targets, bearing in mind the benefit of new technologies and time scale for replacement of older by cleaner aircraft.

STS 421-1

**Contributions to the Greening of Aviation from the Project EFACA
(Environmentally Friendly Aviation for All Classes of Aircraft)**

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Keywords: EFACA project, Green aviation, Hybrid propulsion, Hydrogen fuel, SAF

Abstract

The ECCOMAS 2026 STS session dedicated to the Project EFACA consists of 12 presentations related to a “Technological and Operational Roadmap for Greening of Aviation”, and the present paper 1 serves as an introduction. The EFACA Project involves 3 experimental demonstrations highlighted by: (Paper 2) The ground test bench of a hybrid turboelectric propulsion system consisting of a gas turbine and electric motor driving a 7-bladed propeller through a combiner gearbox; (Paper 3) A novel phase change cooling system for hydrogen fuel cells reducing heat losses and improving efficiency and suitability for operation at altitude; (Paper 4) As part of a complete laboratory liquid hydrogen fuel system, from tank to combustor, demonstration of an injector providing stable hydrogen combustion over a wide range of operating conditions. At level 2 greening technologies are considered for 4 classes of aircraft: (Paper 5) Battery power for small short-range aircraft like e-VTOLs; (Paper 6) Feedstocks, production paths, availability and cost of sustainable aviation fuels for large double aisle long-range airliners; (Papers 7/8) Design of a hybrid turboelectric propulsion system combining gas turbines and hydrogen fuel cells (Paper 7) and its application to a 80-seat 1000 km-range regional propeller aircraft (Paper 8); (Paper 9) Design of a 160-seat 2000 km-range jetliner with liquid-hydrogen fuel. At level 3 the environmental benefits of the level 1 technologies and level 2 aircraft designs are considered: (Paper 10) Reduction of the airport noise footprint, including flight and ground phases, for single aircraft and a whole fleet; (Paper 11) Likewise for carbon and other emissions affecting (a) local air quality near airports and (b) climate change on global scale; (Paper 12) A roadmap on the greening of aviation assessing the benefits of gradual replacement of current fleets by greener EFACA aircraft designs.

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STS 421-2

Preparation for Testing the Gearbox, which Combines the Output Power of the GTE and the Electric Engine to Drive the Air Propeller of a Hybrid Turbo-electric Propulsion

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Abstract

The article highlights the main stages of preparatory work for ground testing of a demonstrator gearbox that transmits power to the air propeller, obtained by combining the power of a gas turbine and electric engines. This hybrid turbo-electric propulsion (HTEP) is being developed with the aim of reducing the environmental impact of aircraft emissions, in line with the European Green Deal with the goal of ensuring environmental neutrality in the European Union by 2050, as well as one of the Goals of the ACARE Flight Path 2050 programme (Challenge 3. Protecting the environment and energy supply).

Design work was carried out to develop a combined gearbox, research and development work was carried out to create an electric engine, select test bench equipment, and develop test plans for the HTEP to meet the objectives set out in the EFACA project.

These findings are based on research conducted within the EFACA (Environmentally Friendly Aviation for All Classes of Aircraft) project funded by the European Commission under the Horizon Europe programme (Grant Agreement No. 101056866), which is part of the Climate, Energy and Mobility cluster. EFACA aims to contribute to the development of a cleaner aviation sector by developing new technologies using electric and hybrid turbo-electric propulsion and new sustainable fuels to combat climate change by 2050 (www.efaca.eu).

STS 421-3

Key Considerations for Defining a Roadmap on the Use of Batteries for Aircraft Propulsion

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Abstract

Batteries are a promising technology for sustainable aviation. They have several advantages, including reducing in-flight emissions and decreasing dependence on fossil fuels.

In the case of battery applications in aviation, safety and specific energy values are two of the most significant challenges [1]. It is therefore crucial to consider these parameters alongside other quantitative and qualitative metrics. Among the quantitative metrics, the number of cycles is particularly important. Among the qualitative metrics, recyclability is another fundamental dimension.

There are different types of batteries of interest within this technology. Each presents its own benefits, limitations, and maturity level.

A classification of battery technologies for use in aviation has been developed by the Environmentally Friendly Aviation for All Classes of Aircraft (EFACA) project. The project has also conducted in-depth analyses of the benefits and challenges of each technology, as well as their potential for future aviation applications.

Further research is currently needed on certain critical battery parameters to enable their scaled use in aircraft propulsion applications. Future battery development is expected to enable short-range passenger flights [2]. It is therefore essential to clearly identify the main challenges associated with each type of battery, as well as the intermediate steps required to enable scalability.

To understand the potential of using this technology for aircraft propulsion, it is important to define a roadmap for the main battery types.

The presentation will cover the main battery types, their advantages and limitations, and a number of key considerations to be taken into account in developing a roadmap for using batteries as the propulsion source for sustainable aircraft in the future up to 2050.

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STS 421-4

**The Design of a Hybrid Turbo-Electric Propulsion (HTEP) with Fuel Cells for a Hybrid Regional Aircraft (HRA) with a Capacity of 80 Passengers and a Range of 1,000 km.
Assessment of the Applicability of Energy Supply Concepts**

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Abstract

Key Words: *Hybrid turbo-electric propulsion, regional aircraft, hydrogen, hybridization level, critical technologies*

The study is based on the idea that the image of a hybrid turbine-electric system with fuel cells for a hybrid regional aircraft with a capacity of up to 80 seats and a range of up to 1,000 km will be determined by the type of energy supply (hydrocarbon or hydrogen fuel) to the gas turbine and fuel cells.

As part of the work to assess the feasibility of creating a commercially attractive hybrid regional passenger propeller aircraft, various hydrogen technology-based power plant energy supply schemes are being developed and evaluated for applicability:

Use of hydrocarbon fuel (kerosene) for a gas turbine engine and hydrogen for a low-temperature proton exchange fuel cell.

Use of hydrogen for a gas turbine engine and fuel cells.

Use of hydrocarbon fuel (kerosene) for a gas turbine engine and hydrogen production directly on board the aircraft. In this scheme, kerosene flows from the aircraft's fuel tank into a cracking reactor. The hydrogen released during the reaction then flows into a solid oxide fuel cell.

At the current stage of the project, power system concepts have been developed, their applicability in a hybrid regional aircraft is being analysed, and activities are underway to select the optimal concept for supplying power to the aircraft's power plant.

The results presented are based on research carried out within the framework of the EFACA project (Environmentally clean aviation for all classes of aircraft), financed by the European Commission through the program "Horizon Europe" (Grant agreement No. 101056866), included in the cluster "Climate, energy and mobility". EFACA aims to promote a greener aviation sector by developing new technologies using electric and hybrid thermoelectric power plants and new sustainable fuels to combat climate change by 2050 (www.efaca.eu).

STS 421-5

Comparison of the Alternative Trends of the Global and Regional Aircraft Fleet Evolution on Noise Exposure and Impact on Population

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Abstract

Assessment of the acoustic performances of the new aircraft designs and their impact on environment within the fleet, airport and single flight scenarios are performed in EFACA project. For the environmental factors analysis and assessment, the Vehicle-Airport-Fleet-DESIGN (VALDES) Space/Platform was constructed with Aircraft Design & Flight Performance Platform (ADFPP) at the bottom level [1], airport air traffic scenario at EFACApport (like CAEPport in ICAO and GREENport in EU contexts) - at the middle, and global fleet - at the top levels of the VALDES predefined limitations. For better understanding of the comparison between the baseline and reference acoustic models the clear difference should be defined between the specific acoustic sources in their aircraft/engine design and how new noise reduction technologies (NRT) should be implemented to make the novel designs quieter.

ADFPP provides an iterative process in novel aircraft designing using the portfolio of available NRT for the dominant acoustic sources to be declined in new aircraft and engine designs and the designing loop should be repeated until the design converges. At airport stage the estimates of aircraft noise levels are performed for the Noise-Power-Distance (NPD) data recommended by ICAO standard and used from the EASA ANP data base for the existing aircraft. For the new baseline aircraft the NPD and flight path data are calculated with detailed look on dominant acoustic sources in reference and baseline aircraft designs, where the sources in baseline aircraft should be improved for their noise exposure reduction by implanting the available technologies [2]. EFACApport scenario is produced for airport noise exposure and LAQ analysis grounding on layout of Gdansk airport (a regional airport with dominant contribution in traffic of both reference aircraft in EFACA project research).

Such a multi-level approach in AN exposure and impact assessment - beginning from the aircraft design with implemented NRT balanced with fuel burn and emission reduction technologies till the fleet-level assessment of their efficiency - may provide the better understanding of the roadmap to strategic goals defined at EU Green Deal Directive (2021) and ACARE Fly the green deal (2022).

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STS 421-6

**Comparison of Alternative Global and Regional Aircraft Fleet
Development Trends That Meet ICAO LTAG and ACARE 2050
Fuel Consumption and Emissions Targets in Specified Aircraft Classes**

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Abstract

The European aviation industry is committed to achieving new targets and complying with the UNFCCC Paris Agreement (2015) and the European Green Deal (2020). The approach outlined in Destination 2050 involves a combination of strategies such as the introduction of new technologies in aircraft design, including so-called disruptive technologies, operational optimization, the use of sustainable aviation fuels (SAFs), and the implementation of economic measures. The transition from fossil to decarbonized fuels is the central point of the transformation within the global aviation sector at present.

Hydrogen plays a very important role in the decarbonization of aviation fuels and in-flight energy consumption. Direct refuelling of aircraft engines is also the subject of the EFACA project, which is looking at research and testing of liquid hydrogen combustion at TRL3 in future engine designs. A hybrid electric propulsion (HEP) aircraft uses a combination of traditional fuel-powered engines and electric motors to provide the thrust for the flight: electric motors will be used for take-off and landing. In contrast, conventional engines will be used in cruise flights. The degree of hybridization H_p - the ratio between the power of the electric motor and the total installed power, is now a design parameter for new HEP aircraft.

The principles of aircraft emission and fuel burn analysis and assessment of the baseline aircraft in comparison with reference aircraft in the EFACA project are formulated for three levels of their evaluation - aircraft (single flight event), airport and fleet scenarios of current and future air traffic in the European perspective [1]. The work planned for this task is divided into the following subtasks: 1. Assessments below 3000 ft (1,000 m) - airport level; 2. Assessments over 3000 ft (1,000 m) - cruise flight level. Gap analysis in fuel/energy consumption and emission inventory assessment for the classes of aircraft at LTO and cruise levels was performed [2] and provided for the four main classes of aircraft in global fleet.

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STS 421-7

Advancing PEM Fuel Cell Suitability for Aviation

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Abstract

Hydrogen fuel cells are intensively discussed as part of the power train in new, sustainable, all-electric aircraft designs. Especially the Low Temperature Polymer Electrolyte Fuel Cell (LT-PEMFC) offers potential for zero-emission propulsion in aviation, due to its comparably high technological readiness level, power density and efficiency. However, several challenges for LT-PEMFC commercialization in aviation remain. Among these, the high cooling system drag associated with conventional LT-PEMFC cooling systems [1,2] and limitations of reactant flow through the Gas Diffusion Layer (GDL) [3] have been identified.

Within the scope of the EU Horizon Project “Environmental Aviation for All Classes of Aircraft” (EFACA), new fuel cell technologies are developed. Most notably, we demonstrate a novel “Phase change plus heat pump” (PCHP) cooling concept for reducing the heat exchanger surface to the ambient air required for fuel cell heat dissipation. Furthermore, a new GDL design is conceived and numerically characterized for its suitability in high-load aviation environments. In this work, we present latest results - experimentally and numerically - on PCHP cooling and our new GDL design and discuss their projected potential for advancing LT-PEMFC suitability for aviation.

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STS 421-8

Numerical Model and Parametric Analysis of a Liquid Hydrogen Injector at Diverse Inlet Conditions

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ABSTRACT

Key words: liquid hydrogen; cryogenic injector; condensation; numerical modeling; parametric analysis; pressure lift; one-dimensional simulation.

Liquid hydrogen is a key energy carrier for decarbonizing heavy-duty transportation due to its high energy density and zero carbon emissions. The reliable delivery of liquid hydrogen from storage to utilization points requires efficient pressurization systems, where conventional mechanical pumps face challenges related to cryogenic cavitation, thermal gradients, and maintenance. In this context, passive injection technologies offer a promising alternative by enabling fluid pressurization without moving parts, thereby enhancing system reliability and compactness. This work presents a numerical model and parametric analysis of a liquid hydrogen injector that operates through direct vapor-liquid interaction and condensation-driven momentum transfer. A one-dimensional, axisymmetric model is developed based on conservation laws across defined control volumes, incorporating real fluid properties and accounting for phase change during mixing. The model is applied to analyze injector performance under diverse inlet conditions, including variations in vapor temperature and pressure, and geometric parameters. Results demonstrate the capability to achieve significant pressure lift, with performance maps identifying optimal operating regions. The analysis provides insights into the thermodynamic process within the device, highlighting the role of condensation shocks in pressure lift.

STS 421-9

Analysis of Ready and Sustainable Aviation Fuels and Their Production Cost Estimation

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Keywords: *Sustainable Aviation Fuels, Advanced Biofuels, electrofuels, costs*

Abstract

The actually most studied and promising pathways for Sustainable Aviation Fuels (SAF) to reach in 2050 no net emissions of greenhouse gases in the aviation sector can be divided in three categories: thermochemical processes, biochemical routes, electrofuel production. The produced SAF are at different readiness level and have different availabilities. Their large-scale utilization is mainly related to evolution of costs. In fact, there is still a significant price gap between sustainable and conventional jet fuels because of the high production costs of SAF. The two most significant items are the feedstock costs and capital costs [1].

The Technology Readiness Level (TRL) assessment provides a structured framework for evaluating the maturity of each SAF production pathway and helps contextualize their economic performance and deployment potential. High-TRL technologies, such as HEFA and co-processing (TRL 8–9), benefit from established industrial infrastructure, proven process reliability, and reduced technical risk, which collectively contribute to their comparatively lower production costs and faster scalability. Conversely, mid-TRL pathways like Fischer–Tropsch (FT), Alcohol-to-Jet (AtJ), and Waste-to-Jet (TRL 7–8) still face challenges related to process optimization, capital intensity, and feedstock logistics, which elevate cost uncertainty and limit widespread adoption in the near term [2,3].

The economic viability of different SAF production routes remains one of the main constraints to large-scale adoption. The higher cost of SAF compared to conventional jet fuel is increasing ticket prices and affecting the affordability of air travel. The introduction of possible regulations might condition the different proportion of the costs. In this work, the SAF with the higher readiness and availability are considered and their costs are analyzed, also in relation to the actual regulations and the effect on flight ticket prices.

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STS 421-10

Design Concept for a Hybrid Turbo-Electric Regional Aircraft

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Abstract

Future regional aircraft will need to achieve a balance between efficiency, sustainability and functionality. Hybrid turbo-electric propulsion (HTEP) is a promising step towards achieving this goal, combining the reliability of conventional gas turbine engines with the advantages of distributed electric power.

This study presents the preliminary design of a regional aircraft powered by a hybrid turbo-electric propulsion system. Concept development included defining baseline requirements for the aircraft and HTEP and addressing specific challenges related to hybrid propulsion. The analysis focuses on selecting an efficient configuration that ensures performance, safety, and operational reliability under typical flight conditions.

The work aims to justify the selection of the aerodynamic layout and perform a comprehensive energy balance assessment in order to support the overall design of a regional hybrid aircraft, based on the results achieved.

The research findings imply that hybrid turbo-electric propulsion could be a useful transitional technology en route to fully electric or hydrogen-based aviation systems, helping to achieve the long-term goal of climate-neutral flight.

Keywords: hybrid turbo-electric propulsion, HTEP, regional aircraft, energy efficiency, aircraft design, fuel cells.

STS 421-11

Design Considerations for a Liquid Hydrogen-Powered Aircraft

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Abstract

The aviation industry is undergoing a major transformation towards achieving net-zero emissions and hydrogen is emerging as one of the most promising alternative fuels. Due to its clean combustion and compatibility with fuel cell technologies, liquid hydrogen offers significant potential for reducing CO₂ and NO_x emissions in future aircraft. This study presents a conceptual design of a liquid hydrogen-powered aircraft, discussing key design considerations relating to cryogenic fuel storage, system integration, and safety. The proposed concept explores the optimal placement of LH₂ tanks to achieve an acceptable balance between structural efficiency, center of gravity control and aerodynamic performance.

