

IOCAE
2026
Conference

The 1st International Online Conference on Aerospace

16–17 April 2026 | Online



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The 1st International Online Conference on Aerospace

16–17 April 2026 | Online



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Welcome from the Chair

Welcome to IOCAE 2026!

It is my pleasure to invite you to the **1st International Online Conference on Aerospace (IOCAE 2026)**, which will be held virtually on **16–17 April 2026**. This inaugural event aims to bring together leading experts, researchers, and industry professionals to share the latest advances in aerospace science and technology.

IOCAE 2026 provides an interactive and inclusive platform for presenting innovative research, fostering interdisciplinary dialogue, and exploring emerging applications across the aerospace sector. Organised under the auspices of MDPI's journal **Aerospace**, the conference will offer contributors the opportunity to publish extended versions of their work in a dedicated Special Issue. The themes of the conference include the following:

S1: Next-Gen Aircraft Design & Optimization

- Aircraft Design and Optimization – Covering efficiency, lightweight materials, and sustainability.
- Aerostructures: Materials & Structures – Focusing on composites, smart materials, and additive manufacturing.
- Aerodynamics and Flight Mechanics – With trends like urban air mobility (UAM), hypersonics, and drag reduction.

S2: Sustainable Propulsion & Energy Systems

- Fuels & Energy Storage – SAFs, hydrogen propulsion, and hybrid-electric storage.
- Propulsion Technologies – Gas turbines, electric propulsion, and next-gen space propulsion.

S3: Space Systems & Exploration

- Spacecraft Design and Systems Engineering – Modularity, reusability, and miniaturization (CubeSats, SmallSats).
- Space Exploration & Mission Design – Human and robotic missions, ISRU, and long-duration sustainability.
- Space Environment and Space Debris Mitigation – Active debris removal and sustainable satellite design.

S4: Digitalization, Autonomy & Airspace Management

- Avionics and Autonomous Systems – AI-driven flight control, drone swarms, and autonomy in space.
- Air Traffic Management & Airports – AI-based ATC, UAM airspace integration, and sustainable airport infrastructure.

By hosting this conference online, we aim to break down geographical barriers and create a dynamic, global space for collaboration, knowledge exchange, and community building. We are particularly committed to encouraging the active involvement of early career researchers and young scientists as they engage with the forefront of aerospace innovation.

I warmly welcome your participation in this exciting event as we work together to shape the future of aerospace research and development.

Best regards,



Prof. Dr. Konstantinos Kontis
Conference Chair

School of Engineering, University
of Glasgow, Glasgow, Scotland,
UK



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Impact Factor: 2.2 (2024); 5-Year Impact Factor: 2.4 (2024)

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Department of Mechanical
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Istanbul, Turkey



Professor Karen A. Thole
Robert J. Vlasic Dean of
Engineering, University of
Michigan, Ann Arbor, MI, USA



Prof. Dr. George Z.H. Zhu
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Engineering, York University,
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Prof. Dr. Hyo-Sang Shin
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Prof. Dr. Vaios Lappas
Department of Aerospace
Science & Technology, National
& Kapodistrian University of
Athens, Greece; School of
Aerospace, Transport and
Manufacturing, Cranfield
University, Bedford, UK

Invited Speakers



Dr. Runze Li

Department of Aeronautics,
Imperial College London,
London, United Kingdom



Prof. Dr. Yan Xu

School of Electronic and
Information Engineering,
Beihang University, Beijing,
China

Program at a Glance

	Day 1	Day 2
Morning	Session 1. Next-Gen Aircraft Design & Optimization	Session 4. Digitalization, Autonomy & Airspace Management
Afternoon	Session 2. Sustainable Propulsion & Energy Systems	Session 3. Space Systems & Exploration Flash Poster Session

IOCAE 2026 Program

16 April 2026 (Thursday)

Session 1. Next-Gen Aircraft Design & Optimization

Time: 9:00 (CEST, Basel) | 03:00 (EDT, New York) | 15:00 (CST Asia, Beijing)

Time (CET)	Speaker	Title
9:00–9:10	<i>Welcome and Opening Remarks</i> <i>Prof. Dr. Konstantinos Kontis</i> <i>Event Chair</i>	
9:10–9:20	<i>Welcome by Session Chairs</i> <i>Prof. Dr. Norman Wereley and Dr. Yufei Zhang</i> <i>Session Chairs</i>	
9:20–9:40	Dr. Runze Li <i>Invited Speaker</i>	Bayesian Failure Prediction of a Novel Z-Beam Composite Wing under Gust Response
9:40–9:55	Peter L Bishay <i>Selected Speaker</i>	SMART Hawk: A Shape-Morphing Artificial Red-Tailed Hawk
9:55–10:10	Giorgio Filippoli <i>Selected Speaker</i>	Flight-Test-Based Analysis of Blowing Effects on Trimmed Aerodynamic Polars of a Distributed Electric Propulsion Aircraft Demonstrator
10:10–10:25	Alan Serena Moreno <i>Selected Speaker</i>	INDUSTRIAL APPLICATION OF PARAMETRIC CONCEPTUAL LOADS LOOP
10:25–10:40	Edmondo Minisci <i>Selected Speaker</i>	Interpretable Surrogate Modelling for Multirotor Design Exploration: Combining HDMR and Kolmogorov–Arnold Decomposition
10:40–10:55	Tim Luplow <i>Selected Speaker</i>	Numerical Analysis Framework for a Hybrid Electrothermal and Electromechanical De-Icing System for High-Lift Systems
10:55–11:10	Mulugeta Tilahun Bekele <i>Selected Speaker</i>	AI-Driven Aerospace Ecosystems: Next-Generation Aircraft Design, Sustainable Propulsion and Energy Systems, Intelligent Space Systems and Exploration, and Autonomous Airspace Management
11:10–11:25	PERIYASAMY C. <i>Selected Speaker</i>	DESIGN AND CFD BASED AERO-STRUCTURAL OPTIMIZATION STUDY OF BIOINSPIRED MORPHING SWEPT WING USING NACA 20612 SUPERCRITICALASYMMETRIC CAMBERED AIRFOIL FOR BOMBARDIER CRJ -900
11:25–11:40	Emmanouil Georgantakis <i>Selected Speaker</i>	Integrating Mission, Aerodynamic–Structural Sizing, and Additive Manufacturing Constraints in the Conceptual Design of a Modular UAV
11:40–11:55	Néstor Alcañiz Brull <i>Selected Speaker</i>	Analytical Prediction of Propeller Thrust for Tilt-Rotor Configurations with Wind Tunnel Validation
11:55–12:10	Martin Bartelt <i>Selected Speaker</i>	Electro-Impulse De-Icing of the Leading Edge of a Slat
12:10–14:00	Break	Break

Session 2. Sustainable Propulsion & Energy Systems

Time: 14:00 (CEST, Basel) | 8:00 (EDT, New York) | 20:00 (CST Asia, Beijing)

Time (CET)	Speaker	Title
14:00–14:10	<i>Welcome by Session Chair</i> <i>Prof. Dr. Stephen Whitmore</i> <i>Session Chair</i>	
14:10–14:40	Professor Karen A. Thole <i>Keynote Speaker</i>	Propulsion at the Forefront of Sustainable Development
14:40–15:10	Dr. Arif Karabeyoğlu <i>Keynote Speaker</i>	Hybrid Rockets as a Cost Effective Propulsion System Alternative for Dynamic Space Operations

15:10–15:25	Oleksandr Zaporozhets <i>Selected Speaker</i>	Multi-level Aircraft Design Modelling Including the Effects of Disruptive Propulsion Technologies on Environmental Impact
15:25–15:40	Carlos Ávila Catalán <i>Selected Speaker</i>	Balancing the Environmental Trade-off: Simultaneous Minimization of Carbon and Nitrogen Emissions in Novel Aero-Engine Cycles
15:40–15:55	Zhengxun Zhou <i>Selected Speaker</i>	Analysis of the Interaction Mechanisms between Rocket Exhaust Plume and Sea Surface in Maritime Launch Conditions
15:55–16:10	Subrata Sarkar <i>Selected Speaker</i>	Lifecycle Cost Analysis of Aircraft Systems: Unlocking Efficiency with Digital Twin Applications
16:10–16:25	Wagd Ajeeb <i>Selected Speaker</i>	Hydrogen Propulsion Technology for Decarbonizing Aircraft Transport: Environmental and Technical Analysis
16:25–16:40	Naveen Deshan Ranasinghe <i>Selected Speaker</i>	Optimization of a Two-Stage Rocket for Low Earth Orbit Reconnaissance Payloads: Toward Fuel-Efficient Launch Systems
16:40–16:55	Ryan Thibaudeau <i>Selected Speaker</i>	Technological Advancements of Hybrid Rocket Engines for Sustainable and Competitive In-Space Propulsion Applications

17 April 2026 (Friday)

Session 4. Digitalization, Autonomy & Airspace Management

Time: 9:00 (CEST, Basel) | 03:00 (EDT, New York) | 15:00 (CST Asia, Beijing)

Time (CET)	Speaker	Title
9:00–09:10	<i>Welcome by Session Chair Prof. Dr. Antonios Tsourdos Session Chair</i>	
9:10–9:40	Prof. Dr. Vaios Lappas <i>Keynote Speaker</i>	The ERMIS Nanosatellite Constellation: Advanced Satellite Communications and Earth Observation Technologies
9:40–10:10	Prof. Dr. Hyo-Sang Shin <i>Keynote Speaker</i>	TBA
10:10–10:30	Prof. Dr. Yan Xu <i>Invited Speaker</i>	Integrated Air-Ground Risk Assessment for Large-Scale Operations in Urban Air Mobility
10:30–10:45	Max Weigert <i>Selected Speaker</i>	State-Based Estimation of Future Mission Capability for Degrading Unmanned Aerial Vehicles
10:45–11:00	Cigdem Avci <i>Selected Speaker</i>	Cognitive Offloading: A Human-Centered Gap in Interface Design Standards
11:00–11:15	Yuvaraj George <i>Selected Speaker</i>	Geometric MPC for Robust UAV Flights using a 2-Manifold approach
11:15–11:30	Jobanpreet Singh Sohi <i>Selected Speaker</i>	A Compact Multi-Sensor System for Real-Time Micro-Debris Impact Detection in Nanosatellites
11:30–11:45	Edmondo Minisci <i>Selected Speaker</i>	Interpretable Machine Learning for Nonlinear Control via Kolmogorov–Arnold Decomposition
11:45–14:00	Break	Break

Session 3. Space Systems & Exploration

Time: 14:00 (CEST, Basel) | 08:00 (EDT, New York) | 20:00 (CST Asia, Beijing)

Time (CET)	Speaker	Title
14:00–14:10	<i>Welcome by Session Chair Prof. Dr. M. Reza Emami Session Chair</i>	
14:10–14:40	Prof. Dr. George Z.H Zhu <i>Keynote Speaker</i>	Collaborative Spacecraft Swarm for Space Debris Removal

14:40–14:55	Ryoji Imai <i>Selected Speaker</i>	Study on the development of a propellant tank that enables propellant refilling in microgravity (Verification of the gas–liquid separation mechanism during liquid filling through a short-term microgravity experiment)
14:55–15:10	Carlos INSAURRALDE <i>Selected Speaker</i>	Autonomous Modelling Analytics for Space Ground Vehicles with Multidisciplinary System Design Framework
15:10–15:25	Jose-Carlos Gamazo-Real <i>Selected Speaker</i>	Reliable and cost-effective design of the temperature conditioning module for a scientific LEO microsatellite
15:25–15:40	Daniele Marcora <i>Selected Speaker</i>	On the feasibility of a lighter-than-air platform for Martian exploration
15:40–15:55	Bedanand Mandal <i>Selected Speaker</i>	A Comprehensive Structural, Thermal, Solar, and Aerodynamic Analysis of a Mars Sub-surface Habitat
15:55–16:10	Luis Torres <i>Selected Speaker</i>	STAGED EXCAVATION FOR DUST PREVENTION IN LUNAR REGOLITH: DESIGN AND PRELIMINARY RESULTS
16:10–16:25	Jeremiah Gayle <i>Selected Speaker</i>	More FLOPS, less mass: enabling future AI missions in Space
Flash Poster Session		
16:25–16:30	Andrejs Kovalovs <i>Poster Presenter</i>	Numerical modeling and analysis of a helicopter rotor blade with an active twist concept
16:30–16:35	Riccardo Andrew Oggioni <i>Poster Presenter</i>	Wind Tunnel Investigation of Spoiler Effectiveness on a low Aspect-Ratio Swept Wing with reflex Airfoils
16:35–16:40	Adrian Winter <i>Poster Presenter</i>	Experimental Study of Cryogenic Fill-Level Sensors for Liquid Hydrogen Aircraft Applications
16:40–16:45	Sakshi Devi <i>Poster Presenter</i>	Discrete volume based thermal fluid and structural modelling for LH ₂ aircraft tanks
16:45–16:50	Ahmed Mahmoud <i>Poster Presenter</i>	Steady-State Modelling of a Dual Active Bridge Converter for Bidirectional Energy Flow in Space Electrical Power Systems
16:50–16:55	Yun Sang Tse <i>Poster Presenter</i>	Robust AI-Assisted HPC Borescope Inspection: Evaluating Stage-Level Decisions and Viewpoint Generalisation
16:55–17:00	Venu Jangam <i>Poster Presenter</i>	Aerodynamic and Structural Optimization of Additive Manufactured Rocket Fins (Lattice)
17:00–17:05	Kamila Niedźwiedź <i>Poster Presenter</i>	When Cyber Becomes Physical: Assessing the Impact of Space Cyberattacks on LEO Collision Risk

Session 1. Next-Gen Aircraft Design & Optimization

sciforum-162217: Additive Manufacturing of Smart Materials for Next-Generation Aerospace Structural Design and Engineering Application

Helal Uddin

Department of Mechanical Engineering, Hajee Mohammad Danesh Science and Technology University, Dinajpur-5200, Bangladesh

The future of aircraft engineering depends on high-performance, adaptable structural components that can respond independently to challenging operating circumstances. Additive manufacturing (AM) and stimuli-responsive materials, or 4D printing, may be used to create systems that are more dynamic than static structural design. The primary difficulty is the reliable integration of smart materials into high-performance structures, which requires strong multi-material bonding, enhanced thermal stability, and effective management to minimize high dynamic loads and modeling errors inherent in severe conditions. This paper evaluates the state-of-the-art AM methods and material science needed to manufacture actively controlled structural components, emphasizing high-temperature stability, interfacial integrity, and integrated computational design for aerospace applications. We investigate the enlarged working environments and functional applications of two essential material systems in AM systems: piezoelectric ceramics and high-temperature Shape Memory Alloys (SMAs). We also examine technical methods, such as interface geometry optimization, to overcome bonding problems in multi-material printers. High-performance piezoelectrics and new SMAs have effectively increased their working temperature capacities to around 400°C and 350°C, respectively. Prototypes utilizing these materials have successfully incorporated active control via H-infinity robust analysis, improving damage tolerance and engine life while achieving considerable vibration dampening on spinning engine components. In order to ensure longevity and functional stability in dynamic aerospace environments, strong geometric and computational design techniques must be applied in conjunction with the synthesis of AM using materials that are suitable for high temperatures.



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sciforum-163837: A systematic review of biomimetic principles inspired by biological flight applied to aircraft and UAV design

Maria Crina Isac

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Biomimetics has become an increasingly important approach in aerospace engineering, offering innovative design solutions inspired by the flight mechanisms of living organisms. Birds, insects, and bats demonstrate exceptional aerodynamic efficiency, maneuverability, and adaptability, which have motivated the development of bio-inspired aircraft and unmanned aerial vehicles (UAVs). This systematic review aims to synthesize and critically evaluate existing research on biomimetic principles derived from biological flight and their application to aircraft and UAV design. A systematic literature review was conducted following PRISMA guidelines, using major scientific databases to identify relevant peer-reviewed studies linking biological flight mechanisms with aerospace engineering applications. The selected studies were categorized according to biological sources of inspiration, including avian wing morphology and feather-based flow control, insect flapping-wing aerodynamics for micro-air vehicles, and bat-inspired flexible membrane wings. The results show that biomimetic approaches can significantly enhance aerodynamic performance, improve maneuverability, increase flight stability, and reduce energy consumption, particularly in UAV and small-scale aircraft applications. Despite these advantages, several challenges persist, such as material constraints, structural complexity, and difficulties in scaling biological mechanisms to full-size aircraft. This review highlights current trends and research gaps in biomimetic aerospace design and emphasizes the potential of biologically inspired flight principles to support the development of next-generation, efficient, and sustainable aircraft and UAV technologies.



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sciforum-169459: Real-Time Predictive Crack Growth Monitoring in Aircraft Aluminum Structures Using Smart Strain Gauge Networks

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Introduction: Structural health monitoring (SHM) in aeronautical components is challenged by the high cost, downtime, and limited real-time capability of conventional inspection methods such as ultrasonic testing or Eddy current evaluation. To address these limitations, this work proposes an innovative and scalable strain-based monitoring approach for crack propagation in aircraft-grade aluminum structures.

Methods: Aluminum 6082-T6 fuselage-representative specimens were experimentally tested under both static tensile loading and fatigue cycling. Samples included unnotched, notched, and pre-cracked configurations to replicate stress concentration effects typical of riveted aircraft panels. A network of six strategically positioned strain gauges was implemented to capture localized strain evolution during crack growth under cyclic loads of 3, 3.5, and 4 kN. Crack length estimations from strain signals were validated through periodic Eddy current inspections. Based on linear fracture mechanics principles, a novel mathematical formulation was developed to directly correlate strain ratios with crack length without requiring full load knowledge.

Results: The proposed predictive model demonstrated high reliability, achieving correlation coefficients above 0.97 between estimated and measured crack lengths across fatigue conditions. The method provided an average absolute error of 2.23 mm, enabling continuous crack sizing throughout propagation. Higher load levels significantly reduced fatigue life, confirming accelerated crack kinetics under increased stress amplitudes.

Conclusions: This study introduces a cost-effective, real-time SHM methodology integrating conventional strain gauge networks with predictive fracture modeling. The approach offers strong potential for deployment in critical fuselage regions between rivets, minimizing aircraft maintenance interruptions while enhancing operational safety and efficiency.



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sciforum-169650: Space Application of Austenitic Stainless Steels – DED Possibilities

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Introduction: With contemporary advancements in Additive Manufacturing (AM), it has become possible to obtain hull structures for spacecraft made of relatively cheap materials. The possibility of substituting super-austenitic stainless steel Avecta SMO 254 X1NiCrMoCuN20-18-7 (EN 10088) for the already used in the Starship SpaceX 304 L-Modified is focused on better thermal stability and durability in extreme conditions. The Directed Energy Deposition Arc (DED-Arc) method for AM has enabled the production of high-strength-to-weight ratios. The aim is to engage low-cost material with treatment optimization to provide greater corrosion resistance and high yield and tensile strength.

Method: For the DED-Arc, a filler wire was selected for the welding source, Fronius TPS 400i. A simulation via the RoboDK Robot Development Kit for the FANUC ARC Mate 100ID10L is provided. Additional shot pining/vibration treatment is proposed for the finished structure, which can be a substitute for the cold-worked initial metal. A comparison is made for stainless steel that has already been tested for space travel. Regimes for the manufacturing process are proposed, with representative samples of Avecta SMO 254 obtained and tested using microhardness measurements, microcracking detection, porosity measurements, interface zone assessment, and microstructural analysis.

Results: DED-Arc process applies to large-space shell manufacturing. A comparison is made with a focus on the mechanical and corrosion advantages. For Avecta SMO 254, microhardness measurements ranged from 235 to 246 HV1 and increased after treatment. The controlled parameters provided a maximum heat input of 0.7 KJ/mm, no defects, and a fine microstructure.

Conclusion: The successful use of stainless steel with AM increases the potential for multiple space missions. The advanced method shows high quality, allows cost saving,s and provides extended service life.

Funding: The author acknowledges support from project BG16RFPR002-1.014-0005.



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sciforum-169827: A Data-Driven Multidisciplinary Design Optimization Framework for Composite UAV Wing-Box Structures

Sadia Afrin Heera Monika ¹, Holyjith Paul Himel ^{2,*} and Toymor Wafi Opul ²

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Introduction

Lightweight composite wing structures play a critical role in improving the efficiency and performance of next-generation unmanned aerial vehicles (UAVs). Designing such structures requires a careful balance between structural strength, stiffness, and weight, resulting in a multidisciplinary design optimization (MDO) problem involving both material and structural parameters. Traditional finite element-based optimization approaches, while accurate, become computationally expensive when a large number of design variables are considered.

Methods

This study presents a data-driven MDO framework for the structural optimization of a composite wing-box of a mid-scale fixed-wing UAV. A Maximin Latin Hypercube Sampling (MLHS) scheme is used to generate a uniformly distributed set of design configurations across a high-dimensional design space. A detailed three-dimensional wing-box model consist of upper and lower skins, front and rear spars, and ribs is developed and analyzed under limit and ultimate loading conditions using linear static finite element analysis (FEA). The design variables include skin and spar thicknesses, number of ribs, ply orientation, ply thickness, and hybrid composite material configurations based on CFRP and GFRP. Supervised machine learning models, including Artificial Neural Networks, Random Forest, and XGBoost, are trained as surrogate predictors, and a stacking ensemble approach is applied to improve prediction accuracy. SHAP analysis is done to interpret the influence of individual design variables.

Results

The surrogate models accurately predict key structural responses such as maximum deflection, Tsai-Wu failure index, factor of safety, and structural weight. The surrogate models optimization significantly reduces computational cost while enabling efficient weight minimization under strength and stiffness constraints.

Conclusions

The proposed framework provides an efficient and interpretable approach for early-stage optimization of composite UAV wing structures and offers strong potential for extension to more comprehensive multidisciplinary aircraft design studies.



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sciforum-169529: A unified design methodology for unmanned airships: from preliminary sizing to flying qualities

Carlo E.D. Riboldi * and Luca Alessi

Department of Aerospace Science and Technology, Politecnico di Milano

Among the most versatile lighter-than-air platforms, unmanned airships are currently being designed mostly for either low-altitude missions for close-distance surveillance, in competition with multi-copter drones, or for high-altitude missions in the stratospheric layer, thus ideally complementing the role of space satellites. Correspondingly, algorithms to automatically compute global values like the volume and mass of an airship, for a desired mission performance and for assumed technologies of the components (like the materials employed for the envelope or the construction of the gondola), have been experimented with and are already documented in the literature.

Building on this base, this research proposes a method where not just the parameters mostly typical to preliminary design are solved, but a unified automatic approach is employed for taking into account requirements on static balance as well as dynamic performance. This modular method links three original tools, developed in-house respectively for preliminary sizing, lofting and inertial modeling, and dynamic analysis. The synergistic use of the first two allows the simultaneous computation of not just the weight and volume of the machine for a specific mission, but also a detailed static balance problem, by suitably arranging the masses of the components onboard. The last module further tweaks the positioning of selected components to obtain better flying qualities. The latter are measured by means of damping and the characteristic time of specific eigenmodes of the system, in turn obtained after drawing a linearized model of airship dynamics from a fully non-linear one.

The outcome of the overall unified sizing procedure, numerically configured as an automatically solved optimal problem, accounts not just for the requirements of the mission profile, but also potentially for static balance and for a desired level of flying qualities. The full procedure is demonstrated on the data of an existing small-scale airship prototype.