The work focuses on key design challenges such as integrating cryogenic hydrogen tanks into the airframe and optimising the fuel system, as well as ensuring efficient thermal management. Particular attention is given to safety aspects, weight distribution and aerodynamic implications associated with large cryogenic systems.

Overall, the concept contributes to the broader goal of achieving climate-neutral aviation within the next decades.

Keywords: liquid hydrogen, cryogenic fuel, hydrogen storage, propulsion system, sustainable aviation, aircraft design, passenger aircraft.

STS 421-12

Methodology for Defining a Roadmap for Climate Neutral Aviation within the EFACA Project Framework

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Abstract

The year 2050 is the main reference point for the aviation industry as it works towards achieving European sustainability goals. To achieve progress by that date, intermediate milestones must be defined to scale up the development of necessary sustainable propulsion technologies and new aircraft concepts.

The Environmentally Friendly Aviation for All Classes of Aircraft (EFACA) project defines a series of roadmaps that take into account technologies, aircraft, and environmental impacts, such as emissions, noise, and local air quality.

This presentation outlines the methodology followed in the EFACA project to develop roadmaps for climate-neutral aviation.

To this end, the presented analysis is structured into four parts: i) The analysis's objectives and the main challenges to be considered, ii) The scenarios defined by the EFACA project framework and considered in the analysis, including its proposed technologies and the design of two aircraft, iii) The stages of the methodology, its main objectives, and considerations and iv) Key variables for developing the roadmap and a comparison of the EFACA project with other sustainable aviation research alternatives.

STS422 - Advanced Numerical Methods for Simulation, Optimisation and Validation for Applications in Aeronautics and Industry

Main Organizer: Dr. Dietrich Knoerzer (Aeronautics Consultant, Belgium)

Chaired by:

STS422A and STS422C:

Dr. Dietrich Knoerzer (Aeronautics Consultant, Belgium), Prof. Jacques Periaux (cimne, Spain);

STS422B:

Prof. Jacques Periaux (cimne, Spain), Dr. Dietrich Knoerzer (Aeronautics Consultant, Belgium)

Part	Date	Time	Room
STS422A	Wed 22.07.2026	09:45–11:15	NM - 2 (Salzburg)
STS422B	Wed 22.07.2026	11:30–13:00	NM - 2 (Salzburg)
STS422C	Wed 22.07.2026	15:00–16:30	NM - 2 (Salzburg)

Advances in numerical methods together with the availability of high-performance computers (HPC) allow to address highly complex design problems and challenging multi-disciplinary optimisation issues. The integration of artificial intelligence (AI) and of machine learning features will enhance this development. Significant advances in adjoint methods have enabled efficient and accurate computation of shape gradients for high-dimensional and high-fidelity aerodynamic shape optimisation problems [1]. A shape optimisation of functional surfaces presents a multifaceted challenge, characterized by numerous geometric, functional, and performance constraints. This is particularly evident in vehicle design, where modern simulation processes have to address a wide spectrum of requirements [2]. In this STS, different novel methods will be discussed, which are aiming to accelerate CFD simulations used to design aeronautics components like aircraft wings, profile shape and other aeronautics or industry components associated with direct design using high-fidelity analysis.

STS 422-1

Vortex Evolution on Hybrid-Delta-Wing Configurations at Transonic Flow Conditions

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Abstract

Leading-edge vortices (LEV) dominate delta wing aerodynamics already at moderate angles of attack (α), inducing suction on the upper wing surface, thereby providing a nonlinear increase in lift. This results in smoother post-stall characteristics and enhanced maneuverability [1]. In this regard, modern high-agility aircraft use multi-swept delta or strake-wing configurations to exploit multiple LEVs, enhancing their ability to perform complex maneuvers [2]. However, at higher angles of attack, the stability of the LEVs diminishes, and vortex breakdown occurs, impairing the flight stability characteristics.

This study investigates the formation, interaction, and breakdown of the LEVs around multi-swept hybrid-delta-wing configurations in the transonic flow regime, including shock-vortex interactions and their impact on vortex flow dynamics. Two main wing configurations are employed: a double-delta wing with leading-edge sweep angles of $\varphi_2 = 75^\circ$ for the strake and $\varphi_3 = 52.5^\circ$ for the main wing section, while the triple-delta wing incorporates a LEV controller segment with $\varphi_1 = 52.5^\circ$. The relative leading-edge nose radii (r_n/c_r) of 0.00%, 0.25%, and 0.50% are analyzed for $c_r = 0.802$ m.

Numerical simulations are performed using the TAU Code, developed by DLR. URANS computations employ the Spalart-Allmaras turbulence model in its negative formulation with rotation correction. Computations are performed at $Ma = 0.75, 0.85$, and 0.95 for $16^\circ \leq \alpha \leq 32^\circ$ in 4° increments under $\beta = 0^\circ$ and 5° , with a time step of $\Delta t = 2 \times 10^{-4}$ s. IDDES simulations are performed based on the URANS results, setting Δt to $2 \cdot 10^{-5}$ s, while α is varied with an increment of 8° . The numerical results are compared with wind tunnel measurements provided by DLR and Airbus Defence and Space.

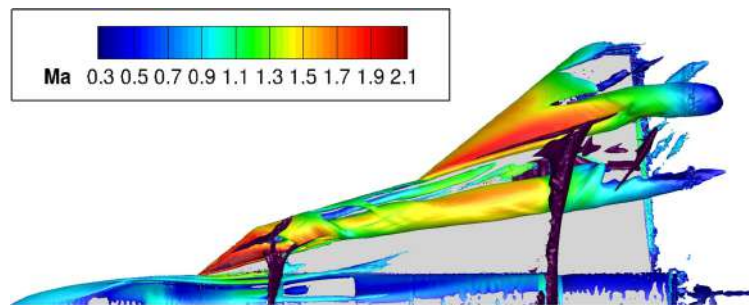


Figure 1: Iso-surfaces of the non-dimensional Q -Criterion of 50 for a triple-delta-wing configuration at $Ma = 0.85$ and $Re = 1.20 \cdot 10^7$ under symmetric flow conditions at $\alpha = 16^\circ$ and $\beta = 0^\circ$.

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STS 422-2

Initial Steps Towards a Multi-Fidelity Surrogate Model to Evaluate Occupant Safety in the Aeronautic Preliminary Design

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Abstract

The adoption of novel high-efficiency aircraft fuselages presents unique safety challenges. Unlike traditional aircraft, their behaviour during “emergency landing” should be studied with an integrated global approach that considers the entire cabin’s structural response, similar to the approach prescribed for general aviation aircraft [1].

This work presents a numerical method for the efficient evaluation of occupant safety during the aircraft preliminary design stage, to be integrated into the process chain for aircraft design established at the German Aerospace Center (DLR). In particular, the aim is to enhance the internal PANDORA design environment [2], which allows the structural evaluation of aircraft concepts, with the capability to estimate occupant survivability.

This preliminary work covers the development of a multi-fidelity seat and dummy model, which has a primary safety role [3], together with a first simple AI surrogate of the low-fidelity seat and dummy assembly. A high-fidelity Finite Element (FE) seat model is generated based on a certified aircraft seat, which is 3D-scanned and experimentally tested to validate key structural parts relevant to occupant safety criteria prescribed by the regulation.

Then, a simplified FE model is derived from the validated high-fidelity model to replicate its inertia and stiffness at a significantly lower cost, to be used in PANDORA-generated full-scale aircraft models. The multi-fidelity surrogate model approach is designed to replace high-fidelity occupant and seat models in full-scale fuselage analysis, with their simplified representation to boost model robustness and computational efficiency. The injury criteria are evaluated by an AI surrogate trained on a small-scale high-fidelity model of the seat and dummies, which correlates the fuselage floor kinematics with the resulting injury levels for each occupant. A first correlation is shown, using simple kinematic approximations and a low-fidelity FE model for training.

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STS 422-3

Development, Calibration and Validation of Low Fidelity Full Platform FE Models of Existing Flying Platforms

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Abstract

There are many reasons why the owner of a flying platform would require a deeper insight into the structural behaviour of the platform. Some of the reasons can be extension of product life [1], predictive maintenance [2], changes to the platform [3], assessing the flight envelope [4], damage [5], and other ways of operation outside the prescribed operational boundaries. Manufacturers are often hesitant to share models and other tools that were used to analyse the platform in the design and production phase. There is a need to investigate aircraft platforms [6] with validated models that are developed with limited data. This research investigates ways to develop low fidelity models of existing flying platforms, based on limited public data, to perform calculations and analyses.

This research attempts to create two different models of a Cessna 550s aeroplane. The two models have different fidelity levels. One is a model based on beam elements and the other is a Finite Element Model with 3D shell elements. Both models are based on public data of the platform.

To calibrate, verify and validate the models a two-part approach is proposed. The models are validated using a 3D scan of the outside of the plane in combination with other public data about the platform. Calibration and validation of the models is done using data from a Ground Vibration Test (GVT) that was performed many years ago.

The research can conclude that it is indeed possible to produce a low fidelity model of a platform using public data. The research demonstrates that a calibrated low fidelity model can reproduce the results of measurements with reasonable accuracy, highlighting the potential of this approach for analysing existing aircraft with unknown or unknown designs.

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STS 422-4

Autonomous Airside Bus Operations: A Case Study at Cluj-Napoca International Airport

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Abstract

Autonomous vehicle technologies are increasingly considered for improving the safety, efficiency, and sustainability of ground transportation systems, including safety-critical airport airside operations. Previous studies have highlighted the potential of automated shuttles and buses in controlled mobility contexts, while emphasizing the need for real-world validation in infrastructure-dense airport environments. This paper presents a case study on the deployment and testing of an autonomous electric bus on the airside of Cluj-Napoca International Airport.

The demonstrator vehicle was a Karsan e-ATAK electric bus equipped with SAE Level-4 autonomous driving capabilities provided by ADASTEC. The implementation methodology comprised environmental scanning, grid-based airside mapping using LiDAR point clouds, generation of georeferenced semantic layers, multi-sensor calibration and fusion (LiDAR, GNSS/IMU, cameras), and configuration of autonomous driving and supervision functions adapted to airport constraints.

A structured set of traffic and operational test scenarios was developed and executed, based on a clearly defined airside ODD and safety validation framework, including interactions with ground support equipment, service vehicles, airport personnel, and static and dynamic obstacles. The results indicate robust localization against the LiDAR-based HD map, reliable perception and obstacle classification, and consistent trajectory tracking and speed regulation across all tested scenarios, with no safety-critical incidents recorded. Fail-safe strategies, including controlled deceleration and safe-stop maneuvers, were validated under both nominal and disturbed operating conditions.

The study concludes that autonomous electric buses can be safely and effectively integrated into airport airside operations, provided that thorough mapping, scenario-based testing, and coordination with airport procedures are ensured. The findings contribute empirical evidence to the limited literature on autonomous airside transport and support the adoption of zero-emission automated mobility solutions in airport environments.

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STS 422-5

A Numerical Simulation Method for Free Response of Airfoil Assembly under Gust Disturbance

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Abstract

Under gust excitation, an aircraft exhibits complex dynamic responses that pose significant challenges for high-fidelity simulation, due to strong coupling among unsteady aerodynamics, structural dynamics, and stochastic environmental inputs. This paper presents a numerical study on the free response of an airfoil assembly under gust disturbances. The main contributions are summarized as follows:

Continuous gust signals are first simulated based on a wind power spectrum using the harmonic synthesis method, ensuring statistical accuracy in both time and frequency domains. These gust excitations are then introduced into the flow field via the momentum source method, which allows precise imposition of gust velocity at specified upstream locations.

The assembly comprises two airfoils representing the wing and horizontal tail. The synchronized motion of the two airfoils is achieved by solving the multi-body dynamics equations, which mathematically enforce the kinematic constraints between the components. Subsequently, pitch and heave degrees of freedom are released to perform fully coupled fluid-structure interaction simulations. The unsteady numerical approach captures the nonlinear interplay between the flow field and structural dynamics, revealing gust-induced aeroelastic responses.

This study establishes an integrated workflow spanning from stochastic environmental modelling to coupled multi-physics response analysis.

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STS 422-6

Sound Insulation of Reconfigurable Intelligent Acoustic Metasurfaces in Complex Low-Altitude Noise Environments

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Keywords: *Low-altitude economy, reconfigurable intelligent acoustic metasurfaces, adaptive wavefield shaping, noise reduction and sound insulation*

Abstract

Accompanied by the rapid development of low-altitude economy, a new economic model driven by low-altitude activities and dominated by manned and unmanned civil aircraft brings immense development opportunities while also facing unprecedented low-altitude noise pollution issues. Our project aims to address the noise problem of urban low-altitude aircraft using the reconfigurable intelligent acoustic metasurfaces. The project will explore the impact of multi-phase modes of intelligent metasurfaces on their physical properties and acoustic responses, utilizing adaptive wavefield shaping technology to achieve reshaping and focusing of the wavefield via acoustic metasurfaces, further realizing a target silent environment. The main research contents include:

- (1) Dynamic sound pressure level testing of low-altitude target zones and simulation of spatial distributions of average noise levels.
- (2) Development of data driven metasurface optimization and noise suppression strategies based on adaptive guidance and focusing of complex open-space wavefields.

This research is expected to provide a feasible pathway for designing reconfigurable intelligent acoustic devices and systems, enabling wavefield reconstruction and intelligent sound isolation in complex low-altitude acoustic environments.

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STS 422-7

An Automated Multi-Fidelity RANS–SRS (LES) Optimization Framework for Turbomachinery Flows

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Abstract

In the Sci-Fi-Turbo project, a multi-fidelity optimization framework is developed to systematically integrate scale-resolving simulations (SRS) into the turbomachinery aerodynamic design process. The framework combines Reynolds-averaged Navier–Stokes (RANS) and SRS-based flow predictions to balance computational cost and predictive accuracy and is demonstrated for the automated optimization of a compressor cascade.

The optimization objective is the reduction of profile losses, while constraining the outflow angle at the aerodynamic design point (ADP) and at two off-design incidences of $\pm 5^\circ$. To achieve this objective, a two-fidelity optimization strategy is employed. The low-fidelity (LF) model is based on RANS simulations using the Menter SST $k-\omega$ turbulence model in combination with the $\gamma-Re_\theta$ transition model, whereas high-fidelity (HF) data are obtained from large-eddy simulations (LES) using a high-order discontinuous Galerkin (DG) solver.

The numerical setup exploits pitchwise and spanwise periodicity in a quasi-three-dimensional configuration [1]. The inflow is characterized by a Reynolds number of $Re_{in} = 150000$, a Mach number of $M_{in} = 0.6$, and synthetically generated isotropic turbulence in the LES. The optimization involves 15 geometric design variables and requires the evaluation of approximately 300 candidate geometries to achieve a converged Pareto front. To ensure tractability at SRS level, the workflow emphasizes a high degree of automation, including automatic transition detection, robust convergence monitoring, and uncertainty-aware evaluation of LES results to control the noise in the surrogate model.

A comparative analysis shows that RANS-based optimization can yield Pareto-optimal designs that exhibit significant performance degradation under off-design conditions and may violate kinematic constraints, when reassessed using LES [2]. These findings motivate the Sci-Fi-Turbo strategy of multifidelity optimization, in which surrogate models trained on extensive LF data are selectively enriched with sparse HF samples. The presented framework establishes the methodological and computational foundation required for subsequent data-driven and adaptive extensions of SRS-informed turbomachinery optimization.

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STS 422-8

Back to the Future: Fast and Robust MDO with Implicit Modelling and Direct Simulation

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Abstract

Current Computer Aided Design (CAD) systems excel in static detailed design but are too fragile and slow to support Design Exploration (DE) and Multidisciplinary Design Optimization (MDO) for conceptual and preliminary design, where 1,000 to 10,000s of variations are generated and analysed [1]. The vast majority of CAD systems are based on Boundary Representations (BReps) developed in the mid-70s [2]. It only takes one computational failure (e.g., surface to surface intersection, blending) out of thousands for a model update to fail requiring arduous human intervention. A second major barrier to DE and MDO is to feed downstream analysis codes (e.g., Aero/CFD, Structures, Electromagnetic) for all model variations without any human intervention. Current practice require the BRep to be converted to a highly analysis-specific mesh, often consuming >70% of the entire design effort [3] while remaining intolerant to major model or topology variations.