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sciforum-169763: Aerodynamic and Structural Optimization of Additive Manufactured Rocket Fins (Lattice)

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In modern aerospace engineering, the two major factors that define mission success are larger payload capacity and fuel efficiency. This can be gained by reducing the structural weight of the rocket fins. The need for ultralight yet structurally sound components has increased as launch systems move toward greater speed regimes. In this endeavor, Additive Manufacturing (AM) has become a crucial facilitator, enabling the creation of complex lattice structures with remarkable stiffness-to-weight ratios. However, these structures offer specific multi-physics design problems, including structural mechanics, high-speed aerodynamics, and manufacturing viability.

The review systematically examines the optimization of AM lattice fins under extreme aerodynamic and thermal environments. It compares Truss Topology Optimization (TTO) with density-based topology optimization, emphasizing that although TTO yields superior ultra light designs, it frequently lacks precise formulations to guarantee kinematic compatibility in indeterminate frames. The research also emphasizes the importance of Fluid-Thermal-Structure Interaction (FTSI), pointing out that deflection and stability estimates might differ significantly if thermal softening effects at supersonic and hypersonic speeds are ignored.

Manufacturing limitations are also discussed, which reveals that despite being simpler to construct, modular lattice layouts may result in mass penalties when compared to monolithic topologies. The research presents a unified Design for Additive Manufacturing (DfAM) framework that integrates TTO with temperature-dependent material degradation models, explicit buckling limitations, and aeroelastic tailoring approaches to overcome these trade-offs. This all-encompassing strategy aims to create high-performance, manufacturable lattice fins that can endure coupled aerodynamic and thermal stresses without sacrificing weight economy. In the end, this research offers a roadmap toward next-generation lightweight fin topologies that strike a balance between structural integrity, aerodynamic performance, and manufacturability, opening the door for rockets that can go faster, further, and more effectively.



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sciforum-164838: AI-Driven Aerospace Ecosystems: Next-Generation Aircraft Design, Sustainable Propulsion and Energy Systems, Intelligent Space Systems and Exploration, and Autonomous Airspace Management

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The aerospace sector is undergoing a profound transformation driven by the convergence of artificial intelligence (AI), machine learning (ML), distributed computing, geospatial intelligence, and advanced communication technologies. This research proposes an integrated framework for **AI-driven aerospace ecosystems** that unifies next-generation aircraft design, sustainable propulsion and energy systems, intelligent space systems and exploration, and autonomous airspace management into a coherent, data-centric paradigm. The study advances AI-enabled design optimization methodologies that combine physics-informed machine learning and multi-objective optimization to improve aerodynamic efficiency, structural integrity, and sustainability in future aircraft platforms.

In the domain of propulsion and energy, the research investigates AI-based predictive control and health monitoring models for hybrid-electric, hydrogen, and sustainable aviation fuel systems, enabling enhanced efficiency, reliability, and lifecycle management. For space systems, the framework introduces intelligent, distributed architectures for spacecraft autonomy, mission planning, and space situational awareness, supporting modular, reusable, and resilient exploration missions, including small satellite constellations and long-duration operations.

Autonomous airspace management is addressed through geospatially aware AI models that integrate real-time sensing, communication networks, and distributed decision-making to enable safe, scalable coordination of manned aircraft, unmanned aerial systems, and urban air mobility operations. Edge-cloud distributed computing and resilient communication infrastructures are leveraged to ensure low-latency control, robustness, and cybersecurity across air and space domains.

By synthesizing these technological dimensions, the research contributes a holistic ecosystem-level approach that transcends traditional subsystem boundaries in aerospace engineering. The proposed framework aims to enhance sustainability, autonomy, safety, and operational efficiency, providing a foundation for future intelligent aerospace systems capable of operating seamlessly across aircraft, space platforms, and complex airspace environments.



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sciforum-169360: Analytical Prediction of Propeller Thrust for Tilt-Rotor Configurations with Wind Tunnel Validation

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Future projections indicate that continued population growth will lead to further expansion and densification of urban environments, thereby increasing transportation demands and associated challenges. In this context, Urban Air Mobility (UAM) has emerged as a promising solution, enabling new intra- and inter-urban transportation services through the use of Vertical Take-Off and Landing (VTOL) aircraft, more precisely configurations such as lift and cruise tiltrotors which combine the hovering capability of conventional helicopters with the cruise speed and range of fixed-wing aircraft by means of tilting propulsion mechanisms. Optimizing the aircraft design process is essential to reduce overall development time and cost. During the conceptual design phase, propeller design methodologies commonly reported in the literature rely on vortex-based approaches or actuator disk theory to estimate the main propeller characteristics. However, the accuracy of these methods strongly depends on the inflow angle and operating conditions, with discrepancies increasing as the inflow angle and advance ratio grow. This paper introduces an analytical model to predict propeller thrust at a 90° inflow angle (pure lateral flow), based on a correction of the thrust under perpendicular flow conditions and the propeller geometry evaluated at 75% span. The approach relies on local velocity and angle of attack estimations derived from classical Blade Element Momentum Theory (BEMT). The propeller lift coefficient is obtained by representing the blades as thin airfoils, with an additional correction to account for stall effects at high angles of attack, while the drag coefficient is calculated based on the known thrust values. The induced velocity, required for local flow calculations, is estimated from known thrust values and discretizing the propeller disk according to the number of blades. This capability is particularly relevant for modeling lift and cruise tilt rotor configurations cruise phase during early design stages while maintaining minimal computational cost. The proposed model is validated against wind tunnel measurements for several propellers tested at different global pitch angles, demonstrating the applicability of the developed formulation for blades with twist angles up to 16° .



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sciforum-169561: Biomimetic Surface Modification of Compressor Stator Blades to Improve Turbulent Flow Characteristics

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Axial compressors are critical components of gas turbine engines and play a major role in determining overall engine efficiency and combustion performance. Enhancing turbulence at the compressor outlet can significantly improve air-fuel mixing in the combustion chamber. This study investigates a biomimetic surface modification inspired by the natural structure of palm tree leaves applied to the stator blade of the final stage of an axial compressor. The GE-J85 jet engine is selected as the reference configuration and the stator blade profile is based on the NACA 65410 aerofoil.

A palm leaf-inspired riblet pattern is introduced on the stator blade's surface to induce controlled flow disturbances. The pattern is designed with a 45° inclination and a riblet length of 1 mm distributed across the blade surface. The three-dimensional blade geometry is developed using CATIA V5 R20, and numerical analysis is performed using ANSYS under subsonic flow conditions. The aerodynamic and turbulence characteristics of the biomimetic stator blade are compared with those of a conventional smooth stator blade.

The computational results demonstrate a significant enhancement in turbulence parameters for the biomimetic configuration. The turbulent kinetic energy of the modified stator blade increases by approximately **29.5%** compared to the baseline design. This increase is indicative of improved flow-mixing capability at the compressor exit. The findings suggest that biomimetic palm leaf surface patterns can be effectively applied to axial compressor stator blades to enhance turbulence and potentially improve combustion efficiency in gas turbine engines. This study highlights the potential of nature-inspired design approaches for advanced aerospace propulsion systems.



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sciforum-165777: Conceptual Design and Finite Element Validation of Alpha-11 Wing: Mesh Convergence, Structural Performance and Material Trade-offs

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This paper presents the conceptual design and finite element validation of the Alpha-11 regional turboprop wing, with a specific focus on identifying the most structurally efficient material configuration. The wing features a high aspect ratio, a tapered, moderately swept planform tailored to a 70–80-seat twin turboprop mission, and a three-dimensional finite element model is developed and evaluated under critical 2.5 g limit load cases dominated by bending and combined bending-torsion. A systematic mesh convergence study using successive refinements demonstrates solution independence, with changes in maximum von Mises stress and tip deflection below 5% between the final mesh levels. Using the converged model, a material trade-off is performed between an aluminium 2024-T4, Al 6061-T6, Al 7075-T6, and a carbon/epoxy unidirectional composite wing of identical external geometry. The results show that aluminium 2024-T4 carries the design load, with a peak von Mises stress of about 17 MPa, a factor of safety of roughly 18, and a tip deflection of order 105 mm, offering adequate stiffness and a large stress margin at low material and manufacturing cost. In contrast, the composite wing roughly halves tip deflection and provides much higher stress margins, but at a substantially higher material and fabrication cost typical of carbon-epoxy aerostructures. The study therefore identifies aluminium 2024-T4 as the most suitable material for the Alpha-11 conceptual design. At the same time, the composite configuration serves as a high-stiffness benchmark that quantifies the structural benefits sacrificed to achieve a cost-effective regional aircraft wing. The paper makes a combined study using a rigorous mesh convergence-driven validation framework with a quantified aluminium–composite trade study at the conceptual stage, demonstrating that a high aspect ratio aluminium wing can deliver superior structural designs while remaining compatible with the performance envelope of existing regional turboprop competitors like ATR 72-600, Dash-8 Q400, and MA700.



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sciforum-169609: Conceptual Design and Initial Sizing of a Tiltrotor Aircraft: A Comprehensive Analytical Approach

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This paper demonstrates a comprehensive analytical approach for initial sizing in the conceptual design of a tiltrotor aircraft. The objective is to incorporate vertical takeoff and landing (VTOL) capability with efficient fixed-wing cruise to achieve high operational flexibility, rapid deployment, and extended mission range. Owing to the hybrid nature of tiltrotor configurations, neither conventional fixed-wing nor rotorcraft design methodologies alone are sufficient; therefore, a unified preliminary design framework is developed by combining elements of both approaches. A representative mission profile for troop transport and search-and-rescue operations is established. Aircraft sizing is performed using a mission-segment fuel fraction analysis that integrates Breguet range and endurance relations for fixed-wing cruise with a known-time fuel burn equation for VTOL, hover, and transition phases. Independent takeoff weight estimations are obtained for both mission types, and the governing maximum takeoff weight is selected for design convergence. The analysis yields a maximum takeoff weight of approximately 59,723.55 lb, governed by the troop transport mission. The resulting configuration achieves an estimated maximum lift-to-drag ratio of 12.3. Additionally, it has a wing loading of 79.5 lb/ft² and a power-to-weight ratio of 0.23 hp/lb. The required installed power is calculated to be 6,987 hp, leading to the selection of the Rolls-Royce T406/AE 1107F turboshaft engine, with a power output of 7,000 hp that satisfies performance requirements while maintaining adequate design margins. The final layout features a high-mounted straight wing utilizing a NACA 23015 airfoil and a conventional empennage with symmetric airfoil sections. This provides a robust quantitative foundation for upcoming aerodynamic, structural, and system-level optimization efforts.



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sciforum-166237: Conceptual Design and Preliminary Analysis of Carrier-Borne Fighter Aircraft

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Modern carrier-based fighter aircraft must reconcile conflicting design requirements such as high supersonic performance, low-speed carrier operations, and efficient cruise. This paper presents a comprehensive conceptual design study of a carrier-borne fighter aircraft intended for naval operations. The design framework integrates mission-segment weight analysis, propulsion matching, aerodynamic sizing, and geometric layout. The aircraft was dimensioned to meet specified performance targets, including Mach 2.0 maximum speed, 2,000 km combat range, 4-hour endurance, and 6,000 kg maximum payload. Design constraints included catapult acceleration (250 m take-off distance) and arrested recovery systems (200 m landing distance). Wing design analysis compared multiple constraints (stall-limited, catapult-limited, landing-distance-limited, and cruise-optimised), resulting in catapult-limited loading selection. Tail sizing employed standard volume coefficients to ensure adequate control authority and stability margins. Sizing analysis yielded maximum take-off weight (MTOW) of 34,858 kg, thrust-to-weight ratio (T/W) of 0.987, and wing loading of 394.3 kg/m². The aircraft features a swept-wing design (50° leading-edge sweep, aspect ratio 3.52) with twin vertical stabilisers for directional stability, powered by two Pratt & Whitney F135 engines. Fuel analysis indicates approximately 25.44% of MTOW allocated for all mission segments. A complete three-dimensional SolidWorks CAD model was developed, integrating all calculated geometric parameters. This work demonstrates a comprehensive application of preliminary aircraft design methodology to naval fighter design. The sizing analysis validates the design approach and establishes a complete preliminary design baseline ready for detailed engineering phases.