This paper introduces a new approach based on implicit modelling [4] popularized in the animation industry that aims to address these shortcomings. Implicit models are constructed by combining signed distance functions [5] that uniquely define whether a point is **in, on or outside** the model which is analogous to Point Membership Classification (PMC) for Constructive Solid Geometry (CSG) [6] modelling making it highly robust against computational failures. Model evaluations and updates are several orders of magnitude faster because PMC computations can exploit massive parallelism on GPU architecture. This paper further introduces physical simulation performed directly on implicit models, enabling the inference of system trends without the need for conversion to conformal meshes. When combined with the ability to train an AI as surrogate response models, this integrated approach substantially reduces human effort and accelerates computational workflows, compressing design studies from months to days and enabling agile responses to emerging competitive design challenges.

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STS 422-9

Multi-Fidelity Aerodynamic Shape Optimization via Deep Reinforcement Learning and Flow Solution Mapping

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Abstract

High-fidelity fluid simulations are essential for accurate aerodynamic analysis but remain computationally prohibitive when coupled with iterative design exploration loops. To address this bottleneck, this work presents a multi-fidelity geometry optimization framework that bridges the gap between rapid Reynolds-Averaged Navier-Stokes (RANS) estimations and computational demanding Large Eddy Simulation (LES), driven by Deep Reinforcement Learning (DRL) [1].

The core decision-making engine relies on the Soft Actor-Critic (SAC) algorithm [2]. SAC utilizes an entropy-regularized formulation that compels agents to maximize both the expected reward and the entropy of the policy. This feature is critical for complex design landscapes, ensuring robust exploration and preventing premature convergence to local optima.

The proposed workflow adopts a hierarchical two-stage strategy. First, the DRL agents interact with a lower-fidelity RANS environment to perform a rapid, broad exploration of the parametric space. This phase efficiently filters the design space to identify promising regions with minimal computational cost. Once a coarse optimum is located, the system transitions to a high-fidelity refinement stage using the spectral element solver SOD2D [3]. In this second phase, LES is employed to capture unsteady flow phenomena and fine-tune the geometry near the optimal point.

To make the high-fidelity phase computationally feasible, we integrate a solution mapping strategy. Instead of initializing each LES case from a uniform field, the framework interpolates initial conditions from previously converged fields. This drastically reduces the physical time required to wash out initial transients during the expensive LES simulations, significantly decreasing time-to-solution.

This study demonstrates that coupling a multi-fidelity framework with a batch-based SAC approach and solution mapping provides a robust pipeline that balances the speed of RANS with the physics-resolving accuracy of LES for autonomous high-fidelity design exploration.

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STS 422-10

On the Usage of Aerodynamic Shape Optimization Tools for Quick Design-to-Market of Fixed-Wing Drones

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Abstract

The drone industry has been experiencing considerable growth, with market demands quickly evolving, which put great pressure on manufacturers. To address this challenge, the usage of flexible, efficient and accurate numerical tools are paramount to speed up to design process. The methodology put in place by Tekever for the aerodynamic design of its next generation fixed-wing drones is outlined and demonstrated with some study cases. The underlying aerodynamic shape optimization framework is composed of five main modules: surface and volume grid generators, free-form deformation (FFD) technique for shape control, high-fidelity Reynolds-averaged Navier-Stokes flow solver, companion adjoint solver for sensitivity analysis, and gradient-based optimizer.

Three application problems are presented and discussed, including the design of (i) fairings for protruding parts, (ii) nacelle of on-wing piston-engine, and (iii) winglets. The fairing and nacelle problems consisted of finding the minimum drag shapes covering the payload protruding from the fuselage or the piston-engine mounted on the wing, respectively, where a careful identification of the encapsulated 3-D body geometry and placement in the aircraft, as well as the definition of the fuselage or wing surface region extension, were necessary. The winglet problem implied a parametrization of its geometry that mapped the degrees-of-freedom of the FFD control points to meaningful engineering parameters, such as winglet cant and sweep angles, length and taper ratio.

All cases presented a significant improvement over the baseline aircraft performance, ranging from a few percent to double digit reduction in aerodynamic drag. Also relevant, the use of large scale computing facilities made overnight turn around possible for every design problem tackled, allowing for the aircraft designers to quickly respond to customer demands as intended.

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STS 422-11

A Transition Model Based Aerodynamic Adjoint Optimization Design Method for Aircraft

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Abstract

Laminar flow is one of the key technologies for the development of green aviation in the future. An efficient and robust optimization design method capable of handling large-scale design variables is one of the key links to promote the engineering application and transformation of laminar flow technology. Based on a high-fidelity Reynolds-Averaged Navier-Stokes (RANS) solver, combined with the Shear-Stress Transport (SST) turbulence model and the Gamma-Theta transition model, accurate simulation of the transition-turbulence phenomenon on the wing surface is achieved. Through the variation of the residual terms of the transition-turbulence model, the establishment of the left-hand side terms of the coupled adjoint equation considering the transition-turbulence effect is realized. Furthermore, combined with the chain rule of differentiation and the LU-SGS implicit time-marching algorithm, an efficient solution method for the coupled adjoint equation is developed. Eventually, a discrete adjoint-based optimization design method for aircraft laminar flow is established. Laminar flow optimization design is carried out for configurations such as high-altitude long-endurance (HALE) unmanned aerial vehicles (UAVs), which significantly delays the transition positions of each section. The optimization results demonstrate that the established gradient-based optimization method for laminar flow wings can effectively address complex three-dimensional laminar flow wing optimization problems.

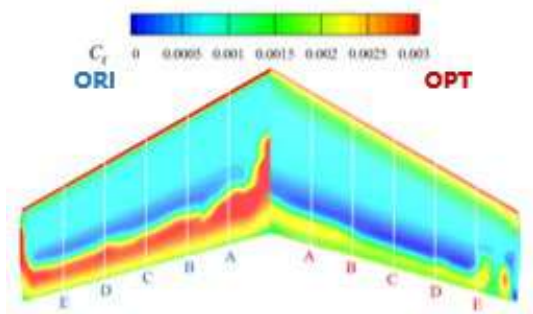


Fig. 1. Optimization Design of M6 Wing

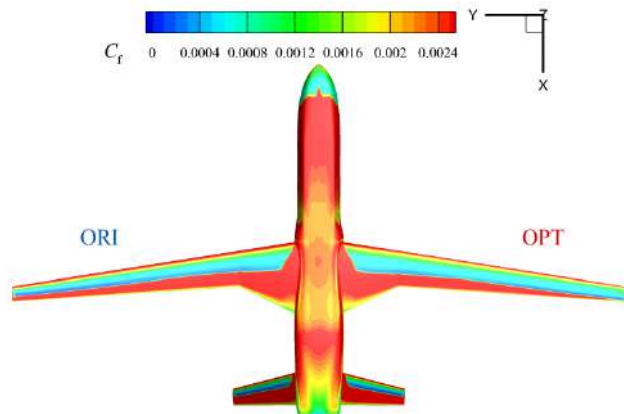


Fig. 2. Optimization design for high altitude long endurance unmanned aerial vehicles

STS 422-12

Green Aircraft Morphing Elevator Aero Optimization through Evolutionary Algorithm and Radial Basis Functions

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Abstract

This work presents the bi-dimensional (2D) aerodynamic design, based on numerical optimization, of a morphing elevator for the horizontal tailplane (HTP) of a future green aircraft, conceived to enhance aircraft efficiency across multiple flight conditions (cruise and low speed). The study focuses on developing a morphing concept to adapt its camber distribution, thereby improving efficiency characteristics, reducing trim drag for cruise condition, and improving lifting coefficient for low-speed conditions. The aerodynamic analysis was carried-out using a 2D viscous-inviscid interaction code coupling an Euler solver for the inviscid outer flow, a boundary-layer solver for laminar, transitional, and turbulent regions, and a strong viscous-inviscid interaction scheme to ensure consistency between the two. The optimization tool uses a CMA-ES evolutionary algorithm [1] to drive geometry update made via Radial Basis Functions (RBFs) algorithm [2]. The results demonstrate that the optimized HTP achieves up to more than 110% efficiency improvement in cruise and over than 9% improvement in lift coefficient in low-speed conditions, exhibiting delayed flow separation and improved pressure recovery, confirming aerodynamic benefits of continuous shape adaptation.

The conclusions highlight that morphing technologies, when properly integrated into tailplane design, offer a promising pathway toward next generation aircraft with enhanced aerodynamic performance. The optimized designs will be used as target shape for structural analysis and optimization of the structural mechanism actuating the elevator.

The activities described in this paper have been carried out within HERFUSE (Hybrid-Electric Regional FUSElage & Empennages) project; which has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101140567.

Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or of the granting authority. Neither the European Union nor the granting authority can be held responsible for them.

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STS 400-13

Nonlinear Corrector and Norm-Oriented Mesh Adaptation for Reynolds-Averaged Navier-Stokes Equations

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Abstract

This work presents a nonlinear error estimation and correction approach for the Reynolds-averaged Navier-Stokes (RANS) equations, coupled with a norm-oriented (NO) error estimate for anisotropic mesh adaptation.

Anisotropic mesh adaptation aims at reducing the interpolation error of the numerical solution and relies on an error estimate to compute the metric and generate the mesh [1]. The choice of the error estimate has a significant impact on the efficiency of the mesh adaptation process. Goal-oriented (GO) error estimates are widely used in aeronautical applications, as they adapt the mesh with respect to a specific scalar quantity of interest, such as drag or lift [2]. However, due to their formulation, GO approaches may neglect important flow features that do not directly influence the chosen scalar output [3].

The norm-oriented approach extends the GO formulation to the entire solution field [4]. By replacing the scalar output with the discretization error itself, the resulting error estimate directly improves the convergence of the solution field. Nevertheless, this approach requires knowledge of the exact solution, which is generally unavailable. To overcome this limitation, we propose a nonlinear corrector formulation for the RANS equations [5]. Using local mesh refinement and flux computation, a corrected solution is obtained from a mesh whose size is locally divided by a factor of two with respect to the current mesh. This corrected solution is then used as a surrogate exact solution in the NO formulation, allowing the computation of the error estimate.

The proposed method will be validated on several aeronautical test cases. The results will show that the nonlinear corrector significantly reduces the discretization error. Furthermore, we will demonstrate that the NO error estimate improves mesh convergence with respect to the full solution field and is more efficient than GO or feature-based error estimates.

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STS 422-14

Numerical Simulation of Realistic Aeronautical Configurations Using a Coupled Lattice-Boltzmann - Immersed Boundary Solver

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Abstract

The numerical simulation of turbulent aerodynamic flows at high Reynolds numbers remains a major challenge, particularly in the presence of thin boundary layers and complex geometries. At Reynolds numbers of the order of 10^6 , the explicit resolution of near-wall structures becomes computationally prohibitive, requiring the use of appropriate wall modeling strategies.

This work presents a numerical framework based on the coupling of the Lattice Boltzmann Method (LBM) with an Immersed Boundary Method (IBM), incorporating a turbulent wall law, for the simulation of high-Reynolds-number incompressible aerodynamic flows. The mesoscopic formulation of LBM offers excellent computational efficiency and scalability on massively parallel architectures, while the IBM enables the treatment of complex aerodynamic geometries without the need for body-fitted meshes.

To account for near-wall effects without resolving the viscous sub-layer, a turbulent wall law is introduced within the LBM-IBM coupling to estimate wall shear stresses from local velocity fields. The proposed approach is compatible with LES turbulence modeling within the LBM framework.

The methodology is validated on a three-element airfoil « 30P30N », which is a reference aerodynamic benchmark at a Reynolds number of $Re = 1.71 \times 10^6$, characterized by a strongly separated flow and a highly turbulent wake. Numerical results show good agreement with available experimental and numerical reference data in terms of mean flow fields, global aerodynamic coefficients, and key flow features. These results demonstrate the potential of the LBM-IBM coupling with turbulent wall modeling as a robust and efficient method for the simulation of complex high-Reynolds-number aerodynamic flows.

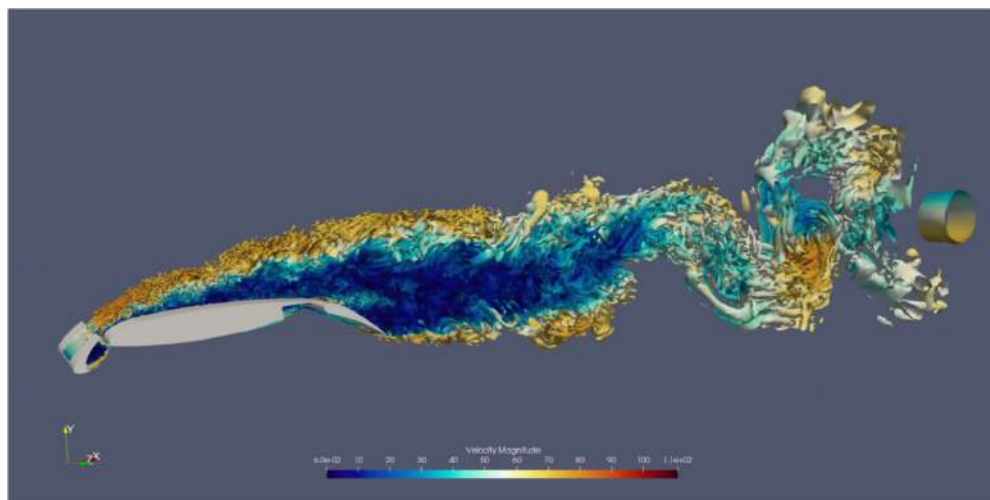


Figure 1: Q-criterion

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STS 422-15

Improving Optimal Focusing in Computational Simulation of Cochlear Implants with Evolutionary Algorithms

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Abstract

The recent surge of interest in advanced multipolar stimulation strategies for cochlear implants has led to a marked increase in the demand for computational tools capable of exploring increasingly complex electrode configurations [1]. Recent research has introduced a state-of-the-art modelling framework that integrates high-fidelity finite element simulations with a hybrid multi-objective evolutionary algorithm [2]. This enables the discovery of Pareto optimal stimulation patterns that jointly reduce power consumption while enhancing spatial focusing.

However, the formulation of the focusing objective remains a critical bottleneck. The sensitivity of this objective to the chosen error norm and weighting scheme can substantially influence the resulting optimization landscape and, consequently, the quality of the electrode designs obtained. The present study systematically investigates alternative mathematical formulations for the focusing objective. The methodology is demonstrated across multiple electrode configurations in a representative cochlear implant test case, with results contextualised against the latest findings in computational neurostimulation research.

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STS 422-16

Flux Limiters for Mixed Element Volume Scheme

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Abstract

Flux limiters are used in numerical schemes to prevent spurious oscillations and ensure the Total Variation Diminishing (TVD) property [1], so that no local extrema are generated by the scheme. This causes an injection of numerical dissipation inside the computation, whose drawbacks are the loss of accuracy and possible convergence stalls in smooth regions of the solution [2].

This gives motivation to perform an analysis on different limiting strategies, in order to reduce the amount of dissipation that is added in the scheme.

In the Wolf solver, a Mixed Element Volume scheme is used to discretize the Reynolds Averaged Navier Stokes (RANS) equations [3]. The convective fluxes are discretized with a node-centered Finite Volume scheme. The flux balance for each vertex is computed with an integral on the boundary of the finite volume cell, decomposed in the interfaces between the vertex and its neighbors. Each interface is associated with an edge, and the corresponding flux is computed by solving a one-dimensional Riemann problem in the direction of the normal to the interface.

To achieve higher order, Monotonic Upstream-Centered Scheme for Conservation Laws (MUSCL) reconstructions are done, using the V4 scheme [4] to compute gradients that are multiplied to a limiter function.

Thanks to the mono-dimensional approach of the scheme, classical limiters can be used. An extension of the Van Albada limiter called Gamma limiter is used in the solver, and is tuned using a parameter [3]. In this work, the limiter will be optimized, in order to inject the minimum quantity of dissipation, while keeping the limiter in the TVD region.

An alternative approach is to associate a flux limiter to the vertex. Limiters of this type will be tested, as the ones proposed by Nishikawa [5]. The comparison will be made on different test cases.

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STS424 - Integrating AI and Fluid Dynamics

Main Organizer: Prof. Yao Zheng (Zhejiang University, China)

Part	Date	Time	Room
STS424A	Wed 22.07.2026	11:30–13:00	NM - 4 (Hamburg)
STS424B	Wed 22.07.2026	15:00–16:30	NM - 4 (Hamburg)
STS424C	Wed 22.07.2026	17:00–18:30	NM - 4 (Hamburg)

The integration of Artificial Intelligence (AI) and Fluid Dynamics is opening new frontiers in computational modeling and simulation. This Special Technology Session (STS) is dedicated to exploring cutting-edge methodologies that leverage data-driven approaches to enhance, accelerate, and redefine traditional fluid mechanics analyses. We invite contributions on a wide range of topics, including but not limited to: AI-augmented turbulence modeling and closure strategies, physics-informed neural networks (PINNs) for forward and inverse problems, deep learning techniques for flow field reconstruction and super-resolution, and machine learning-enabled reduced-order modeling for real-time simulation and control. Additional areas of interest encompass AI-empowered aerodynamic shape optimization, data-enhanced experimental methods, and uncertainty quantification in multi-scale flow systems. A key focus will be placed on hybrid frameworks that integrate physical knowledge with data-driven insights to improve predictive accuracy, computational efficiency, and design innovation. We welcome submissions presenting novel algorithms, rigorous validations, and impactful applications that demonstrate the transformative role of intelligent computational methods in fields such as aeronautics, aerospace propulsion, renewable energy, environmental flows, and biomedical engineering.

STS 424-1

Learning Multiphase Flow Evolution via Latent Neural Operators

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Abstract

Multiphase flows are ubiquitous in natural and engineering systems and are characterized by strong nonlinearity, multiscale coupling, and sharp interfacial dynamics. Conventional partial differential equation (PDE)-based solvers provide accurate descriptions but remain computationally prohibitive for large-scale or real-time spatiotemporal prediction. Recent data-driven approaches, such as neural operators and latent-space reduced-order models, have shown promise, yet their application to multiphase flows is still limited by insufficient nonlinear expressiveness, poor robustness to noise, and weak generalization across different phase configurations.

To address these challenges, we propose MultiOKAN, a composite latent-space operator learning framework that integrates a Kolmogorov-Arnold Network-based autoencoder (KAE) with a KAN-enhanced Deep Operator Network (DeepOKAN). The KAE compresses high-dimensional phase volume-fraction fields into compact latent representations that preserve essential interfacial features, while DeepOKAN learns the nonlinear temporal operator that maps initial latent states directly to future evolution. This design enables efficient, end-to-end prediction of multiphase spatiotemporal dynamics without explicit PDE solvers.

Notably, this study presents the first systematic validation of the deep learning architecture across a broad spectrum of multiphase scenarios (including bubble rise, particle deposition, and fluidized bed two-phase flows, as well as a coupled three-phase system). It demonstrates its excellent efficiency and accuracy in accelerated computation and spatiotemporal evolution prediction, while exhibiting strong robustness under noisy training conditions. Further analyses reveal its data efficiency and clarify the effects of training-set size and temporal resolution on predictive accuracy. Extension studies confirm the scalability of the framework to higher-order multiphase systems.

Overall, MultiOKAN provides an efficient and robust neural-operator-based pathway for real-time spatiotemporal prediction of complex multiphase flows, with significant potential for scientific modeling and engineering applications.

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STS 424-2

A Fast Transition Prediction Method for High-Speed Boundary Layers Based on Neural Network

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Abstract

The accurate prediction of boundary layer transition in high-speed represents a persistent and extensively studied challenge in fluid mechanics and aircraft aerodynamic design. Its prediction accuracy has an important impact on the calculation of drag and heat flux, and is related to the safety and economy of aircraft. At present, the e^N method based on linear stability theory (LST) analysis is one of the most widely recognized transition prediction methodologies. However, LST analysis requires calculating the second derivatives of velocity and temperature profiles along the wall normal direction in a body-fitted coordinate system, guessing initial eigenvalues, and solving eigenvalue problems. This process is very cumbersome and hinders its engineering application. Considering the powerful feature extraction and nonlinear fitting capabilities of neural network, it is introduced to replace the traditional eigenvalue solving process. Baseflow of boundary layer and linear stability analysis data are used as samples for training to predict the disturbance amplification factor of the most unstable mode. A large number of numerical examples show that the proposed model can achieve high-precision prediction of the disturbance amplification factor, and the neural network model can be reused infinitely after one-time training. These findings provide an efficient data-driven alternative method for high-speed boundary layer transition prediction and promote the engineering application of LST.

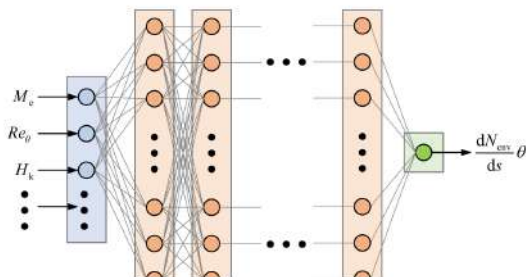


Figure 1: Schematic diagram of prediction model

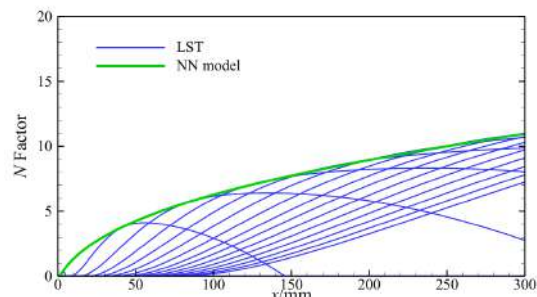


Figure 2: Validation of flat-plate case

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STS 424-3

Data-driven Intelligent Simulation Technology for the Aerodynamic Drag of the High-speed Train

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Abstract

With the increasing of the train speed, the aerodynamic drag rapidly increases and the drag reduction design has become one of the main objectives for the train aerodynamic shape design. Simulation is the main method of evaluating the train aerodynamic performance, hundreds or even thousands of aerodynamic drag simulations are required in the process of train design. The traditional train aerodynamic simulation faces a prominent challenge in balancing accuracy-efficiency-cost. High-precision simulation results rely on refined modeling strategies and high-fidelity physical model algorithms, leading to large computation. Using supercomputing resources significantly increases simulation costs, while simulation efficiency still cannot meet design requirements. The development of AI technology provides technological directions for solving these issues. In the present paper, the data-driven intelligent simulation technology was proposed to rapidly predict the aerodynamic drag of the high-speed train. The standard dataset was established using the surface mesh data, pressure data and shear stress data of trains. An AI model geometry-informed neural operator (GINO) with 250-billion parameters was constructed to predict the surface pressure and shear stress of the train, and the aerodynamic drag can be obtained by integrating the surface pressure and shear stress. The proposed AI model was used to predict the aerodynamic drag of high-speed trains with different shapes, and the results show that the data-driven intelligent simulation technology proposed in the present paper has good geometric generalization and can rapidly evaluate the aerodynamic drag of different train shapes. The computation error is less than 5% compared with wind tunnel tests, and the computation time has been reduced from days for the traditional CFD simulation on supercomputing platforms to seconds on a single GPU.

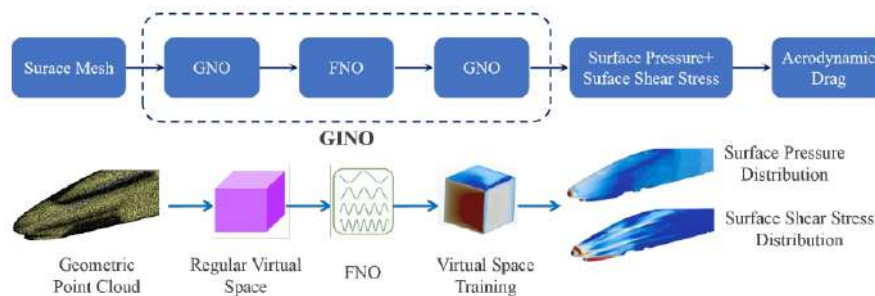


Figure 1: Data-driven intelligent simulation technology

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STS 424-4

Enhancing Predictions of Unsteady Separated Flows via Super-Resolution and Reduced-Order Modeling

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Abstract

Morphing wings are widely regarded as one of the most promising technologies for improving the aerodynamic performance in large civil aircraft. The controllable adjustment of the wing trailing edge in response to external operative conditions naturally improves the aerodynamic efficiency. However, the deformation of trailing edge plays a crucial role in flow separation, leading to significant changes in lift, drag, and stability. Therefore, quickly and accurately predicting the unsteady separated flow around the airfoil is essential for optimizing aerodynamic performance and ensuring stability under different flight conditions.

This paper presents a hybrid model that improves the prediction of unsteady separated flows over an airfoil using reduced-order modeling (ROM) and super-resolution techniques. Delayed detached eddy (DES) simulations of the OAT15A airfoils with various trailing edge deformations are conducted and used as the dataset for the model. The model decomposes the temporal flow field data to obtain low-order reconstructed flow fields and their temporal parameters. The Vision Transformer enhances the spatial details of the low-order reconstructed flow field with physical constraints, while the reduced-order model is used for time stepping. By combining reduced-order modeling and super-resolution techniques, the model improves flow prediction resolution, capturing fine-scale features often missed by conventional models. This enhancement provides a more accurate representation of the flow, offering valuable insights for airfoil design and optimization.

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STS 424-5

A GPU-Accelerated Reduced Order Modelling Framework for CFD-Based Ship Hull Design

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Abstract

This work presents a proof-of-concept (PoC) numerical workflow for fast and accurate ship hull design and resistance prediction, based on the synergistic integration of three enabling technologies: CFD, advanced mesh morphing, and AI-based modelling. The proposed methodology targets the marine sector, leveraging approaches that have already demonstrated strong performance and industrial maturity in other domains such as automotive and aeronautics.

The AI-based surrogate framework is built using NVIDIA's DoMINO technology, which has proven effective in learning complex nonlinear mappings from high-dimensional CFD data while enabling real-time predictions on GPU architectures. Extending such AI-driven approaches to naval hydrodynamics represents a promising opportunity, provided that the training data generation pipeline is robust, scalable, and physically reliable.

A key enabling factor for training data generation is the efficient creation of large families of geometrically consistent hull variants. In this context, radial basis function (RBF) mesh morphing is employed as a fast and flexible parametrization technique, allowing the generation of numerous high-quality geometric configurations from a single baseline hull while preserving mesh integrity without the need to guarantee the topological consistency.

The data foundation is provided by ENGYS' open-source CFD technology, based on Reynolds-averaged Navier-Stokes simulations with a linearized free-surface model, extensively validated in marine applications. CFD simulations are performed for a design of experiments built on the "Kriso Container Ship" hull, producing a comprehensive database of flow solutions.

The resulting AI model enables real-time prediction of hull deformation effects, pressure and shear stress distributions, and calm-water resistance, achieving a maximum relative error below 7% on unseen configurations. The PoC, developed within the Italian AI4TwinShip initiative, demonstrates how the integration of validated CFD solvers, RBF-based geometric morphing, and GPU-accelerated AI models forms a solid foundation for future ship digital twin technologies.

STS 424-6

Physics-Informed Neural Networks for the Design of ORC Supersonic Axial Turbine Stator Blades

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Abstract

The recovery of low- to medium-temperature waste heat via Organic Rankine Cycles (ORCs) has become increasingly important for industrial and energy systems driven by sustainability demands. In compact ORC turboexpanders, high specific power and large pressure drops are often achieved using single- or two-stage turbines operating in transonic or supersonic regimes. Under these conditions, conventional design heuristics are challenged by complex compressible-flow physics and real-fluid effects.

Supersonic axial turbine stator blades are typically designed using the method of characteristics (MOC), which is applied only to the supersonic (diverging) portion of the blade passage, while the converging region is prescribed heuristically [1]. This paper proposes a systematic inverse design approach based on physics-informed neural networks (PINNs) for the complete supersonic stator blade geometry of an ORC Laval turbine. The proposed PINN framework [2] embeds the governing partial differential equations of irrotational compressible flow and incorporates real-gas thermodynamics of organic working fluids to ensure physical consistency. Training targets are prescribed along the mean flow line within the inter-blade channel. Blade surface coordinates are then reconstructed by deriving suction- and pressure-side contours from stream functions predicted by the network.

The resulting blade geometries are validated using high-fidelity CFD simulations of inviscid flow, demonstrating close agreement between the mean-line flow distributions and the design specifications. Subsequent turbulent CFD simulations confirm that the PINN-designed supersonic stator blades support smooth, shock-free flow fields. Furthermore, a single-stage transonic ORC Laval turbine equipped with the designed stator blades achieves efficiency comparable to that of a multistage subsonic Rateau turbine operating under the same expansion conditions.

Overall, the proposed method integrates advanced machine-learning techniques with physics-based modeling, providing a robust and verifiable framework for supersonic blade design that effectively bridges data-driven approaches and classical CFD practice.

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STS 424-7

A Hybrid CNN-based Fourier Neural Operator for Airfoil Flow Field Prediction

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Key words: Fourier Neural Operator, Airfoil, Convolutional Neural Network, Hybrid Architecture

Abstract

Fourier Neural Operators (FNO) have emerged as a powerful paradigm for solving partial differential equations (PDEs) by learning discretization-invariant solution operators that effectively capture global flow dependencies. However, due to the global nature of Fourier basis functions and the truncation of high-frequency modes, standard FNO often struggle to resolve fine-grained local features and discontinuities, limiting their fidelity in capturing detailed flow structures. To address this limitation, this study introduces a Hybrid FNO-CNN architecture for airfoil flow field prediction. The proposed framework employs a parallel dual-branch structure: an FNO branch responsible for resolving global flow patterns in the frequency domain, and a Convolutional Neural Network (CNN) branch dedicated to the refinement of local spatial details. A key innovation is the integration of a learnable fusion mechanism that dynamically weights the contributions of both branches, enabling the model to synergize global coherence with local precision during the learning process. The model was evaluated on a comprehensive dataset of airfoils under a wide range of inflow conditions. Numerical experiments demonstrate that this hybrid approach achieves superior predictive accuracy, reducing the relative error by approximately 5% compared to the standard FNO. Notably, this accuracy improvement incurs negligible computational overhead, maintaining training efficiency comparable to that of the standard FNO under identical experimental settings. Furthermore, the proposed model offers a computational speedup of 3 to 5 orders of magnitude over traditional CFD solvers. By effectively integrating spectral information with local convolutional receptive fields, the proposed architecture significantly enhances the prediction of velocity and pressure fields, offering a robust and efficient surrogate model for aerodynamic design optimization.

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STS 424-8

Accelerating the training procedure of Physics-informed neural networks for phase field method via various strategies

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ABSTRACT

Physics-informed neural networks (PINNs) combined with domain decomposition have shown promise for multiphase flow simulation, yet their application is often constrained by high training costs.

To address this, we enhance the phase-field PINN framework with JAX for high-performance computing, automatic mixed precision for memory efficiency, and redesigned communication strategies for multi-GPU parallel training.

Additionally, we evaluate data parallel, domain decomposition, and a hybrid data-domain parallel approach using a coaxial bubble rising case. Results indicate that the data parallel method offers the best trade-off between accuracy and efficiency, while the hybrid method reduces inter-partition communication and achieves lower loss than domain decomposition. These strategies collectively enable accurate, efficient direct numerical simulation of multiphase flows with acceptable training costs.

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STS425 - Disruptive Aircraft's Wing Design through Innovative Electroactive Morphing towards Sustainable Aviation

Main Organizer: Ms. Marianna Braza (INPT, France)

Chaired by:

STS425A:

Mr. Yannick Hoarau (University of Strasbourg, France), Ms. Marianna Braza (INPT, France);

STS425B:

Ms. Marianna Braza (INPT, France), Mr. Yannick Hoarau (University of Strasbourg, France)

Part	Date	Time	Room
STS425A	Thu 23.07.2026	15:00–16:30	NM - 2 (Salzburg)
STS425B	Thu 23.07.2026	17:00–18:30	NM - 2 (Salzburg)

The present STS at ECCOMAS 2025 will include five contributions concerning novel wing morphing, able to drastically increase the aerodynamic performances leading to a considerable fuel's consumption decrease and noise sources reduction. Emphasis will be attributed in the efficiency of multiscale electrical actuations with increased DoF over strategic areas of the lifting structures, able to attenuate harmful instabilities and optimise the fluid-structure interaction system by means of AI. These objectives are inscribed in the HORIZON-EIC-2023-2027-PATHFINDER Project N° 101129952 – BEALIVE, "Bioinspired Electroactive multiscale Aeronautical Live skin, <http://horizon-europe-bealive.eu/>. The presentations will analyse the morphing effects on the fluid-structure interaction, beneficially manipulating the surrounding turbulence towards simultaneous drag reduction, increase of lift and noise sources attenuation. The new morphing designs ensure a considerable energy decrease for the propulsion, beneficial for all sources of renewal energy. The presentations will demonstrate through well focused experiments on morphing wing prototypes and High-Fidelity numerical approaches, the effects of Travelling Waves (TW) and Standing Waves (SW) produced by the "live-skin", as well as by other novel morphing concepts thanks to new generation of smart actuators. These designs are able to produce optimal interfacial layers interacting with the coherent and chaotic turbulence structures and applying deformation of strategic parts of the wing. The topic of this session prepares future wing design for aeronautics industrial applications aiming at saving energy and at reducing the pollution through these new, multiple-degrees-of freedom morphing concepts, enabling a considerable reduction of emissions, reaching ACARE's European Commission targets (DG MOVE/ DG RTD, (<https://data.europa.eu/doi/10.2777/15458>) Flightpath 2050 that include a 80% reduction in CO₂ emissions per passenger kilometers to support the Air Transport Action Group target: "Carbon-neutral growth starting 2020 and 90% or practically zero CO₂ emission reduction by 2050", as well as a 90% reduction in NO_x emissions and noise emissions reduced by 65%.