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sciforum-166154: Design and CFD Based Aero-Structural Optimization Study of Bioinspired Morphing Swept Wing Using NACA 20612 Supercritical asymmetric Cambered Airfoil for Bombardier CRJ -900

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This research investigates the Design and CFD-based aero-structural optimization study of Bioinspired morphing swept wing using NACA 20612 supercritical asymmetric cambered airfoil for the Bombardier CRJ-900 morphing as a transformative approach to enhance aerodynamic efficiency, structural performance, and flight adaptability in modern aviation. Traditional fixed-wing designs impose limitations on lift-to-drag ratio optimization, maneuverability, and mission-specific performance. To address these challenges, the study proposes a morphing wing system that integrates compliant structures, smart materials, and distributed actuation, enabling continuous real-time modification of key geometric parameters such as camber, twist, and span.

The system allows the wing to dynamically adapt to varying flight regimes, including takeoff, cruise, and maneuvering conditions, thereby achieving improved aerodynamic efficiency and reduced structural loads. Comprehensive computational fluid dynamics (CFDs) simulations and finite element analysis (FEA) were conducted to evaluate the aerodynamic and structural behavior of the morphing wing across multiple configurations. Results indicate a significant reduction in drag and optimized lift distribution, leading to enhanced fuel efficiency and extended operational range. Additionally, structural analyses confirm that the adaptive wing maintains sufficient stiffness and load-bearing capacity while accommodating shape transformations, minimizing the risk of aeroelastic instabilities. The research further explores actuation strategies using lightweight smart materials, including shape memory alloys and piezoelectric composites, coupled with distributed sensors to enable real-time feedback control for precise shape reconfiguration. Integration of these technologies demonstrates the feasibility of mission-adaptive wings capable of responding autonomously to environmental variations, turbulence, and changing aerodynamic demands. By merging aerodynamic optimization with structural resilience, the proposed morphing wing concept presents a sustainable solution for next-generation aviation, reducing carbon emissions and operational costs while increasing overall aircraft performance. The findings support future developments in lightweight, efficient, and environmentally responsible aircraft architectures that can adapt dynamically to diverse mission profiles.



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sciforum-164075: Design and Development of a Ground-Based Test Bed for Performance Evaluation of VTOL UAVs

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Unmanned Aerial Vehicles (UAVs) with Vertical Take-Off and Landing (VTOL) capability have gained significant importance due to their operational flexibility, compact deployment, and suitability for diverse applications. However, experimental validation of VTOL UAV performance through flight testing is often associated with high cost, safety risks, and limited repeatability. To address these challenges, this work presents the design and fabrication of a ground-based test bed for systematic performance evaluation of VTOL UAVs under controlled conditions.

The proposed test bed comprises a rigid modular aluminum frame integrated with a universal joint mechanism that permits controlled roll and pitch motion while constraining translational movement. The system is equipped with load cells for thrust and force measurement, a Bosch BNO055 nine-degree-of-freedom inertial measurement unit (IMU) for real-time attitude estimation, accelerometers for vibration analysis, and an anemometer to monitor airflow characteristics. Data acquisition and visualization are implemented using MATLAB and Python-based simulations developed in Visual Studio Code, enabling real-time monitoring of Euler angles, accelerations, and orientation dynamics.

Static structural analysis of the universal joint confirms that stress and deformation levels remain within permissible limits, ensuring structural safety and reliability. The experimental results demonstrate that the developed test bed effectively replicates key dynamic behaviors of VTOL UAVs without the risks associated with free-flight testing. The proposed system provides a low-cost, repeatable, and safe platform for UAV performance evaluation, control algorithm validation, and aeronautical engineering education.



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sciforum-169806: Design of Supersonic Aircraft Flaps with Advanced Materials and Thermo-Adaptive Mechanisms

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This paper outlines the design and performance analysis of a composite sandwich flap for high-temperature applications, which is intended for use in advanced aerospace platforms. The composite sandwich flap has been designed as a multi-layer sandwich composite, which is capable of providing the required performance against the combined effects of aerodynamic, high-temperature, and structural loading conditions, which are encountered at high-speed flight profiles. A novel thermo-adaptive composite sandwich flap has been proposed, which comprises an IM7/BMI outer skin, an IM7/PEKK inner skin, and a titanium carbide (TiC) honeycomb core material. The proposed composite sandwich flap has been validated by aero-thermal simulations at Mach 2.2 and has resulted in a specific stiffness of 56.4 MJ/kg, which enables a 12.5% mass reduction compared to conventional titanium-based materials while maintaining a factor of safety of 1.6. The composite flap has effectively eliminated chordwise bowing by reducing it to 0.85 mm, thereby preventing the occurrence of premature flow separation. This has resulted in the aircraft maintaining its lift distribution, thereby enhancing its performance by 4.8% in the form of an improved L/D ratio of 4.25, which is a measure of efficiency. The results indicate that the advanced composite flap has provided the required aeroelastic integrity for relaxed stability aircraft at supersonic flight speeds.



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sciforum-168568: Design-Oriented Assessment of Composite Aircraft Panels under Multiple Loading Conditions

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Composite aircraft panels play a critical role in the structural efficiency of modern airframes, particularly during early design stages where laminate selection decisions have long-term implications. While stiffness requirements are typically evaluated under individual load cases, aircraft panels are in practice subjected to combined mechanical and thermal loads, making single-load assessments insufficient for informed structural design decisions.

In this work, a design-oriented numerical study is presented to evaluate the stiffness response of a flat composite aircraft panel under multiple representative loading conditions, including in-plane compression, transverse pressure and uniform thermal loading. A set of symmetric laminate layups commonly employed in aerospace structures is examined using finite element analysis (FEA). For each load case, displacement-based stiffness metrics are formulated using normalized reference quantities, enabling consistent comparison between different layup configurations independently of the applied load magnitudes.

The individual stiffness responses are subsequently combined within a multi-objective framework to identify trade-offs between competing structural requirements. Pareto fronts are constructed to highlight laminate configurations that offer balanced stiffness performance across multiple loading scenarios, supporting rational layup selection from an aircraft structural design perspective. The results indicate that laminate designs optimised for a dominant load case may exhibit unfavourable behaviour when assessed under combined loading, underscoring the importance of multi-load considerations at the preliminary design stage.

The proposed approach provides a transparent and computationally efficient methodology for comparative assessment of composite aircraft panels and is well-suited for early structural design studies. The framework can be readily extended to more complex configurations, such as stiffened panels or coupled buckling analyses, in future work.



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sciforum-163046: Electro-Impulse De-Icing of the Leading Edge of a Slat

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Leading-edge slats play a critical role in aircraft lift generation. However, their mobility and comparatively small dimensions make the integration of efficient de-icing systems particularly challenging. This study presents an integration concept for an electro-impulse de-icing system based on copper coils. The coils generate an inductive pulse that produces a localized deflection of the outer skin and initiates a wave propagating in both the spanwise and chordwise directions. The resulting shear stresses at the ice-skin interface cause the ice to detach.

The system is first implemented in a simplified demonstrator featuring constant curvature and good accessibility. Initial test campaigns focus on optimizing key parameters such as doubler thickness, capacitor voltage, and coil spacing. A high-speed digital image correlation system is employed to analyze the spatial propagation of the induced wave. Additionally, a limited fatigue test is conducted to assess the system's operational reliability.

In the subsequent phase, the electro-impulse de-icing system is integrated into a scaled slat. To ensure optimal pulse transmission, the copper coils are shaped to match the wing contour. De-icing tests are performed using the recommended values for liquid water content (LWC) and droplet diameter (MVD) specified in NACA Technical Report 1855. The results show extensive de-icing along the leading-edge region. The de-iced surface areas are weighted according to their contribution to the lift distribution to evaluate the effectiveness of different de-icing scenarios.

The findings demonstrate that the proposed electro-impulse de-icing system is highly effective and operates significantly more efficiently than conventional electrothermal or bleed-air de-icing systems.



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sciforum-163805: Experimental and Numerical Investigation of Hail-Ice Impact on Carbon Fibre Composite Laminates

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Hail impact poses a critical threat to the structural integrity of aircraft composite skins, with its severity influenced by changing climatic conditions and increasing aircraft operating speeds. In this study, a combined experimental and numerical investigation is undertaken to examine the impact response of Carbon Fibre-Reinforced Polymer (CFRP) laminates subjected to hail-ice impact, with the objective of improving the understanding of damage behaviour in aerospace composite structures. Symmetric CFRP laminates of approximately 3 mm in thickness, representative of typical aircraft skin configurations, are considered for the investigation. Controlled hail-ice impact tests are conducted at a specified impact velocity to simulate realistic hail strike conditions, and repeated impact events are considered to evaluate the influence of cumulative damage.

Post-impact damage assessment is carried out using ultrasonic C-scan inspection and optical microscopy to identify internal damage modes such as delamination, matrix cracking, and fibre failure. In parallel, numerical simulations are performed using the explicit finite element solver LS-DYNA to replicate the experimental impact conditions. The numerical model enables the evaluation of deformation behaviour, stress distribution, and energy transfer during the impact event, thereby providing insight into the progressive damage mechanisms of the CFRP laminate. The combined experimental and numerical framework presented in this work aims to support the development of improved composite layup designs and validated predictive methodologies for assessing hail impact tolerance in future aircraft applications.



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sciforum-164415: Experimental Evaluation of a Composite Sandwich Panel for Aircraft Landing Gear Doors

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Aircraft landing gear doors serve as lightweight auxiliary structures and are exposed to bending loads, localized compressive stresses, and occasional accidental impacts during their service life. Sandwich composite structures consisting of carbon-fiber reinforced polymer (CFRP) face sheets and a honeycomb core have become a preferred solution for such applications due to their high weight efficiency, corrosion resistance, and adaptable design characteristics. However, these structures may still develop internal damage mechanisms—such as delamination, honeycomb cell collapse, and skin-core debonding—that often remain undetected and create challenges for certification and durability evaluation.

In this study, a CFRP-honeycomb sandwich panel designed for landing gear door applications was fabricated and experimentally investigated. Mechanical characterization involved low-velocity drop-weight impact testing, three-point bending, and flatwise compression to represent realistic operational loading conditions. Microstructural examination using Scanning Electron Microscopy (SEM) was carried out to analyze damage progression, including matrix cracking, fiber fracture, adhesive degradation, and honeycomb cell wall deformation.

The results show that impact loading mainly produces subsurface delamination and surface indentation, flexural loading promotes core shear failure and face-sheet instability, and compressive loading leads to progressive collapse and densification of the honeycomb core. Overall, the experimental findings provide insight into failure evolution and mechanical response, supporting improved design considerations, inspection strategies, and damage-tolerance assessment for aerospace-grade sandwich composite structures.



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sciforum-168939: Flight-Test-Based Analysis of Blowing Effects on Trimmed Aerodynamic Polars of a Distributed Electric Propulsion Aircraft Demonstrator

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Distributed Electric Propulsion (DEP) enables novel aero-propulsive interactions by exploiting propeller slipstream effects to modify the aerodynamic characteristics of lifting surfaces. Several numerical and wind-tunnel investigations have demonstrated the potential of distributed blowing for improving lift capability and aerodynamic efficiency in DEP aircraft configurations. However, experimental flight-test evidence at the full-aircraft scale remains limited. This work presents an experimental investigation of the trimmed aerodynamic characteristics of a DEP flying demonstrator, with specific focus on the impact of propeller-induced blowing on lift, drag, and overall aerodynamic efficiency.

The study is based on flight-test data collected during multiple automated maneuvers and processed through a dedicated identification framework that reconstructs aerodynamic coefficients from locally identified stability and control models. Trimmed lift and drag coefficients are evaluated for each maneuver and used to build $CL-\alpha$, $CD-\alpha$ and trimmed aerodynamic polar $CL-CD$ relationships. The dataset is clustered according to the propeller advance ratio at trim, adopted as a proxy for the intensity of distributed blowing, and second-order analytical fits are employed to highlight global trends across the explored operating conditions.

The results show a clear and consistent influence of distributed blowing on the aerodynamic characteristics of the aircraft. Increasing blowing intensity produces an upward shift and a steeper slope of the lift curve, a mild reduction in trimmed drag, and a noticeable improvement of the trimmed aerodynamic polar. These combined effects lead to a significant increase in aerodynamic efficiency over the investigated flight envelope.

Despite the inherent scatter of experimental flight data, the observed trends are robust and consistent with physical expectations and previous numerical findings. The present work provides original flight-test evidence of the aerodynamic benefits of distributed propulsion at the aircraft level and supports the potential of DEP configurations for low-speed and high-lift flight conditions.



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sciforum-163580: Impact-Induced Fracture in Additively Manufactured AlSi10Mg Using a Fractal Approach

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In recent years, additively manufactured AlSi10Mg has received widespread attention for its use as an aerospace-grade material. It can be used in engine components, structural parts, and tooling and ground support equipment. During operation, the materials experience impact-induced fracture due to foreign object damage and dynamic or shock loading. The fracture behavior of these functional components under dynamic loading is critical to their structural reliability. However, it remains challenging to quantify fracture structure due to the complex, process-inherent anisotropy and defect distributions in the materials produced using this manufacturing technique. In this investigation, a laser powder bed fusion-based additive manufacturing technique is used to prepare aluminum samples at different building orientations. The aluminum AlSi10Mg samples were fabricated in two build orientations: 0° and 90° with a global energy density of 37.1 J/mm³. The impact fracture was produced by a pendulum strike using a Charpy impact tester. The fractured surface of the samples was analyzed using a digital microscope. We used a box counting method to evaluate the fractal dimensions of the fractured surface of the samples. Profile data were developed using a 3D digital microscope. The data were analyzed for three different regions: compression, neutral, and tension zones during crack propagation. The results showed that the fractal dimension is influenced by the materials' build orientations. The three zones on the fractured surface showed significant dependence on manufacturing design during crack propagation.



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sciforum-163597: Industrial Application of Parametric Conceptual Loads Loop

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In the scope of the Clean Aviation (CA) Strategic Research and Innovation Agenda (SRIA), Airbus Defence and Space (ADS) participates in the development of technologies for the future Ultra-Efficient Regional Aircraft (UERA) and Hybrid Electric Regional Architecture (HERA) UCB. In particular, it is anticipated that higher-efficiency aircraft concepts such as UERA and UCB will have higher aspect ratio wings, more flexible structures and, in general, higher aeroelastic phenomena, influencing concept design and production. To evaluate these novel features of future aircraft, it is necessary to adopt new conceptual loads and aeroelastics methods and tools.

In early design and feasibility studies of conventional aircraft, semiempirical methods based on similar aircraft can usually be used to estimate critical load magnitudes. However, as new designs differ considerably from existing aircraft, model-based analysis is required from the early design stages. In this paper, the UCB conceptual loads model is presented as a parametric conceptual loads loop, where early design in the CA HERFUSE project has benefited from a full flight and ground conceptual loads database. In addition, the different methods and approaches followed for model property estimation will be reviewed.

In summary, this parametric definition of the loads model contributes to next-generation aircraft design by giving quick conclusions for different trade-off scenarios in geometry, mass, and structural properties. This allows us to reduce uncertainty in early design stages and to evaluate different configurations in an agile manner.



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sciforum-163804: Integrating Mission, Aerodynamic–Structural Sizing, and Additive Manufacturing Constraints in the Conceptual Design of a Modular UAV

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Conceptual design of small UAVs intended for tactical ISR missions is often complicated by the disconnect between early-stage aerodynamic/mission sizing and the manufacturability and field-deployment constraints that emerge later in the design cycle. This work presents an additive-first conceptual design framework that embeds those constraints from the outset. Mission-driven sizing equations based on Raymer and Sadrey are coupled with a parametric OpenVSP model, while the sizing loop is constrained by practical limits imposed by low-cost fabrication: maximum printable part dimensions, PLA's orientation-dependent stiffness, integration of carbon-tube spars, internal placement of thin subsystems, like servos, cables, and connectors, and the detachable interfaces required for hand-launch and backpackable operation. These constraints directly affect the admissible geometry, structural layout, and mass distribution and are therefore treated as first-order design drivers rather than downstream corrections.

Structural feasibility is evaluated through finite element analysis of printed PLA components and PLA–carbon hybrid substructures, providing stiffness and failure predictions that inform the conceptual iterations. A prototype vehicle is fabricated to assess deviations between analytical, numerical, and as-built characteristics, with emphasis on structural margins, assembly tolerances, and the practical penalties introduced by modularity. Results show that including printability and field-handling constraints at the conceptual stage leads to materially different optima in wing loading, aspect ratio, and internal structural layout when compared to traditional unconstrained sizing. By integrating mission analysis, aerodynamic estimation, and manufacturability into a unified early-stage process, the framework offers a fast, practical approach for the preliminary design of low-cost, rapidly deployable UAV systems.



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sciforum-169782: Interpretable Surrogate Modelling for Multirotor Design Exploration: Combining HDMR and Kolmogorov–Arnold Decomposition

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Multirotor unmanned aerial vehicles increasingly require design optimisation balancing aerodynamic efficiency, noise emissions, and operational constraints. While machine learning surrogates enable rapid performance prediction, their opacity limits physical insight into how design variables, such as rotor speed, blade pitch, and geometry, interact to shape system behaviour. For safety-critical applications, this lack of transparency complicates certification and informed design decisions. This work presents a framework combining High Dimensional Model Representation (HDMR) and Kolmogorov–Arnold Modelling (KAM) to extract interpretable structure from rotor aerodynamic performance models.

HDMR provides variance-based sensitivity indices and quantifies parameter interactions through additive decomposition. KAM complements this with a compositional representation that identifies localised functional regimes and reveals how variable importance shifts across the design space. The methodology is first validated on analytical benchmark functions exhibiting tuneable interaction structures, then applied to a parametric study of rotor thrust and efficiency generated using a mid-fidelity vortex particle method. The framework provides a foundation for extending the analysis to multi-rotor configurations where parameter interactions become increasingly complex.

The results will demonstrate how HDMR effectively ranks dominant parameters globally, while KAM uncovers regime transitions corresponding to shifts in dominant parameter interactions across the design space. The combined approach supports transparent design exploration and provides a starting point for regime-aware optimisation strategies in multirotor development.



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sciforum-174766: Load-carrying capacity of cold bonded inserts oriented parallel to facings on honeycomb sandwich panels used in aero-structures applications

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Structure sandwich panels with honeycomb cores are widely used in the aerospace industry due to their excellent mechanical properties. However, their structural performance is strongly governed by load introduction points, where mechanical inserts play a critical role in transferring the localized loads between the face-sheets and the core, as well as other various structural elements attached. Most existing studies on potted inserts have focused on inserts oriented perpendicular to the face-sheets, while other configurations remain insufficiently investigated, like inserts oriented parallel to face-sheets. This study focuses on load-carrying capacity and characterizes the mechanical performance of potted inserts oriented parallel to the face-sheets in the sandwich structure under various loading forms. The bonded joints with standard metallic inserts used in the present investigation are potted into the honeycomb core panel with a cold bonded process. The specimens were tested under three different static loadings: in-plane pull-out insert, in-plane shear insert, and out-of-plane insert tests. The mechanical behavior and failure mechanisms of the cold-bonded inserts placed parallel to the facings are described in detail for each load case. Afterwards, finite element analysis is performed to investigate the stress fields. Finally, the obtained results for three different loadings are compared with static strength capability results obtained from the FE model, and the load capacity as well as the applicability of the boundary insert are identified.



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sciforum-169826: Multi-Objective Material Selection Framework for Additively Manufactured Aircraft Wing Ribs

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Aircraft wing ribs form the skeletal backbone of the wing. They maintain the aerodynamic profile and transfer structural loads from the skin to the spars. Conventional manufacturing processes struggle to produce complex geometries, making these components difficult and expensive to manufacture. Recent advances in additive manufacturing (AM) address these limitations. Additive manufacturing enables the production of complex geometries that significantly reduce weight. Most designers use the standard Ashby method to identify the strongest or lightest metal. However, they often overlook whether the material will behave as expected during additive printing. This research focuses on Multi-Objective Material Selection for the design of additive manufacturability of aircraft wing ribs using aluminium-based alloys. A key innovation in this research is the formulation of Hybrid Performance Indices (HPIs). These indices go beyond the traditional Ashby methodology. They mathematically couple structural efficiency metrics with a weighted Processability Factor. The structural metrics include specific density, stiffness, specific strength and Embodied Energy Strength to Embodied Energy Index. The Processability Factor accounts for local material availability, thermal conductivity, printability, recyclability and material cost. This dual evaluation assesses both structural integrity and manufacturing risk simultaneously. The process produces an Additive Pareto Optimal set of candidate materials. This helps engineers predict and prevent issues like warping and residual stress before printing begins. The framework also emphasises sustainability. It prioritises materials that minimise waste and considers Embodied Energy in the selection process. The framework identifies high-performance aluminium alloys that are specifically optimized for the additive manufacturing of aircraft wing ribs. It provides a definitive ranking based on their ability to withstand aerodynamic loads while remaining easy to print. This data-driven approach replaces trial and error with a clear selection matrix for the early design stage. It ensures that the chosen alloy is both structurally sound and manufacturable for aerospace applications.



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sciforum-163100: Numerical Analysis Framework for a Hybrid Electrothermal and Electromechanical De-Icing System for High-Lift Systems

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Ice accretion on high-lift systems reduces lift, increases drag and can lead to unsafe operating conditions. In conventional aircraft, ice protection is usually provided by hot bleed air from the engines. However, this method is energetically costly and not feasible in more-electric or fully electric aircraft. Therefore, ice protection systems for more-electric and fully-electric aircraft must work with bleedless systems and limited power available. In this context, hybrid de-icing concepts that combine electrothermal heating with electromechanical excitation are a promising option.

This work presents a simulation strategy for a hybrid de-icing system for a slat that incorporates an electro-impulse de-icing (EIDI) system alongside structural electrothermal heating. In this framework, ice shedding is modelled using a temperature-dependent cohesive zone formulation at the ice-structure interface combined with a brittle cracking model in the ice, representing crack initiation and fragmentation. Embedded resistance heaters are represented by prescribed heat input in defined zones, generating transient temperature fields. These fields, together with temperature-dependent material properties, link the thermal and mechanical analyses.

The simulations demonstrate that the hybrid concept resolves the conflict between thermal and mechanical de-icing methods. Modest, localized electrothermal heating reduces ice adhesion, enabling EIDI to achieve near-thermal shedding performance using less energy than thermal-only operation. Further improvements in efficiency are achieved through the selective activation of heater zones, which reduces the required impulse levels and structural loading while avoiding the very high energy input of fully thermal systems and the limited de-icing of purely mechanical approaches. Overall, the framework provides a basis for designing and optimizing hybrid ice protection systems in terms of energy demand and de-icing efficiency. This supports the integration of effective ice protection systems into more- and fully electric aircraft.



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sciforum-169767: Numerical Analysis of Boundary Layer Ingestion for Electrified Aft-Fuselage Propulsion

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Boundary Layer Ingestion (BLI) is a promising approach for improving propulsive efficiency in electrified aircraft by recovering wake momentum deficit and reducing propulsive power. In conventional aircraft, engines ingest freestream air while the low-momentum wake is unutilized, resulting in kinetic energy loss. The aft-BLI propulsor enables partial recovery of this lost energy. Despite renewed interest in BLI, many numerical studies remain limited to cruise-only evaluations or isolated propulsor modeling, without examining broader flight-envelope performance.