STS 425-1

Aerodynamic Performance Increase of an A320 Morphing Wing in Subsonic Regime at Reynolds Number of 1 M

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Abstract

Key words: *Electroactive morphing, Fluid-Structure Interaction, Control, turbulence, wing*

An electroactive morphing “live-skin” approach has been developed by the IMFT and LAPLACE laboratories to enhance aerodynamic performance in subsonic flow. The system employs piezoelectric actuators positioned near the trailing edge and near 70% of the chord (Fig. 1). Experimental investigation was conducted on an Intermediate Scale (IS) A320 wing prototype within the HORIZON-2023-2027-PATHFINDER-Open Project No 101129952-BEALIVE-“Bioinspired Electroactive multiscale Aeronautical Live skin”, <http://horizon-europe-bealive.eu/>. The concept is bioinspired by both sharks and birds, aiming to implement a “live-skin” system on various A320 wing prototypes to increase the degrees of freedom of the actuation, thus enhancing the aerodynamic performance. This enhanced actuation capability enables simultaneous manipulation of the vortex dynamics and surrounding turbulence resulting - as demonstrated in the results - in lift increase, drag reduction, and mitigation of noise sources. The A320 IS, “Intermediate Scale” morphing prototype of the BEALIVE project has a 70 cm chord and 59 cm span. The experiments are carried out in the S4 subsonic wind tunnel under take-off conditions: angle of attack: 10°, Ma: 0.06, Re of 1 million. The live-skin system of the piezo-ceramic actuators near 70% chord, placed just upstream of the separation point location, enhanced local momentum and disrupted large coherent vortex structures via the eddy-blocking effect [1]. This resulted in shear layer thinning and delayed von Kármán vortex formation, thus contributing to drag reduction. At the same time, coherent structures rotating in phase with the shear layer intensified KH vortices, increasing lift. The experiments yielded a lift increase of 4%, a drag reduction of 6% as well as a 10% lift-to-drag ratio increase. The PSD analysis of the pressure signals showed an 8 dB decrease (Fig. 2-3) of the energy spectrum and of the predominant frequency peaks due to breakdown of coherent structures related to noise sources produced from the trailing edge. TRPIV with a 10 kHz sampling rate has been performed (Fig. 4); in this study, the results were supported by a SPOD analysis, which provides a frequency-resolved decomposition of the flow and highlights the dominant coherent structures (Fig. 5). In strong synergy, Hi-Fi simulations were conducted using the NSMB solver with an ALE framework [2,3] and the Organised Eddy Simulation - OES turbulence model [4,5].

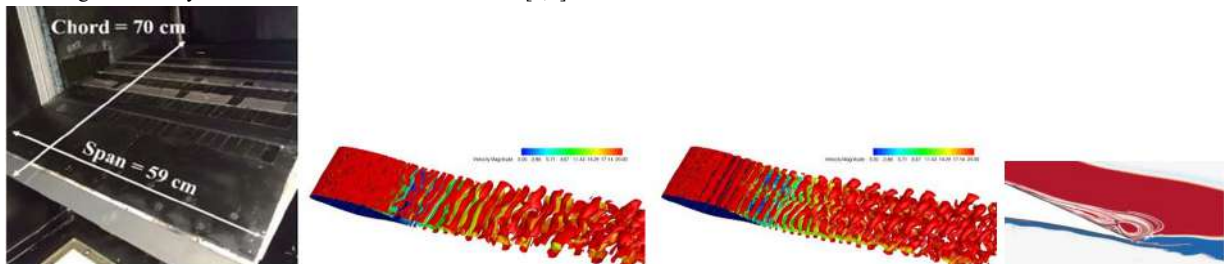


Figure 1: Left: subsonic Intermediate Scale (IS) A320 wing prototype with a chord length of 70 cm, representing half the real A320 wingtip chord, equipped with the live-skin.

Figure 2: middle and right: Top left: Q criterion iso-contours around the A320 wing (static, e.g. non-actuated case), coloured by the spanwise vorticity. Top right: Q criterion iso-contours around the A320 wing (morphing case), coloured by the spanwise vorticity, comparing to the static case, illustrating a more regular vortex pattern in the shear layers and in respect of the secondary instability, pushing the spanwise undulation farther downstream and producing a wake thinning, resulting to drag reduction. The TW morphing enhances the upper shear layer, thus yielding lift increase and the shedding of Kelvin-Helmholtz vortices. The interaction of these vortices plays a crucial role in the appearance of secondary instability in a region closer to the trailing edge, resulting in the formation of smaller-scale vortices within the shear layers that constrict the shear layers resulting to thinner wake. The spanwise vortices become smaller and more regular than in the static case. Bottom: Streamlines showing the separated area (static case).

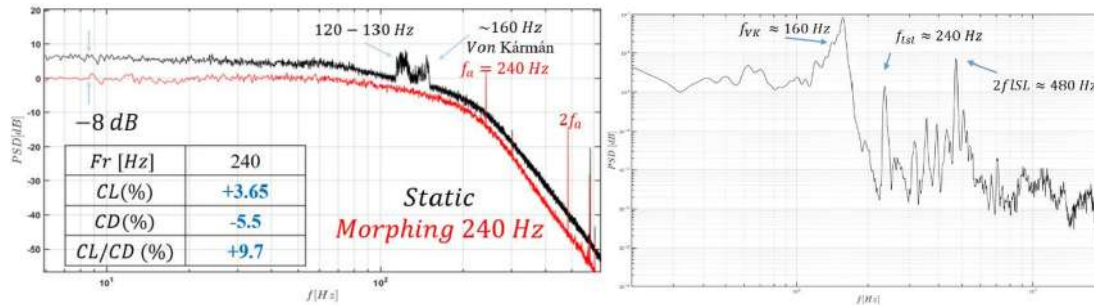


Figure 3. Left: Experimental Power Spectral Density of the unsteady pressure for the static and morphing cases corresponding to a wall sensor location at $x/c=0.80$. Right: PSD of the lift coefficient through simulations showing comparison of the main instability modes with the experiment. A considerable reduction of the Power Spectral Density is obtained together with attenuation of the predominant instability modes.

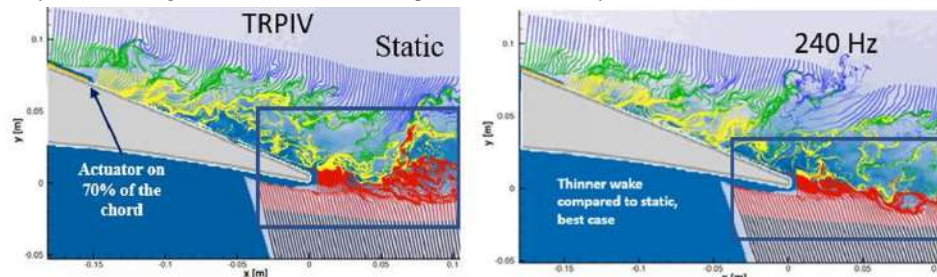


Figure 4. Left: Streaklines from Time Resolved Partial Image Velocimetry in the static case showing Turbulent-Non-Turbulent (TNT) interfaces (green/red) and the Turbulent-Turbulent (TT) interface (yellow). Right: Streaklines in the morphing case with $f_a = 240$ Hz. The TNT interfaces are more closely spaced and the TT interface remains closer to the wing surface. The lower shear layer, marked in red (blue rectangle), is more coherent and its width has decreased. These characteristics result in a thinner wake, a reduction in drag and a strengthening of the lower shear layer, leading to an increase in the lift.

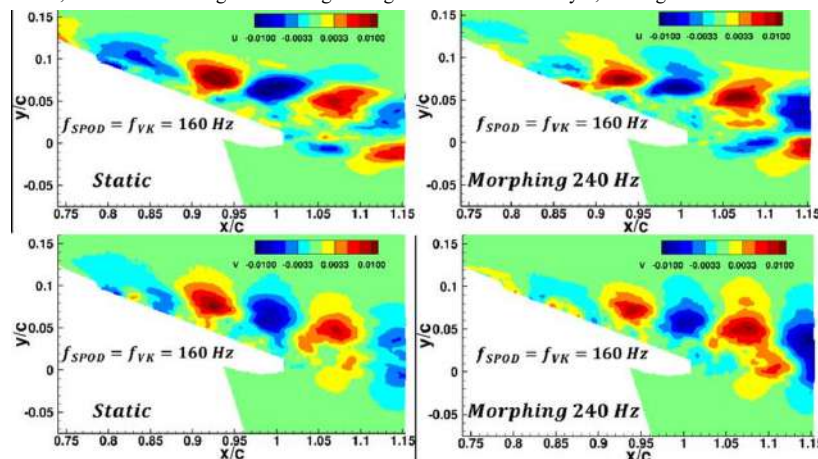


Figure 5 Comparison of the Spectral Proper Orthogonal Decomposition (SPOD) mode 1 associated with the von Kármán shedding frequency (160 Hz) for both the static (left) and morphing (right) configurations. The streamwise (u) and cross-stream (v) components are shown in the upper and lower rows, respectively. The morphing results in breakdown of the large vortices into smaller ones, indicating a weakening of the VK vortices impact on the wing due to the feedback effect in the present low subsonic regime.

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STS 425-2

**Experimental and numerical analyses of the travelling waves
electroactive morphing implemented on the high lift A320 wing flap
system in the subsonic regime.**

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ABSTRACT

Key words: *electroactive morphing, high-lift, subsonic regime, travelling waves, wing, shear layers, fluid-structure interaction*

The studied A320 wing prototype is near full-scale (1:1) consists of two elements. First, the fixed wing section of 1.4 m and then, the high-lift flap with a chord of 1.0 m, yielding a total take-off chord of 2.70 m with a span of 2 m. In the analysed take-off configuration, the flap is deflected at 10°. This investigation is conducted within the framework of the European project HORIZON-2023-2027-PATHFINDER- Open Project N° 101129952-BEALIVE-"Bioinspired Electroactive multiscale Aeronautical Live skin", <http://horizon-europe-bealive.eu/>, aiming at the development of a morphing actuation system forming a "live-skin" in strategic regions of the lifting surfaces of an A320 wing, with the objective of improving aerodynamic performance. The airflow around an A320 wing is numerically investigated in a low-subsonic take-off regime at a Reynolds number of 2.25 million. The Large-Scale (LS) wing prototype is tested under subsonic conditions in the S1 wind tunnel at IMFT [1].

The live-skin actuation is implemented exclusively on the suction side of the flap which induces significant modifications in the averaged wall pressure coefficient (C_p) distribution along the whole configuration compared to the static case (Figure 1). These important modifications are induced by feedback effect naturally occurring in this type of flow, the morphing effect propagated upstream, with observable changes (suction increase) in C_p extending to the leading edge of the fixed wing section (Figure 2). In addition, a substantial alteration in pressure distribution was recorded on the lower (super-pressure) surface, confirming a global aerodynamic impact of the actuation. The experimental lift coefficient (CL) showed an improvement of up to 8%, further validating the effectiveness of the live-skin strategy at full scale (Figure 2-3).

Four key parameters are considered to model the "live-skin" actuation: wavelength (λ), frequency (f), amplitude (a), and the length and position of the actuation zone on the suction side (x_0/c , x_f/c), where c is the wing chord (Figure 5). The flow is computed using the Navier-Stokes Multi-Block (NSMB) solver [3], and mesh deformations induced by morphing are handled with the Arbitrary Lagrangian-Eulerian (ALE) method [4]. The first numerical simulation campaign is based on performances obtained from the parametric spectrum performed in the S1 wind tunnel at IMFT. The simulated domain is willingly different from the experimental one of S1, in order to quantify more accurately the structural modifications of the flow around the LS configuration and in the wake when the "live-skin" is actuated.

In this configuration, inflexional points in the velocity profile from both the fixed part and the flap lead to the development and growth of instabilities that generate Kelvin-Helmholtz vortices along each shear layer (Figure 7). Their interaction engenders the von Kármán vortex street farther downstream (Figure 6). These wake dynamics are closely related to drag and lift, which the morphing actuation intend to optimize in experiments [1,2].

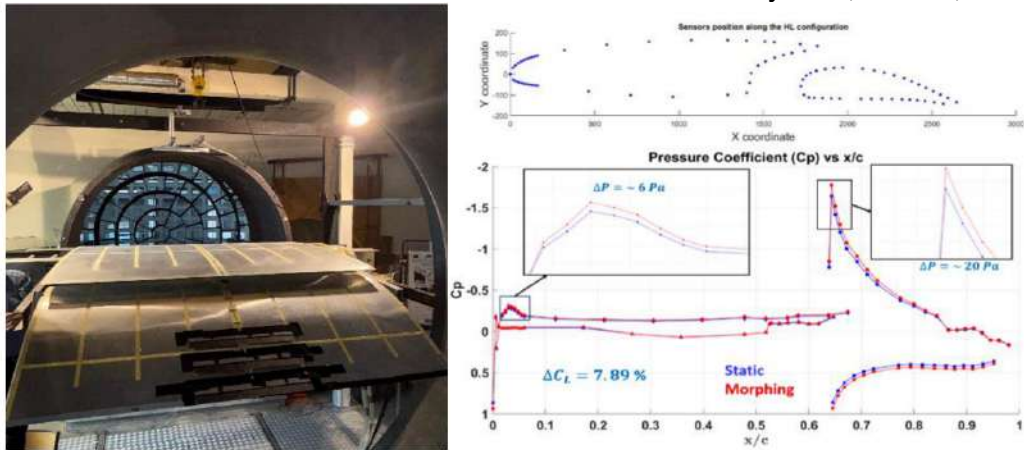
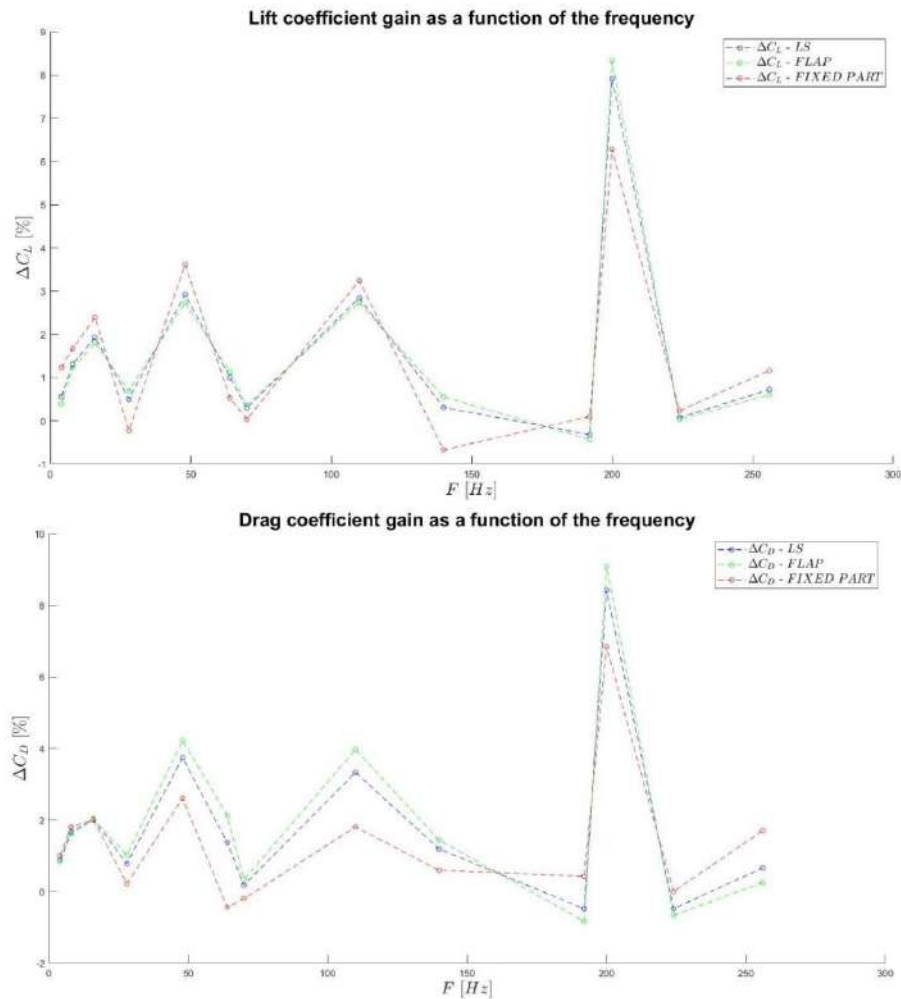


Figure 1: (Left): Large-Scale (LS) A320 wing + high-lift flap prototype, tested near full scale in the S1 wind tunnel at IMFT. The live-skin morphing system is implemented on the flap. (Right): Static pressure sensors location along the experimental Large-Scale (LS) A320 wing (top); Pressure coefficient distribution comparison between static (blue) and morphing (red) configurations, showing an 8% increase in lift coefficient thanks to the live-skin actuation (bottom).