In this work, a numerical framework is developed to study electrified aft-section BLI on an A320 aircraft configuration across multiple operating conditions. Three configurations are considered: a baseline aircraft, a cruciform-tail configuration introduced to reduce tail-wake interaction, and an aft-mounted BLI-integrated configuration. Steady, compressible CFD simulations are performed in ANSYS Fluent using geometries generated in OpenVSP. An unstructured mesh with body-of-influence refinement and inflation layers is used. Cruise conditions are defined at an altitude of 11 km under ISA assumptions, with turbulence modeled using the $k-\omega$ SST formulation and electrified propulsion represented using an actuator disk approach.

Under cruise conditions, the baseline configuration yields a drag coefficient of $C_d = 0.04498$ (53.28 kN drag, 591.6 kN lift) using a reference wing area of 123 m². The cruciform-tail configuration shows a small drag increase with negligible lift variation. Passive BLI installation increases drag to $C_d = 0.0471$, corresponding to an aerodynamic penalty of ~4.8%. When the BLI propulsor is activated, a reduction in effective drag to $C_d \approx 0.044$ is observed, corresponding to a 2% reduction relative to the baseline. Propulsive power requirements decrease from 16.34 MW to 14.35 MW, yielding a Power Saving Coefficient of ~11.6%.

A conservative assessment indicates a realistic propulsive power saving of ~7%. Overall, this work establishes a consistent numerical methodology and demonstrates the preliminary aerodynamic and propulsive potential of electrified aft-section BLI.



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sciforum-169817: Numerical Investigation of Aerodynamics of a Wing with Spanwise-Varying Flap Deflection

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This study presents a numerical investigation of the aerodynamic effects of flap deflection, which varies along the span of the wing, with particular emphasis on lift distribution and wake formation of the flow. The objective of this study is to understand non-uniform flap deflection, which can be used as a passive flow control strategy in order to improve the efficiency of the wing. Two spanwise flap deflection profiles are considered, linear and cosine, in which deflection is maximum at the wing root and decreases towards the wing tip following the respective functional distribution. These include incompressible and compressible flow regimes to measure the overall impact of flap scheduling and compressibility on overall aerodynamic performance. Aside from analyzing global aerodynamic forces (lift and drag), the study also estimates pressure recovery and pressure uniformity to better characterize flow quality and the mixing of the flow downstream. The flow physics are analyzed from the surface- and field-based visualizations with flow path characteristics such as static pressure, Mach number, Q-criterion and streamlines, which provide the ability to clearly see separation directions, vortex cores and wake thickening features. The key findings of the study provide deep insights about pressure distribution and circulation, which significantly influences aerodynamic performance of the wing. These insights will help in designing a flexible wing with variable flap deflection. Such configurations have strong potential applications in the field of UAVs and commercial aircraft.



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sciforum-161301: Numerical modeling and analysis of a helicopter rotor blade with an active twist concept

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Senior Researcher

During flight, helicopter rotor blades generate significant vibrations and noise due to aerodynamic loads. These effects limit maximum flight speed, increase operating costs, and reduce the fatigue life of structural members. The use of active control systems for helicopter rotor blades is a current scientific trend of research into noise and vibration reduction. Several methods exist for actively controlling helicopter rotor blades. One control strategy applied to suppress vibrations is Higher Harmonic Control (HHC) and Individual Blade Control (IBC). Currently, several methods of helicopter blade control are being researched with the development of piezoelectric fibres: Active Trailing Edge (ATE) and Active Twist (AT).

Active Twist is based on the fact that the actuator control elements can be located on the blade's load-bearing skin surface. The orientation of the piezoelectric fibres in the piezoelectric actuator on the top and bottom surfaces of the skin is $\pm 45^\circ$, resulting in dynamic blade twisting when the piezoelectric actuators are activated. Thus, Active Twist can be integrated into the existing rotor blades without significant design changes.

In the present work, an analysis of a numerical study of a helicopter blade with the piezoelectric actuators integrated into the skin of the main rotor blade was performed. The results of static blade twisting as a function of the piezoelectric actuator chord-wise length are presented. Additionally, the effect of changing the geometry of the blade's cross-section on the twist angle was examined. The influence of piezoelectric actuators and changing the geometry of the blade's cross-section on the stiffness characteristics of the helicopter blade are demonstrated.



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sciforum-163825: SMART Hawk: A Shape-Morphing Artificial Red-Tailed Hawk

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Introduction: The red-tailed hawk (RTH) is a remarkable soaring raptor with a broad wingspan that grants it impressive aerodynamic efficiency, allowing for effortless gliding and rapid transitions into high-speed dives for instant prey capture. These capabilities make the RTH an ideal biological model for developing a feathered, morphing drone that is capable of achieving glider-like aerodynamic efficiency while retaining the maneuverability of quadcopters. **Methods:** This work presents “SMART Hawk,” a biomimetic, non-flapping Unmanned Aerial Vehicle (UAV) with wing- and tail-morphing capabilities. SMART Hawk’s target weight and size are based on the physical characteristics of a female RTH. A mathematical model was first developed in MachUpX to guide the selection of the design parameters for optimal aerodynamic performance at various morphing configurations. SMART Hawk’s wing incorporates artificial composite feathers that are distributed along the wingspan and connected to a linkage mechanism modeled after avian wing bones, allowing the wing to sweep in a way that mimics the natural deformation of the hawk’s wing natural. The wing’s airfoil profile was extracted from the cross-section of the RTH obtained through 3D scanning of an RTH cadaver. A compact tail mechanism was designed to actuate three degrees of freedom: pitching, tilting, and feather expansion. Composite shells, balsa wood, and 3D-printed ASA plastic were used strategically for the structural and load-bearing components. Propulsion was achieved via a single electric motor located at the nose of the fuselage. Computational fluid dynamics (CFD) and finite element analysis (FEA) simulations were performed to validate the design of all UAV components. **Results:** A proof-of-concept prototype was built and flight tests were performed to prove the effectiveness of the proposed design. **Conclusions:** The proposed biomimetic morphing UAV design can replicate the aerodynamic qualities of the RTH. The selected materials and servomotors enabled the achievement of the design objectives.



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sciforum-168725: Structural Analysis and Optimization of a Jet Trainer Aircraft Wing Using Fluid–Structure Interaction

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The current research aims to investigate the structural deformation, equivalent von Mises stress, and safety factor outcomes of a simplified jet trainer aircraft wing using a fluid-structure interaction (FSI) approach and optimize the structure for safe flight without lowering the structural safety margin of 1.2. The wing geometry is designed in the Ansys Design Modeler, and Aluminum alloy 2024 T3 and Aluminum alloy 7075 T6 are assigned as the material of the wing. The pressure distribution on the wing is calculated from the commercial software code Ansys Fluent and, later on, coupled with static structural analysis to solve the FSI problem. Experimental pressure coefficient data of Onera M6 aircraft wing, tested in NASA laboratory is validated using Ansys Fluent. Keeping an angle of attack of 3° , the Mach number is varied from 0.5 to 0.8, and it was found that increasing the Mach number would increase the equivalent von Mises stress drastically, from 61.946 MPa to 236.52 MPa, passing the safety margin of the yield stress of 315 MPa. In addition, keeping the Mach number constant at 0.8 and changing the angle of attack from 0° to 12° would result in a rise in equivalent stress up to 411.33 MPa in linear analysis, which is higher than the yield stress, suggesting the potential plastic failure of the wing. Considering the maximum Mach number of 0.8 and angle of attack of 8° , an optimization is proposed to check how the thickness of the skin, ribs, and spars can be varied to bring down the stress generated on the root of the wing. A response surface optimization was conducted for satisfying the margin of safety for the wing.



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sciforum-162575: Topology Optimisation Using Additive Manufacturing for Lightweight Aerospace Structures: Experimental Investigation of Functionally Graded Lattice Architectures

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Additive manufacturing (AM), defined as a layer-by-layer fabrication process driven by digital design data, enables the realisation of geometrically complex structures that are unattainable through conventional subtractive or formative methods. By allowing material placement only where structurally necessary, AM provides unprecedented control over internal architecture, mass distribution, and functional integration. Lightweight structural design is a critical requirement for modern aerospace systems, particularly for unmanned aerial vehicles (UAVs) and small-scale platforms where mass directly governs endurance, payload capacity, and operational efficiency. Topology optimisation combined with additive manufacturing offers a promising route to overcome the inherent limitations of polymer materials by enabling highly efficient internal material architectures.

This study investigates the experimental performance of topology-optimised lattice structures manufactured using fused deposition modelling (FDM) for lightweight aerospace applications. A function-representation (F-rep) based parametric design framework was developed to generate cylindrical lattice architectures with controlled lattice frequency and vertical phase shift. Seventy-eight (78) specimens were fabricated from polylactic acid (PLA) across three infill regimes (30%, 70%, and 100%) and tested under quasi-static axial compression in accordance with ASTM 1621-16. Mechanical performance was evaluated in terms of maximum compressive load and strength-to-mass ratio.

The results show that topology-optimised lattice structures significantly outperform solid reference specimens in mass-specific mechanical performance. The greatest enhancement was observed at 70% infill, where lattice structures achieved improvements in strength-to-mass ratio of up to 68.42% compared to solid specimens. Lattice architectures also exhibited progressive collapse behaviour, indicating improved damage tolerance.

These findings demonstrate that topology-optimised, additively manufactured polymer lattice structures provide a viable and scalable pathway for developing lightweight, structurally efficient aerospace components, particularly for UAV and small-platform applications.



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sciforum-169659: Topology-Dependent Evaluation of Automated Homogenization for Lattice Structures in Aerospace Design

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Lattice structures provide significant potential for lightweight aerospace components due to their high stiffness-to-weight ratios and tunable mechanical behavior. However, explicit numerical modeling of large assemblies is computationally expensive, limiting their practical application. To address this, homogenized equivalent solid representations are commonly employed, though the ability of automated homogenization tools to accurately reproduce the mechanical response of different lattice topologies is not yet fully established.

This study evaluates the elastic equivalence of two lattice topologies, simple cubic (SC) and body-centered cubic (BCC), using an automated workflow in ANSYS Material Designer. A 5mm×5mm×5mm representative volume element (RVE) was modeled as a 3D solid element and homogenized to extract effective elastic properties. The equivalent material models were applied to a 100mm×50mm×25mm solid block, while explicit lattice blocks of identical dimensions were generated through periodic replication of the unit cell. Ti-6Al-4V material properties (density 4420 kg/m³, Young's modulus 112 GPa, Poisson's ratio 0.35) were used for all the cases.

Mesh convergence studies were conducted for each configuration, and a uniform 0.5 mm mesh was adopted as an optimal compromise between accuracy and computational cost. Displacement-controlled compression up to 2% nominal strain ensured a linear elastic response. Equivalence between explicit lattice and homogenized models was evaluated using total strain energy and stress across twenty incremental load steps.

The results indicate excellent agreement for the SC lattice, with total strain energy and stress deviations of approximately 1.28%, while the BCC lattice exhibits higher deviations of approximately 2.98%. The larger discrepancy for BCC is attributed to its bending-dominated deformation, which is less localized than the axial stretching of SC struts, making it harder for a homogeneous model to capture accurately.

These findings quantify the accuracy of automated homogenization for fundamental lattice topologies, providing engineers with clear, topology-specific error margins for preliminary design of aerospace lattice components.



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sciforum-153341: Toward Generalizable AI: Physics-Regularized Transfer Learning Across Aerospace Alloys in Additive Manufacturing

Aswin Karakadakattil

Independent researcher India (Indian institute of technology Palakkad class of 2025)

Additive manufacturing (AM) is increasingly applied in aerospace for producing lightweight brackets, turbine blades, and propulsion components. A persistent challenge, however, involves the fact that process–property relationships learned from one alloy rarely transfer effectively to another. Aerospace alloys such as Ti-6Al-4V, Inconel 718, and AlSi10Mg each exhibit distinct thermal and absorptive behaviours, making qualification costly and reliant on extensive trial-and-error. Conventional machine learning models provide useful predictions but often act as black boxes, limiting both interpretability and cross-alloy applicability. This study introduces a **physics-regularized transfer learning framework** that adapts knowledge from a source alloy with extensive data (Ti-6Al-4V) to target alloys with limited datasets (Inconel 718, AlSi10Mg). A baseline neural network is fine-tuned for the target alloys, while the training is guided by physics-informed constraints, including volumetric energy density, thermal diffusivity, and absorptivity scaling. Embedding these terms into the loss function encourages the model to remain physically consistent while capturing alloy-specific features. Preliminary results suggest that the proposed approach improves predictive accuracy for surface roughness and porosity compared with both standalone neural networks and conventional transfer learning. Beyond accuracy, the framework represents a step toward **generalizable and interpretable AI tools** for aerospace AM. By reducing reliance on trial-and-error, such methods can accelerate alloy qualification, lower experimental costs, and contribute to more sustainable and efficient aircraft and spacecraft design.



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sciforum-164135: Toward Integrated Thermal-Tribological Design Framework of WFAAM Functionally Graded Metals for Hypersonic Applications

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Hypersonic aerospace components experience multiple extreme conditions (up to 3000°C) due to repetitive and abrupt thermo-mechanical shocks, severe aero-thermal heating and repeated thermal gradients. Existing traditional monolithic alloys or coating solutions are unable to meet such concurrent requirements due to interfacial deterioration and limited thermal and wear protection. Development of functionally graded materials through the wire-feed arc additive manufacturing process (WFAAM) become established as a viable large-scale (deposition rate 3-5 kg/h) solution to mitigate critical challenges through tailored compositions and properties. Existing WFAAM-fabricated multi-material systems have emerged that primarily address thermal management and tribological performance as distinct design goals. Therefore, there is limited research on integrated frameworks due to their concurrent incorporation. This study addresses a hybrid critical review and conceptual design approach for future simulation-driven optimization. It introduces an innovative design framework, the WFAAM-driven FGM system, aimed specifically at hypersonic applications. Significant limitations and knowledge deficiencies are examined critically in existing WFAAM-based FGM studies, with a focus on tribology, alloy development and thermal barrier structures. The major aims are (i) to analyze WFAAM-derived FGMs for thermal regulation, specifically on wear and surface degradation mechanisms, and (ii) to analyze graded thermal transition layers to reduce heat flux and thermal shock durability, which is estimated to reach 25-40% in extreme environments. Particular emphasis is placed on the absence of design approaches that balance dilution control, metallurgical compatibility and functional property gradients in high-temperature gradients and shocks. A structured design framework is proposed to develop WFAAM-driven functional gradient metallic systems for extreme performance in hypersonic applications without depending on distinct coating interfaces. This study underscores the capability of WFAAM-fabricated FGMs to combine thermal, mechanical and tribological properties in one structural multifunctional material, suitable for extreme hypersonic aerospace conditions.



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sciforum-169793: Wind Tunnel Investigation of Spoiler Effectiveness on a low Aspect-Ratio Swept Wing with reflex Airfoils

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During the design phase of a fixed-wing remotely piloted aircraft developed at Politecnico di Milano, an experimental investigation was conducted to validate preliminary sizing methods for spoileron. Traditional regression-based and semi-empirical approaches (such as DATCOM and Roskam) were compared with results obtained from a dedicated wind tunnel test campaign.

The need for validation arises from the application of these methodologies to a non-conventional configuration characterized by newly designed reflex airfoils and a distinctive geometric layout, including a highly swept wing, low aspect ratio, and pronounced taper. The lack of prior experimental data on reflex airfoils applied to similar wing configurations equipped with spoileron-type control surfaces raises uncertainties regarding the reliability of estimates derived from traditional approaches, which are generally calibrated on conventional airfoil geometries.

The wind tunnel campaign was conducted using a 1.3 m wingspan aluminum model at a Reynolds number of 1×10^6 , during which roll and yaw performance was systematically mapped by varying the spanwise and chordwise spoiler positions. In an initial phase, the ratio between spoiler chord and local wing chord was kept constant. Subsequently, the sensitivity to variations in this ratio, spoiler spanwise extension, and control surface deflection was analyzed.

Results show qualitative agreement with trends reported in the literature, highlighting maximum effectiveness at intermediate angles of attack ($5-8^\circ$) and a reduction in effectiveness when the spoiler is placed toward the wing tip. Quantitatively, the measured performance is slightly higher than that predicted using traditional preliminary methods. The results therefore indicate that conventional regression-based approaches can be reasonably applied to wings equipped with reflex airfoils, despite their original calibration on conventional airfoil geometries. Moreover, the observed systematic deviation suggests the need for minor correction factors when applying these methods to similar unconventional configurations, contributing to enhanced confidence in early-stage control surface sizing.



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Session 2. Sustainable Propulsion & Energy Systems

sciforum-168565: Balancing the Environmental Trade-off: Simultaneous Minimization of Carbon and Nitrogen Emissions in Novel Aero-Engine Cycles

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The aviation sector faces an urgent mandate to decarbonize while simultaneously limiting the emission of harmful pollutants. This work presents a Mixed-Integer Nonlinear Programming (MINLP) framework for the design of next-generation gas turbine engines, specifically targeting the trade-off between CO₂ reduction and NO_x mitigation. The model encompasses advanced architectures featuring Rotating Detonation Combustion (RDC), intercooling, heat recuperation, and three-stream flow management, enabling transitions from conventional Joule–Brayton to complex Joule–Humphrey cycles.

The modeling framework integrates semi-empirical correlations linking local thermodynamic conditions—specifically flame temperature and residence time—to NO_x formation rates via the Zeldovich mechanism, while CO₂ emissions are minimized through specific fuel consumption optimization. These emission models are coupled with a rigorous thermodynamic cycle solver, yielding a bi-objective formulation that simultaneously minimizes the two primary environmental contributors over a representative cruise mission, without the confounding influence of weight penalties.

Optimization is performed using a Multi-Start Physics-Acquainted Branch and Bound (MS-PABnB) algorithm, which exploits interdependencies among binary architectural decisions to efficiently navigate the non-convex design space. Pareto fronts are generated for three thrust classes (10 kN, 30 kN, 50 kN), strictly quantifying the environmental cost of disparate architectural choices. Our results demonstrate that Optimized Novel Architecture Engine Designs (ONAEDs) can unlock unique design points where advanced cooling and reheating strategies mitigate the traditional penalty of rising NO_x associated with high-efficiency cycles, offering a pathway toward truly sustainable propulsion.



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sciforum-168021: Design and Analysis of a Propeller with Winglets for Improved Thrust Performance

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The aerodynamic efficiency of small unmanned aerial vehicle (UAV) propellers is affected by losses arising from tip-vortex formation. At the blade tip, pressure differences between the suction and pressure surfaces induce vortical structures that increase induced losses, reduce effective thrust generation, and degrade propulsive performance. Mitigating these tip-related losses is critical for improving the efficiency of small-scale propellers operating at low Reynolds numbers.

This work presents an investigation into the effectiveness of blade-tip winglets as a passive flow-control technique to reduce thrust losses in a seven-inch propeller. Three distinct winglet configurations were examined: a canted winglet, an up/down wingtip fence, and a wingtip fence. All winglet geometries were designed using the NACA 4412 airfoil profile to ensure geometric consistency and aerodynamic characteristics. The baseline propeller and the winglet-integrated variants were modelled using CATIA V5 and fabricated from ABS material via fused deposition modelling.

Experimental evaluation was conducted using a custom-designed thrust measurement rig. Thrust data were acquired over a speed range of 4000 to 6000 rpm under repeatable conditions. Each winglet configuration was tested independently and compared against the baseline propeller to quantify performance improvements.

The results demonstrate that the incorporation of winglets leads to a measurable increase in thrust across the entire operating range. The canted winglet configuration yielded the most significant improvement, with thrust increases of 71% at 4000 rpm, 24.6% at 5000 rpm, and 32.8% at 6000 rpm, indicating superior suppression of spanwise flow and tip-vortex strength. The wingtip fence showed moderate thrust increases of 42%, 16.6%, and 10.7%, while the downward wingtip fence exhibited smaller but consistent increases of 13%, 8.7%, and 5%. Overall, the study establishes winglet integration as a simple, low-cost, and effective method for improving the aerodynamic performance of small UAV propellers.



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sciforum-169557: Multi-level Aircraft Design Modelling Including the Effects of Disruptive Propulsion Technologies on Environmental Impact

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The EU EFACA project considers two conceptual aircraft design configurations for cleaning European air traffic in future decades. The EU SENECA project considered four conceptual configurations for supersonic aircraft design—it is also expected to impact air traffic in future decades. Recently, several different technologies have led to propulsion designs that have the potential to reduce greenhouse gas emissions and replace existing conventions, including jet fuel technology. On one hand, H₂-powered aviation just recently regained significant attention from the industry, e.g., Airbus launched the ZEROe program, where they pledged to develop the world's first zero-emission commercial aircraft by 2035. On the other hand, sustainable aviation fuels or biofuels have been identified as an alternative option, also with the potential for use in supersonic flights. In both projects, the results of the assessment of environmental factors are considered using a multidimensional approach, ranging from aircraft certification requirements to regional/global assessment of new designs in air traffic. Any factor reduction technology is simulated and compared to a reference, usually the current best in its aircraft class, providing the possibility to assess its efficiency for necessary certification requirements and for real or forecasted operational conditions, in particular due to the ACARE goals assessment in mid-2035 and long-term 2050 terms.



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sciforum-161406: A Phenomenological Framework for Anomalous Electron Transport in Hall Effect Thrusters: Bridging Bohm Diffusion, Near-Wall Conductivity, and Plasma-Wall Transition Layers

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Hall effect thrusters (HETs) exhibit electron cross-field mobility 10–100 times above classical predictions, yet no single mechanism consistently explains performance across the 1–100 kW range. This work presents a fully predictive, parameter-free phenomenological transport model that unifies three dominant anomalous channels into a single effective collision frequency:

$$\nu_{\text{eff}} = \alpha_B/(16B) + \nu_{\text{NWC}} + \nu_{\text{trans}}$$

The Bohm term employs a theoretically derived $\alpha_B \approx 1/32$ arising from quasi-linear saturation of azimuthal $E \times B$ drift waves damped by ion-sound waves in the near-plume, eliminating empirical 1/16–1/100 fudge factors. Near-wall conductivity ν_{NWC} is computed self-consistently using velvet-regime secondary electron emission yields ($\gamma_{\text{SEE}} \approx 0.55$ at 150–300 eV for BN) and exact channel geometry. The novel plasma-wall transition term ν_{trans} accounts for pre-sheath expansion via a generalized Boltzmann relation incorporating κ -distributed non-Maxwellian tails ($\kappa \approx 5$ –8), which naturally limits axial conductivity when the Debye length approaches channel half-width.

The resulting closed-form mobility reproduces breathing-mode frequency (within 8 %), discharge current oscillations (amplitude and shape), and thrust efficiency of the SPT-100 (1.35 kW), NASA-300M (9 kW), and nested-channel X3 (up to 102 kW) with errors below 3 % across three orders of discharge power. Most importantly, the model predicts—without adjustment—the observed abrupt efficiency collapse above 70 % channel utilization in high-power nested designs, directly linking it to pre-sheath choking of NWC. This framework delivers transparent scaling laws and design guidelines for next-generation >50 kW HETs required for lunar gateways and Mars cargo missions.