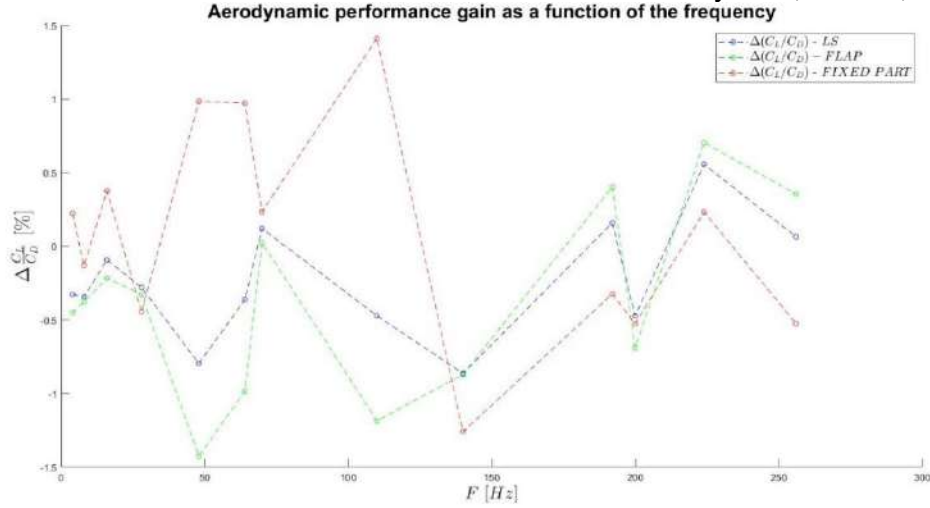


Figure 2: (Top): Experimental lift percentages obtained for different actuation frequencies at fixed λ and same actuated area for, the flap (green), the fixed part (red) and the Large-Scale overall configuration (blue); (Middle): Experimental pressure drag percentages obtained for different actuation frequencies at fixed λ and same actuated area for the flap (green), the fixed part (red) and the Large-Scale high-lift configuration (blue); (Bottom): Aerodynamic performances percentages obtained for different actuation frequencies at fixed λ and same actuated area for the flap (green), the fixed part (red) and the Large-Scale overall configuration (blue).

$f_a = 200$ (LS)	$C_{L_{F200}} = 1,40$ $C_{D_{F200}} = 0,167$	$\frac{C_{L_{F200}}}{C_{D_{F200}}} = 8,42$	$\Delta C_{L_{F200}} = 7,91\%$
$f_a = 224$ (LS)	$C_{L_{F224}} = 1,44$ $C_{D_{F224}} = 0,167$	$\frac{C_{L_{F224}}}{C_{D_{F224}}} = 8,64$	$\Delta C_{L_{F224}} = 0,0764\%$ $\Delta C_{D_{F224}} = -0,478\%$
$\Delta \left(\frac{C_{L_{F224}}}{C_{D_{F224}}} \right) = 0,557\%$			

Figure 3: Experimental lift, drag and aerodynamic efficiency values and percentages obtained with 200 Hz and 224 Hz. While 200 Hz displays the highest increase in lift, 224 Hz show a promising region where an increase in lift and a decrease in drag are observed.

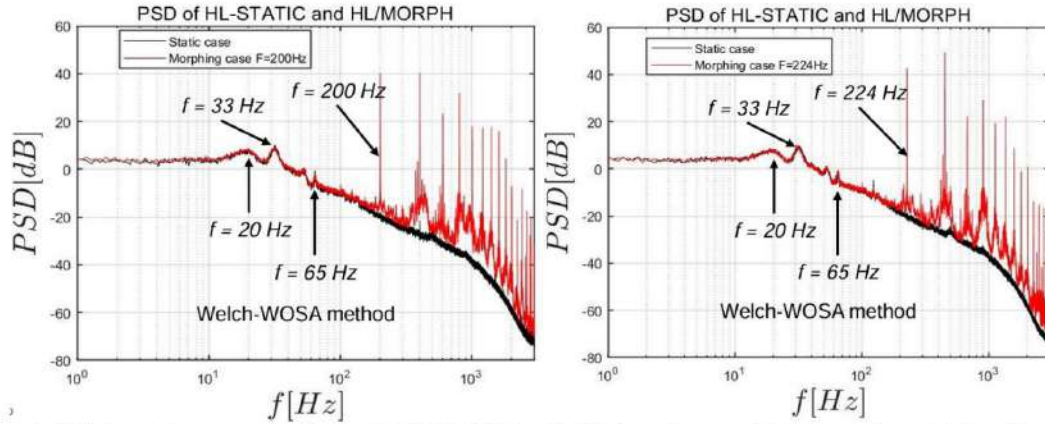


Figure 4: PSD of unsteady pressure signals using the Welch-WOSA method for the static case and its corresponding actuated configuration: $f_a = 200$ Hz (Left) and $f_a = 224$ Hz (Right).

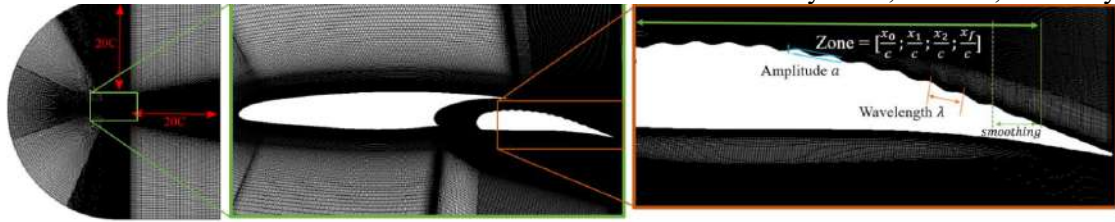


Figure 5: Mesh around the high-lift wing and travelling wave live-skin parameters

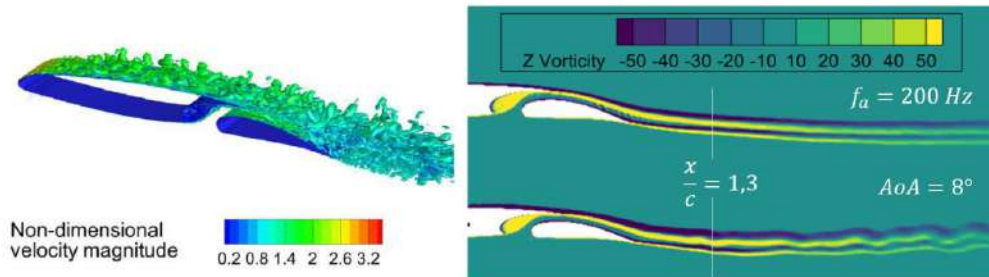


Figure 6: (Left) Flow dynamics around the high-lift system using DDES-OES model, iso-surfaces of the $Q_{criterion} = 1500$ coloured by the non-dimensional velocity magnitude. Angle of attack of 8° . Right: vorticity comparison around the flap and in the wake at an angle of attack of 8° , with (top) TW actuated with $f = 200\text{Hz}$ showing suppression of the wake instabilities. Bottom: no actuation.

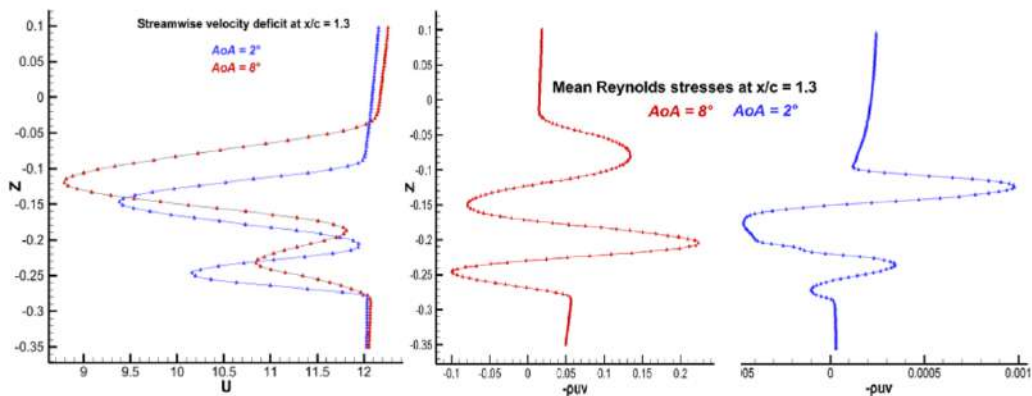


Figure 7: (Left) Mean streamwise velocity deficit at $x/c = 1.3$ for $AoA = 2^\circ$ and 8° . (Right): Mean Reynolds stresses component profile at $x/c = 1.3$ for $AoA = 2^\circ$ and 8° .

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STS 425-3

Comparative Analysis of Radial Basis Function and Polynomial Parametrisation for Camber-Morphing Aerofoil

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Abstract

Morphing wing with variable camber provides a mean of optimising aerodynamic performance (e.g. lift, drag, moment) across different flight phases without the gaps, noise and drag penalties associated with conventional high-lift devices [1]. Among morphing concepts, camber morphing remains one of the most aerodynamically effective and structurally practical strategies for adaptive lifting surfaces [2]. Parametrisation techniques include parabolic camber morphing and B-spline- or Class-Shape Transformation-based methods. However, most Computational Fluid Dynamics studies adopt a single morphing approach and rarely assess how the choice of parametrisation influences geometric fidelity and aerodynamic accuracy for widely used aerofoils, e.g. NACA-2412.

Radial Basis Function (RBF) interpolation is typically used as a mesh-deformation tool, propagating prescribed structural or geometric displacements while the morphing law is defined independently, so its potential as a camber-morphing parametrisation remains underexplored. This study addresses that gap by using RBF control-point displacements as the parametrisation and comparing them, under same morphing inputs, with a traditional polynomial (parabolic) camber morphing. Test case is the Leading- and Trailing-edge Camber Morphing (LTCM)-2412 aerofoil, a variable-camber derivative of NACA-2412 with simultaneous leading-edge (LE) and trailing-edge (TE) camber morphing with same deflections imposed. Two-dimensional steady Reynolds-averaged Navier-Stokes simulations are conducted using ANSYS Fluent solver at $Re = 3.9 \times 10^6$, $M = 0.15$, and angles of attack from 0° to 20° .

Geometric fidelity is evaluated by chord length, nose-curvature and camber-line smoothness, while performance is assessed by aerodynamic coefficients. Results show that the polynomial method shortens the chord and alters nose curvature under combined LE and TE deflection, whereas RBF preserves baseline geometry. These differences lead to prediction discrepancies in lift, drag and stall onset, with RBF giving slightly higher maximum lift and a delay in stall. The findings clarify how parametrisation choice influences both geometry and aerodynamics and provide guidance for variable-camber wing design and optimisation.

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STS 425-4

Numerical Study of a Pitching Aerofoil with a Morphing Leading- and Trailing-Edge Section for Improved Aerodynamic Performance

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Abstract

Nature's capacity to achieve dynamic wing-shape adaptation has motivated ongoing research into morphing wing technologies. Implementing smooth, continuously morphing sections, as opposed to traditional discrete control surfaces, addresses the longstanding challenge of optimising aerodynamic performance across varying operational regimes, rather than at a single design point. Recently, significant progresses have been made in dynamically actuated leading-edge (LE) [1, 2] and trailing-edge (TE) [3, 4] aerofoil technologies individually. However, a gap remains in the dynamically coupled LE-TE morphing motion. This study aims to build on existing knowledge by combining these two separate motions to investigate further potential aerodynamic improvements and noise mitigation. First, numerical predictions of the baseline case are compared with experimental results [5, 6] for validation. Then, adopting the mathematical formulation proposed in [7], a harmonic function is introduced to enable independent control of morphing amplitude and frequency for the LE and TE sections, e.g. shown in Figure 1(a-d). Proceeding to use a similar approach to that in [1], in which a LE morphing section with a phase angle offset is shown to delay the onset of dynamic stall. Whereas the TE morphing section parameters are determined following the methodology outlined in [3], where a fixed morphing amplitude is employed alongside a range of morphing frequencies, showing improvements in aerodynamic efficiency in terms of lift/drag ratio. Further details will be presented in the full paper later.

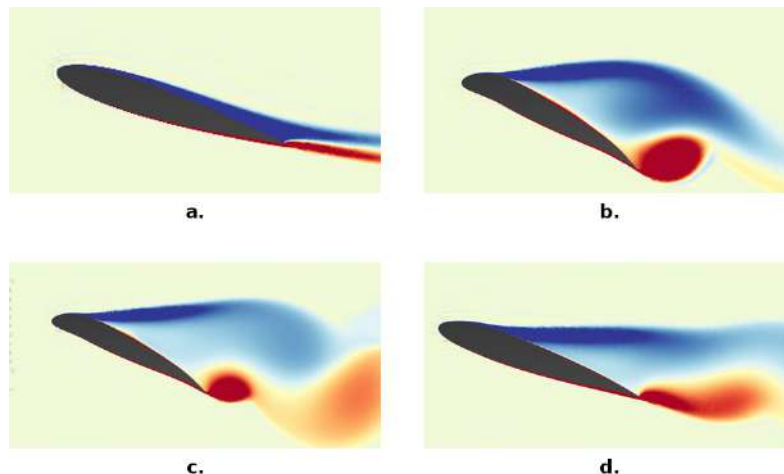


Figure 1. Normalised vorticity contours at different flow times, with dynamic LE and TE motions while pitching.

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STS 425-5

Analysis of Travelling and Standing Wave Morphing Around an A320 Wing Prototype in the Subsonic Regime Using POD and SPOD

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Abstract

Key words: *Electroactive morphing, travelling waves, standing waves, Fluid-Structure Interaction, Control, turbulence, wing*

This study investigates the morphing effects around the Intermediate Scale “IS” Airbus A320 wing prototype of the European project HORIZON-2023-2027-PATHFINDER- Project N° 101129952-BEALIVE-“Bioinspired Electroactive multiscale Aeronautical Live skin”, <http://horizon-europe-bealive.eu/> using a novel morphing concept of electroactive “live-skin” thanks to a significant number of piezo-ceramic actuators disposed along strategic areas of the wing’s suction side surface. A strong synergy between the experiments carried out in the S4 wind tunnel of IMFT through TRPIV and unsteady pressure and force measurements and the Hi-Fi numerical simulations through modelling the live-skin effect by means of surface travelling-waves (TW) and standing-wave (SW). This morphing concept is developed to drastically increase the aerodynamic performance. The morphing effects are analysed around the 70 cm-chord IS prototype under low-subsonic take-off conditions at incidence of 10°, inlet velocity of 21.5 m/sec corresponding to Mach number of 0.063 and Reynolds number of 1×10^6 .

A large parametric study has been conducted by varying four key actuation parameters: wavelength, frequency, amplitude, and the position and length of the actuation zone along the chord. Numerical simulations are performed using the Navier-Stokes Multi-Block (NSMB) solver [1], with mesh deformation handled through an Arbitrary Lagrangian-Eulerian formulation [2]. The turbulence model used is the Organised Eddy Simulation (OES) approach [3,4], sensitised to correctly capture the coherent flow structures and instability mechanisms. The objective of this study is to analyse the aerodynamic efficiency increase induced by this morphing concept able to manipulate the instabilities in the separated shear layers and in the wake. Thanks to the feedback effects at the present subsonic flow, the present morphing disposed in the rear part of the wing is able to modify the wall pressure distribution up to the leading edge. The morphing actuation introduces, in optimal cases, an eddy-blocking effect in the shear layers, injecting small-scale vortices that constrict the shear layers and significantly reduce the wake’s width and delay the development of the von Kármán instability, swept farther downstream. Overall, the present morphing demonstrates strong benefits, leading to drag reduction up to 8% and increases in aerodynamic efficiency exceeding 8% (fig. 2).

Proper Orthogonal Decomposition (POD) and Spectral POD (SPOD) are applied to extract, analyse and compare the coherent structures developed in the flow field in static and morphing cases. These modal decomposition techniques reveal the dominant energetic coherent structures and their associated frequencies. The morphing effects are shown in figures 5 and 6.



Figure 1: “Live-skin” embedded on the subsonic “Intermediate Scale - IS” A320 morphing prototype (left), in the S4 wind tunnel of IMFT. Right: Schematic visualisation of the wavy surface modelling the present actuation.

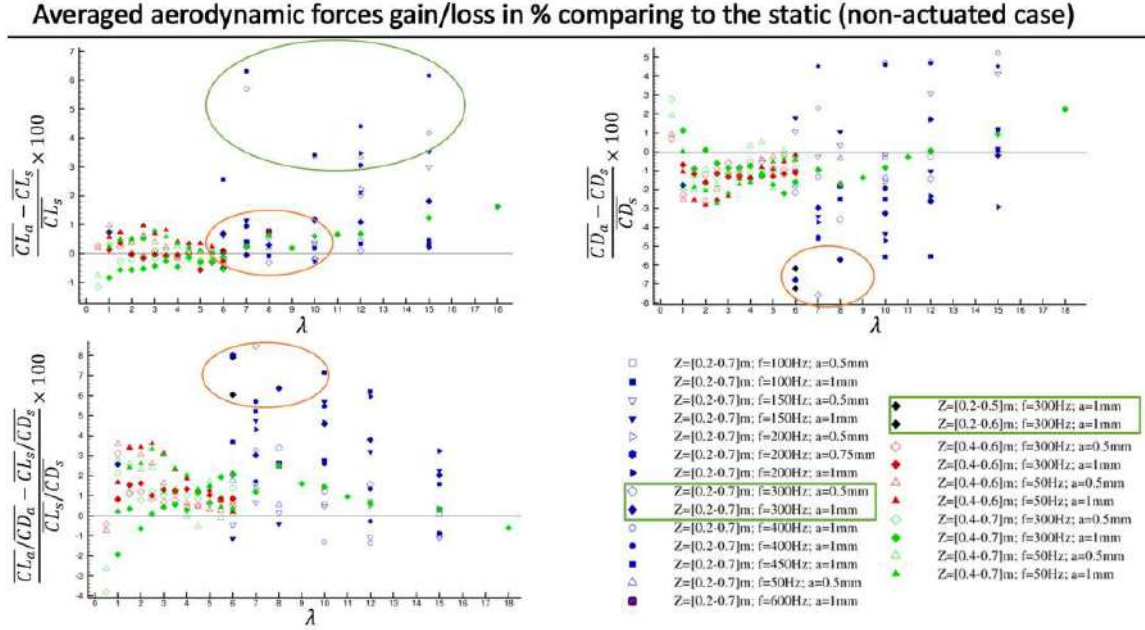


Figure 2: Relative variation of lift and drag coefficients for different sets of travelling wave (TW) actuation parameters with respect to non-actuated case.

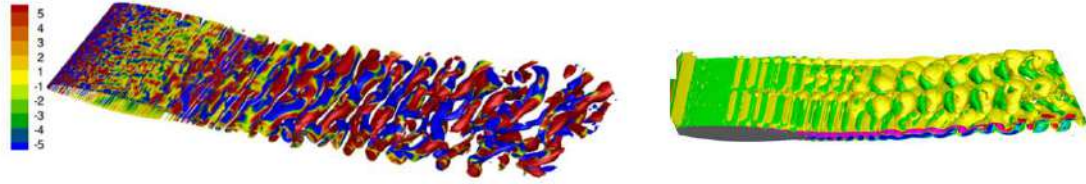


Figure 3: Instantaneous three-dimensional flow fields, Q -criterion iso-surface ($Q = 2000 \text{ s}^{-2}$), showing the secondary instability coloured by velocity magnitude. (Top) Static non-actuated case (Bottom) TW morphing wing with $f=300 \text{ Hz}$, $a=0.5 \text{ mm}$, $\lambda=6 \text{ cm}$, $x/c = [0.28-0.86]$.

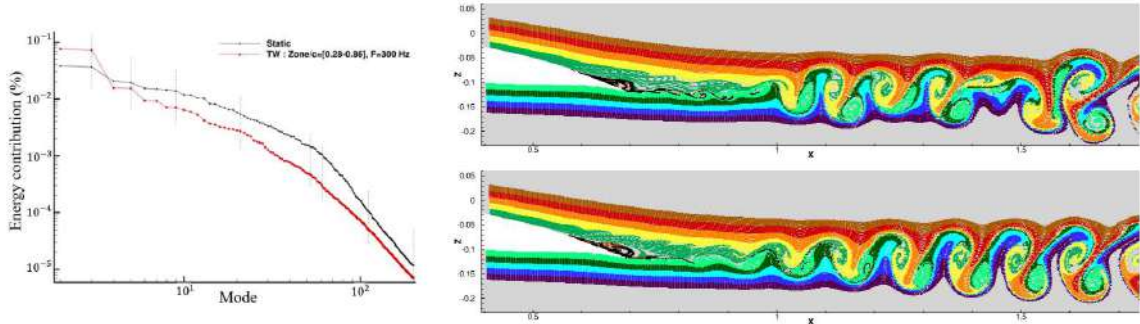


Figure 4: Left: Energy diagram of the POD modes, comparing the static case to TW morphing case. Right: Streaklines visualisation of the **reconstructed** fields from the first most energetic POD modes. (Top) static case (bottom) TW at $f = 300 \text{ Hz}$, $a = 0.5 \text{ mm}$, $\lambda = 6 \text{ cm}$, $x/c = [0.28-0.86]$. The colour of each particle represents its initial position. In the morphing case, a **drag reduction of 7.86%** is obtained, associated to a **lift to drag ratio increase of 8.67%**.

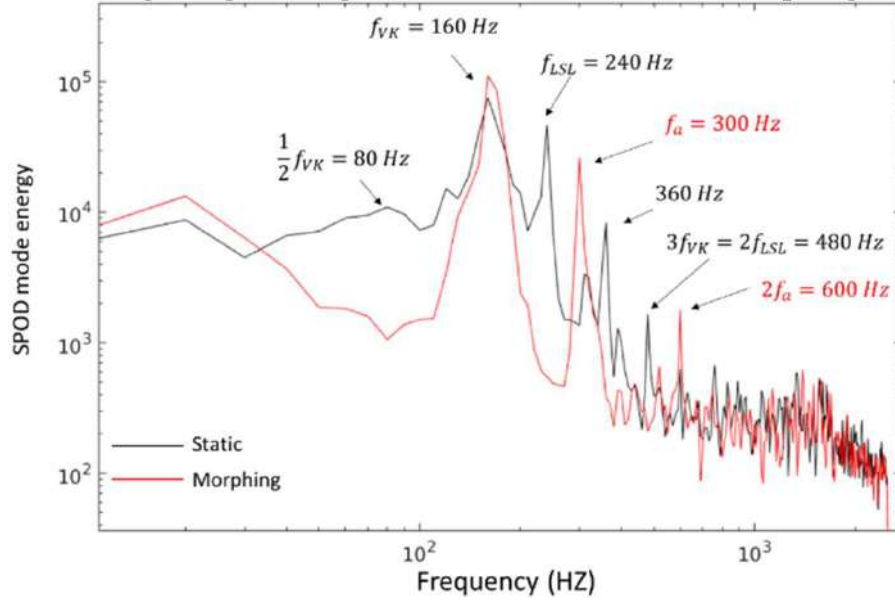


Figure 5: Eigenvalue spectrum of the first SPOD mode

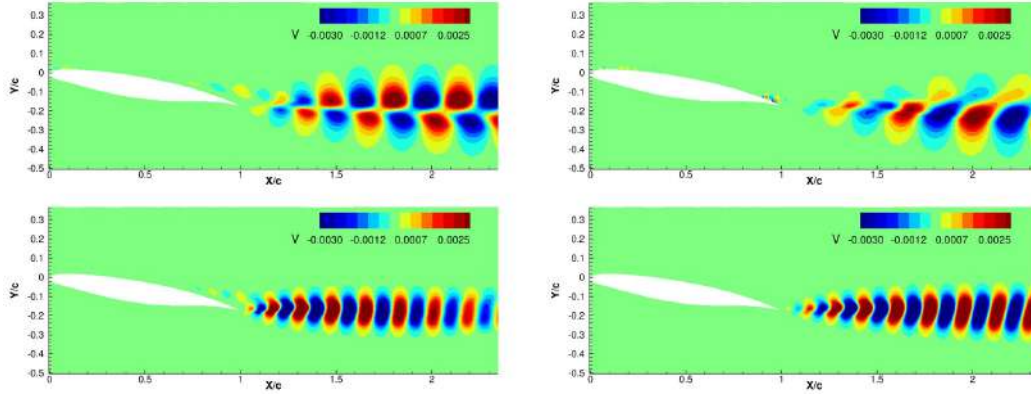


Figure 6: SPOD spatial modes comparison between (left) static case and (right) TW morphing. Vertical velocity component at $f=80$ Hz (top). Bottom: vertical velocity component at $f=160$ Hz. For the first subharmonic of the von Kármán frequency (80 Hz), the static case exhibits alternating vortex structures aligned along nearly vertical axes, while in the morphing case, the upper shear layer vortices are attenuated. At 160 Hz, the spreading rate of the wake becomes more linearly expanded.

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STS 425-6

POD and Machine Learning based Reduced Order Modelling for Wave Morphing Actuations on an A320 Wing Prototype

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Abstract

Key words: *Morphing, wing, ROM, POD, LSTM, PSO, Machine Learning, ALE, turbulent flow.*

This study introduces a reduced-order modelling (ROM) method and optimization strategy for predicting unsteady flow around morphing wings. The framework is applied to the Intermediate Scale (IS) A320 morphing wing prototype of the HORIZON-2023-2027-PATHFINDER Project No. 101129952 (BEALIVE - Bioinspired Electroactive multiscale Aeronautical Live skin, <http://horizon-europe-bealive.eu/> (Figure 1), at Reynolds number of 1 million, Mach number 0.063 corresponding to inlet velocity of 21.5m/sec and a 10° angle of attack. The chord is of 70 cm and the span of 59cm. A synergy between the experiments carried out by TRPIV in the S4 wind tunnel of IMFT and Hi-Fi simulations is carried out. The flow separation occurs near $x/c \approx 0.7$. The flow dynamics are governed by two shear layers, an upper shear layer (USL) over the separation region expanded farther downstream and a lower shear layer (LSL) below the trailing edge and in the wake. Both are governed by shear-layer instability dynamics leading to Kelvin-Helmholtz vortices. These two shear layers interact farther downstream and form the von Karman vortex shedding. Building on previous morphing-wing studies [1,2].

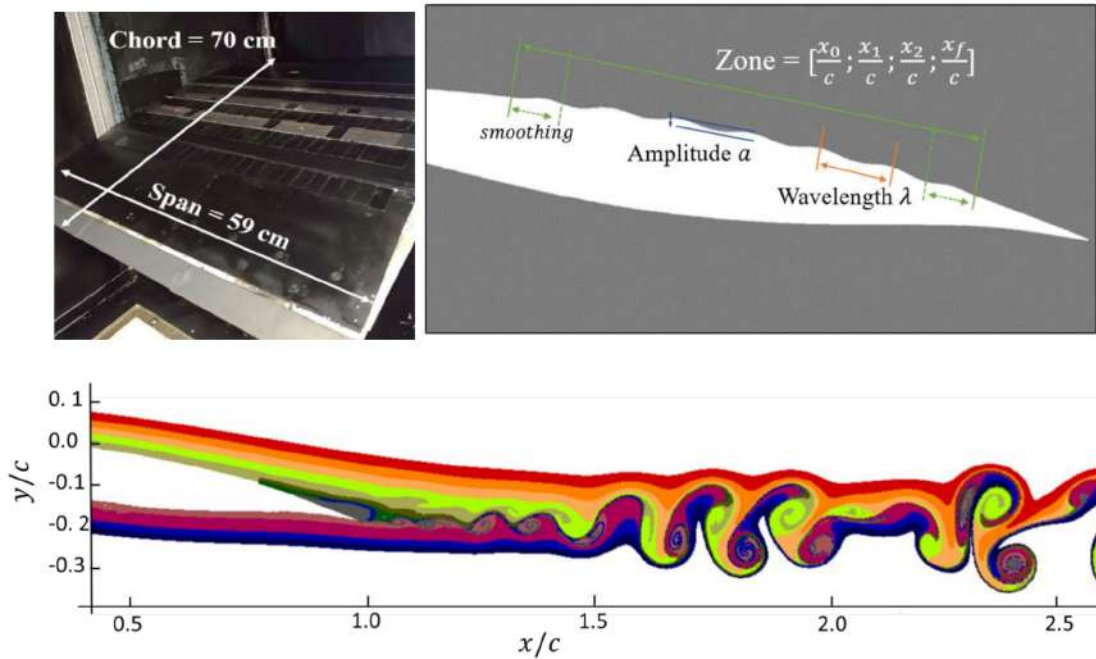


Figure 1: Top-left: “Live-skin” embedded on the subsonic “Intermediate Scale - IS” A320 morphing prototype (left), in the S4 wind tunnel of IMFT. Top-right: schematic visualisation of the wavy surface modelling the present actuation. Bottom: 2D view of the flow dynamics around the IS A320 morphing wing prototype at $Re=1$ Million through numerical simulation.

The objective is to improve aerodynamic performance by manipulating these coherent structures using a novel morphing concept generated by a system composed of a considerable number of piezoceramic actuators forming a “live-skin”, disposed along a strategic area on the suction side (Fig. 1- right). The effects of this actuation, experimentally realised, is modelled in the Hi-Fi simulations of the study through surface Travelling or Standing Waves with optimised wavelength, amplitude and frequency. The design space is defined by wavelength (λ), frequency (f), amplitude (a), and suction-side actuation-zone bounds (x_0/c , x_f/c), making exhaustive high-fidelity exploration and optimisation impractical.

High-fidelity (Hi-Fi) data are produced with the Navier-Stokes Multi-Block (NSMB) solver [4] and an Arbitrary Lagrangian-Eulerian (ALE) formulation for dynamic grid deformation [5]. The turbulence modelling approach used is the Organised Eddy Simulation - OES [9,10], sensitised for the coherent structures development. A database of morphing cases (Figure 2) is processed with Proper Orthogonal Decomposition (POD) and Long Short-Term Memory (LSTM) networks [7]. For each actuation setting, a snapshot matrix embedding both velocity and grid-deformation information is decomposed by POD into spatial modes and temporal coefficients. The LSTM learns the nonlinear temporal evolution of these coefficients, enabling accurate reproduction of unsteady turbulent features and mesh motion over extended prediction horizons at a fraction of the Hi-Fi cost (Figures 3-4). A parametric POD strategy extends the ROM across the actuation space to reconstruct unsteady flows at unseen parameters with minimal additional cost [8]. The parametric ROM is embedded within Particle Swarm Optimization (PSO) [6] to identify actuation configurations that optimize aerodynamic performance, enabling efficient, physics-consistent exploration of morphing-wing designs.

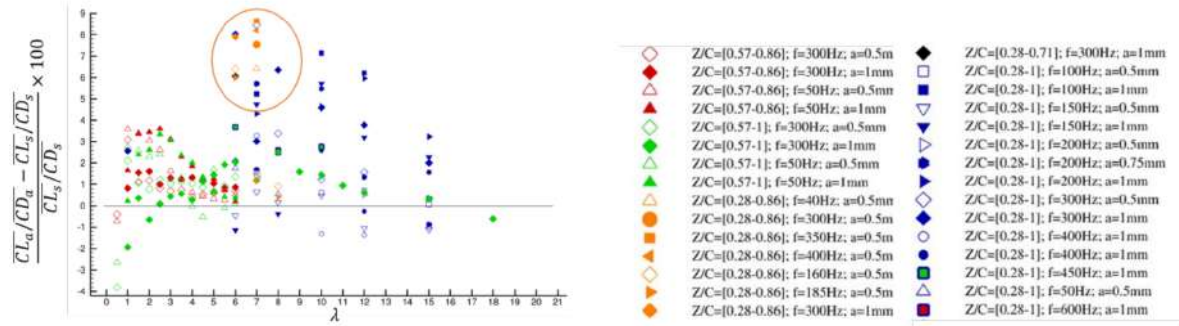


Figure 2: Relative variation of aerodynamic efficiency for different sets of travelling waves (TW) actuation parameters with respect to non-actuated case.

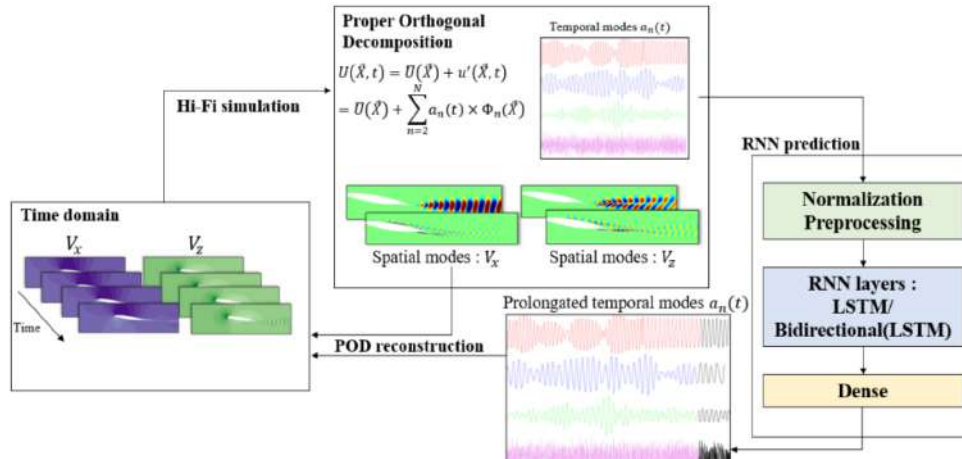


Figure 3: POD-LSTM time extrapolation flowchart.

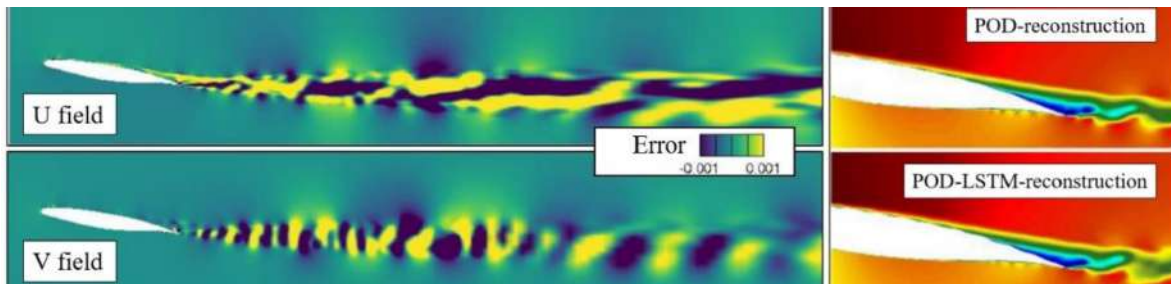


Figure 4: Comparison between classical POD reconstruction and POD-LSTM reconstruction on the prolonged time sequence. Error on the velocity field stays below 0.1%.

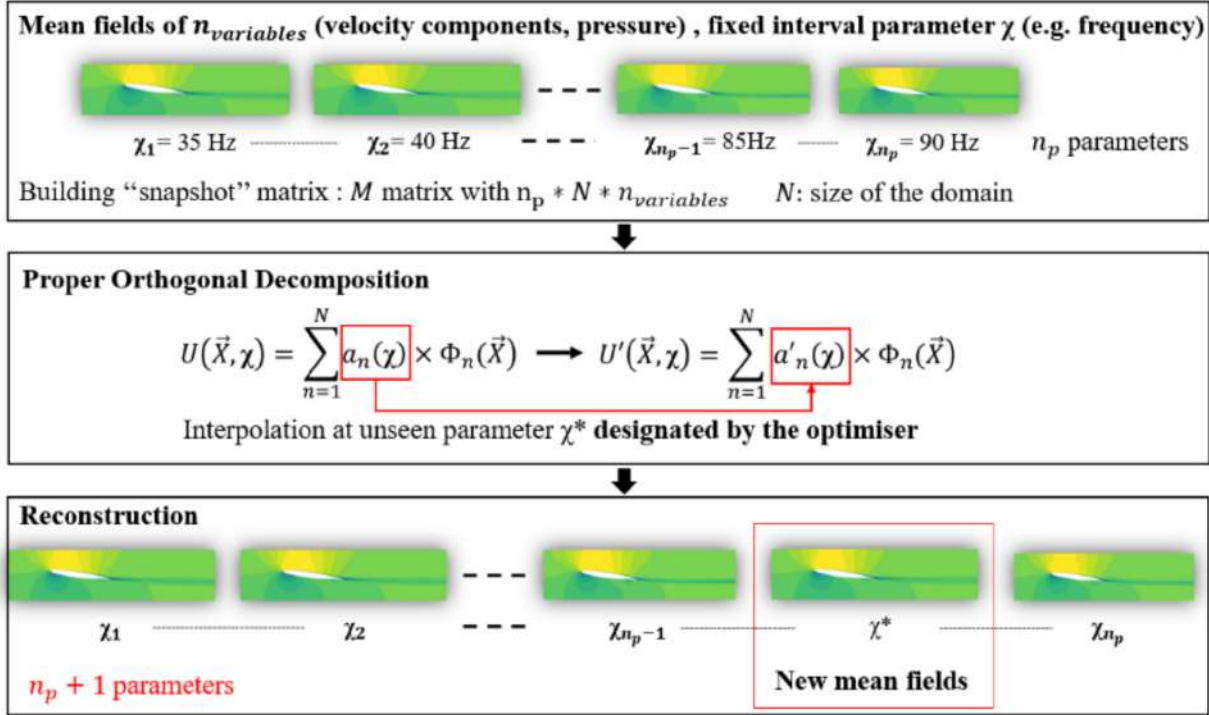


Figure 5: Flowchart of the parametric POD allowing prediction of a new unseen parametric case from a database of Hi-Fi simulations.

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Aerodynamic performance gains in transonic regime on an A320 morphing wing at Reynolds number of 4.5 million through numerical simulation

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Abstract

Key words: *Morphing, transonic regime, Travelling Waves, wing, turbulence, fluid-structure interaction*

A morphing wing prototype of an A320 wing, having a 70 cm chord length, an angle of incidence of 1.8° , an upstream Mach number of 0.78, and a Reynolds number of 4.5 million is examined through Hi-Fi numerical simulations (figure 1) as part of the HORIZON-2023-2027-PATHFINDER- Open Project N° 101129952-BEALIVE-"Bioinspired Electroactive multiscale Aeronautical Live skin", <http://horizon-europe-bealive.eu/>. This investigation focuses on testing different actuation zones located both upstream and downstream of the shock position to mitigate buffet effects (figure 2), using a Traveling Wave (TW) approach that model a "live-skin" surface in experiments. The deformation of the grid applied for the TW has been treated using the Arbitrary Lagrangian-Eulerian [1] method in the Navier-Stokes Multi Block CFD solver. The OES - Organised Eddy Simulation turbulence modelling approach [2, 3], able to capture the physical development of coherent structures and their interaction with the chaotic turbulence, has been employed.

This study highlights the significant feedback effect of the near-wake unsteadiness on the SBLI region and further upstream. The morphing manipulates the downstream unsteadiness, specifically attenuates the shear layer instability and the effect of the associated Kelvin-Helmholtz and von Kármán vortices (figures 1 and 3). A large parametric study has been performed in respect of wavelength (λ), vibration frequency (f), amplitude (a) and application zone [4]. Particular attention was paid to configurations where the actuation zone began upstream or overlapped the shock region (Figure 2) to directly influence the separation bubble under the shock foot and near-wake structures. A remarkable outcome of this study was the identification of an optimal configuration using $\lambda = 3$ and $\lambda = 6$ cm, $f = 750$ Hz and low amplitude of 0.3 mm in the green zone (from $x/c = 0.514$ to $x/c = 0.686$), which led for the first time in the state of the art to a **simultaneous lift increase and drag reduction** of (+0.85%) and (-2.3%), respectively and to an improved aerodynamic efficiency (Cl/Cd) of +2.65%, a 91.7% accompanied to a **practically total reduction in the lift rms** (from 0.06 to 0.005) due to mitigation of the transonic buffet, (Figure 4). These facts are obtained thanks to a downstream shift and weakening of the shock accompanied by a significant attenuation of the spectral energy in the wake, indicating reduced generation of trailing edge noise. Furthermore, pressure fluctuation spectra and wall C_p distributions confirm that the morphing concept alters both the steady and unsteady components of the transonic flow, stabilizing the wake and moving the shock towards more favorable aerodynamic positions.

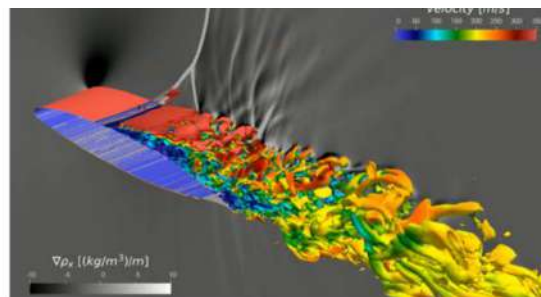


Figure 1: Turbulence structure around the A320 morphing wing: Q-criterion contours coloured with velocity magnitude and density gradients displayed at the symmetry plane shows the formation of Kelvin-Helmholtz (KH) vortices and the von Karman vortices during the buffet cycle together with chaotic turbulent vortices. The unsteadiness in the near wake region highly influences the upstream area. This 3D simulation clearly visualizes the development of the secondary instability (undulation of the vortex rows in the spanwise direction) and the appearance of secondary shocks at each crest of the 3D coherent vortices undulation streamwisely and spanwisely.



Figure 2: Left – Visualization of the maximum upstream and downstream positions of the shock wave in the static (non-actuated) case, located between $x/c = 0.66$ and $x/c = 0.72$. The green area (dashed vertical lines) corresponds to an optimal actuation zone indicated on the right. Right – Schematic representation of the various travelling wave (TW) actuation zones tested in the continuation study, covering regions upstream of the shock as well as zones that extend across and beyond the shock excursion envelope.

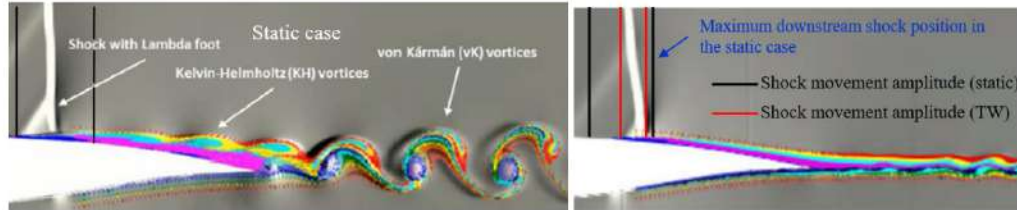


Figure 3: Left: Static case: The formation of Kelvin-Helmholtz (KH) and Von Kármán (VK) vortices results in a thick wake, causing upstream shock movement. Right: TW case, suppression of the shear layer instabilities, delaying and sweep of the VK vortices much farther downstream and reduction of the wake thickness, resulting in a significant reduction of shock amplitude: difference between red (morphing) and black (static) vertical lines.

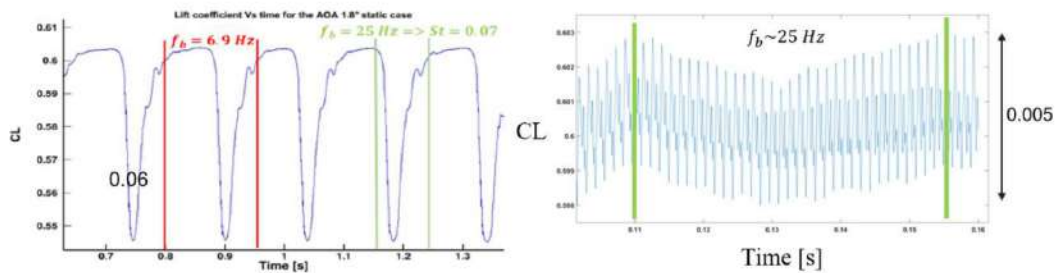


Figure 4: Left: Static case showing the lift coefficient with an amplitude of 0.06. Right: TW case, green area, $x/c \in (0.514-0.686)$ showing the lift coefficient with an amplitude of 0.005, demonstrating a significant reduction in the RMS.

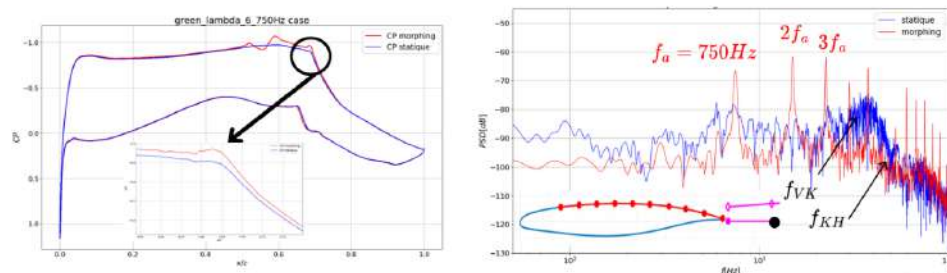
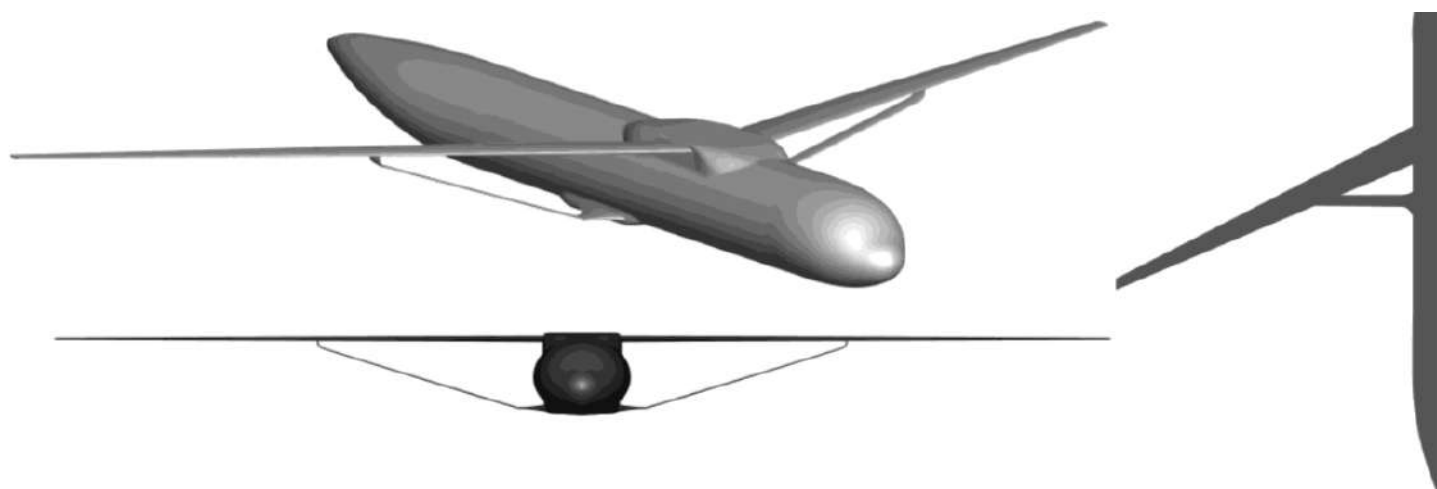


Figure 5: Left: averaged wall C_p distribution showing downstream shock displacement in the morphing case, associated with lift increase. Right: PSD of pressure fluctuations at a wake monitor point, showing reduced spectral energy in the morphing case, indicating lower wake perturbation and noise emission.

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