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sciforum-162066: Analysis of the Interaction Mechanisms between Rocket Exhaust Plume and Sea Surface in Maritime Launch Conditions

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Sea-based rocket launches have become a critical capability in aerospace engineering due to their operational flexibility and expanded safety zones. However, the interaction between high-temperature supersonic exhaust and the ocean surface poses severe challenges to the structural integrity of launch platforms. Unlike land-based launches, the marine environment presents a deformable boundary with complex phase-change dynamics. This study employs the Volume of Fluid (VOF) method coupled with the $k-\omega$ SST turbulence model to conduct a comprehensive numerical investigation of these multiphase interactions. Distinct from classical internal combustion instabilities, this research reveals an external "shock-vortex-thermal" coupling mechanism formed among exhaust shockwaves, shear layer vortices, and seawater vaporization. Simulation results demonstrate that under low launch altitude conditions, rapid expansion of high-pressure steam significantly alters the shock structure, generating strong reverse jets that impose extreme thermal and mechanical loads on the platform foundation. Based on flow field topological evolution patterns, critical safety boundaries are identified. Below this altitude threshold, coupled effects trigger hazardous splashing and pressure feedback; above it, interactions effectively decouple. The parametric analysis further reveals how varying launch altitudes influence the evolution of key flow features including shock standoff distance, steam plume geometry, and pressure distribution on the platform surface. These findings provide theoretical guidance for optimizing initial launch altitude to mitigate adverse jet effects, thereby ensuring structural safety and operational stability of offshore launch platforms.



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sciforum-163790: Bio-Inspired Hybrid Optimization Integrated with MFAC for Energy-Efficient BLDC Propulsion in UAVs

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Improving the efficiency of drone propulsion is crucial in extending flight times and cutting down on energy losses during dynamic maneuvers. Traditional Brushless DC (BLDC) motor controllers depend on mathematical models and reactive adjustments, which often struggle to keep up with sudden changes in load, wind disturbances, and fluctuations in battery voltage. To tackle these challenges, this study presents an innovative control strategy that merges Model-Free Adaptive Control (MFAC) with a bio-inspired hybrid optimization technique inspired by Eel Foraging and Gooseneck Barnacle behaviors. Unlike model-based methods, MFAC continuously fine-tunes its control actions using real-time sensor data, eliminating the need for motor parameters and making it robust against unpredictable operating conditions. The hybrid optimization algorithm enhances this adaptability by swiftly identifying the most energy-efficient control inputs that ensure necessary thrust while minimizing switching losses, torque ripple, and power consumption. Experimental tests with a 1000 KV BLDC motor show significant improvements in torque-speed stability, rapid convergence in controller tuning, and a marked reduction in power demand during critical drone flight modes like hovering and ascending. These findings suggest that combining MFAC with bio-inspired optimization paves the way for developing high-efficiency UAV propulsion systems that can achieve longer endurance, reliable real-time control, and less reliance on complex motor models.



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sciforum-163362: Computational Analysis of Passive Acoustic Liner Techniques for Jet and Compressor Noise Reduction

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The growing expansion of commercial aviation has intensified the need for effective noise mitigation strategies in aircraft propulsion systems. Broadband jet noise and tonal compressor noise remain significant contributors to overall aircraft acoustic emissions. This study investigates passive aeroacoustic control techniques aimed at reducing such noise sources through numerical modeling and parametric analysis.

A computational framework based on the Transference Matrix Method (TMM) combined with acoustic impedance modeling is employed to evaluate the sound absorption and transmission characteristics of perforated and microporous liner materials. The acoustic performance is analyzed over a frequency range of 100 Hz to 5000 Hz. Key geometric parameters, including porosity, hole diameter, and cavity depth, are systematically varied to determine their influence on attenuation efficiency under representative operating conditions.

The simulation results indicate that microporous liners exhibit improved absorption capability and a more uniform frequency response compared to conventional perforated liners, particularly within the mid- and high-frequency bands where compressor tonal components are dominant. An optimized configuration with 5% porosity and a hole diameter of 1 mm achieves a maximum transmission loss of approximately 18 dB within the evaluated frequency spectrum.

The findings provide a structured computational approach for the early-stage design and optimization of passive acoustic liners in modern turbofan compressor systems. This study supports the integration of advanced liner configurations to enhance noise reduction performance in aerospace propulsion applications.



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sciforum-163661: Design Aspects and Performance Evaluation of Free Double Piston Devices in a Composite Cycle Engine

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The Composite Cycle Engine (CCE) concept combines the benefits of a gas turbine and a piston engine. In CCEs, the piston engine is integrated into the high-pressure part of the gas turbine to increase the engine's thermal efficiency through closed-volume compression and combustion at high peak pressures and temperatures. As such, the prime purpose for the piston system in a CCE is to act as a high-quality gas generator with the turbine section of the engine extracting the useful work. Therefore, free-piston engines appear even more promising than previously studied crankshaft-based [1, 2] and rotary piston engines [3]. This is due to engine mass and efficiency improvements (minimization of mechanical losses), simpler bearings and lubrication, as well as increased installation flexibility within the core engine casing. The present work focuses on the particularly innovative concept of a Free Double Piston (FDP) device, in which a free piston oscillates between two oppositely located combustion chambers, generating power to pre-compress the air in connected annular piston compression chambers [4].

This contribution discusses design aspects and performance of the FDP engine compared to crankshaft-based variants. In the first step, piston compressor and engine performance modeling is introduced with special emphasis on the features of FDP devices like the piston movement characteristics and the brake power calculation. Furthermore, the whole FDP system is assessed by kinematically combining the piston compressor and engine. Moreover, a failure mode analysis of the FDP system is performed.

The FDP is modeled using Bauhaus Luftfahrt's in-house piston engine performance simulation tool [1-3], which represents a time-resolved OD-model of a single piston compressor and engine and is adapted for FDP modeling in this contribution. The used heat transfer model and the combustion characteristics were adapted to hydrogen combustion and calibrated and verified against literature data.



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sciforum-169638: Discrete volume based thermal fluid and structural modelling for LH₂ aircraft tanks

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The adoption of liquid hydrogen (LH₂) as a sustainable aviation fuel presents unique challenges, particularly regarding fuel tank dynamics during flight. Sloshing-induced thermodynamic changes in cryogenic tanks can significantly impact pressure stability and fuel management systems. This study addresses the critical need to model and understand these complex interactions to ensure safe and efficient LH₂ storage in dynamic flight environments.

An integrated computational framework was developed using Cranfield University's in-house thermal-fluid code as the foundation. Ludwig's thermal diffusivity model, originally validated for liquid nitrogen (LN₂), was adapted from a temperature-based to an energy-based approach and incorporated into the thermal-fluid model to capture sloshing dynamics. The enhanced model underwent validation against experimental LN₂ data before being applied to LH₂ systems under the assumption of similar cryogenic fluid behaviour. A comprehensive three-phase methodology encompassed validation, LH₂ case studies, and parametric analysis examining initial pressure, fill levels, and excitation characteristics.

Model validation achieved agreement with experimental data, showing maximum deviation of only 7%. LH₂ simulations revealed a sloshing-induced pressure drop of approximately 100 kPa over 40 seconds, attributed to enhanced condensation and turbulence at the liquid-vapour interface. Parametric analysis demonstrated that higher initial pressures and fill levels (85%) increased pressure drop rates by 5-8%. Notably, chaotic sloshing patterns produced substantially faster pressure decrease (5.2 kPa/s) compared to planar wave sloshing (3.2 kPa/s).

This research demonstrates the capability of the enhanced thermal-fluid model to simulate complex cryogenic tank behaviour under dynamic conditions. The findings provide valuable design insights for optimizing LH₂ tank configurations and operational strategies in future hydrogen-powered aircraft, contributing to the advancement of sustainable aviation technologies.



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sciforum-169357: Experimental Study of Cryogenic Fill-Level Sensors for Liquid-Hydrogen Aircraft Applications

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The safe and accurate measurement of liquid hydrogen (LH₂) tank fill levels is a critical enabling technology for the adoption of hydrogen as a sustainable aviation fuel. Although LH₂ level measurement techniques have been applied in industrial, automotive, and space applications, no integrated system has yet been validated at the scale, robustness, and precision required for modern aircraft Fuel Quantity Indication Systems (FQIS).

Differential pressure sensors are commonly employed in industrial cryogenic systems and hydrogen refueling stations; however, their accuracy is strongly influenced by dynamic effects such as filling transients and liquid sloshing, rendering them unsuitable for aviation-grade FQIS requirements. While simulations and analytical studies propose alternative LH₂ level sensing concepts, experimental validation and direct comparative assessments of different sensor architectures remain scarce. Furthermore, although several manufacturers offer LH₂ level sensors, their stated measurement accuracies have not been independently verified, highlighting the need for systematic experimental investigation under representative operating conditions.

In this work, five liquid level sensing concepts based on measurements of dielectric constant, thermal capacity, and optical absorption are experimentally evaluated. Cryogenic tests are conducted using liquid nitrogen as a representative surrogate for liquid hydrogen. The results demonstrate that optical absorption-based approaches are unsuitable for reliable cryogenic liquid level measurement. In contrast, capacitive probes and discrete resistive thermal sensors exhibit robust and repeatable performance under cryogenic conditions, achieving measurement accuracies better than ± 1.5 mm. These findings provide experimentally grounded guidance for the development of future LH₂-compatible FQIS architectures for aviation applications.



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sciforum-162749: Hydrogen Propulsion Technology for Decarbonizing Aircraft Transport: Environmental and Technical Analysis

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Decarbonizing aircraft transport, such as aircraft, is becoming a central priority in global efforts to reduce greenhouse gas emissions and meet long-term climate targets. This study evaluates the technical and environmental performance of hydrogen fuel-cell propulsion as an alternative to conventional jet fuel in commercial aviation. The analysis examines key aircraft design requirements, including the integration of liquid hydrogen storage tanks, fuel-cell power systems, cryogenic handling components, and electric propulsion units. It also considers the airport-side needs for hydrogen production, liquefaction, storage, and refueling, highlighting the importance of coordinated infrastructure planning for future deployment.

An environmental assessment indicates that hydrogen fuel-cell aircraft can eliminate in-flight CO₂ emissions and substantially reduce other pollutants, supporting cleaner operations and improved air quality around airports. From a technical standpoint, fuel-cell propulsion provides high energy efficiency, reduced mechanical complexity, and low noise levels, making it particularly suitable for short- and medium-range aircraft segments where electric propulsion architectures are more readily implemented.

Overall, the findings emphasize the strong potential of hydrogen fuel-cell systems to contribute to aviation decarbonization. The study offers practical insights for aircraft manufacturers, airport planners, and policymakers seeking to enable the transition toward zero-emission air transport and guide future development pathways for hydrogen-powered aviation.



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sciforum-169307: Lifecycle Cost Analysis of Aircraft Systems: Unlocking Efficiency with Digital Twin Applications

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Lifecycle cost (LCC) analysis is a vital methodology for assessing the economic sustainability and long-term viability of aircraft systems across their entire operational lifespan. As highly complex engineering products, aircraft involve substantial initial acquisition costs, continuous operation and maintenance (O&M) expenditures, and strict safety and regulatory compliance requirements, all of which contribute significantly to overall lifecycle expenses. This study focuses on the comprehensive evaluation of aircraft lifecycle costs by integrating advanced digital twin (DT) technologies to enhance the accuracy and reliability of cost estimation and prediction. A structured mathematical modeling framework for LCC is developed, encompassing all major cost components, including acquisition, operational usage, scheduled and unscheduled maintenance, repair activities, and end-of-life disposal. The proposed framework enables systematic identification and quantification of key cost drivers that influence aircraft performance and economic outcomes. The results and discussion highlight how LCC analysis supports optimized maintenance planning, improves resource allocation, and facilitates informed decision-making for fleet management and system design. By leveraging real-time data, predictive analytics, and continuous system monitoring, DT-enabled LCC analysis reduces uncertainty associated with traditional cost estimation methods and enhances the ability to anticipate failures and maintenance needs. Furthermore, the integration of digital transformation trends within the aviation industry demonstrates the potential of DT technologies to improve operational efficiency, enhance safety performance, and extend asset life. Overall, the findings suggest that the application of digital twin-supported LCC analysis provides a powerful decision-support tool that strengthens economic efficiency, supports sustainable aircraft operations, and contributes to more resilient and cost-effective aviation systems.



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sciforum-161924: Mammalian Capillary Network-Inspired Near-Wall Cooling System for High-Pressure Gas Turbine Blades

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St. Paul's College

This study presents a novel near-wall cooling system for high-pressure gas turbine blades using a network of dichotomously branched minichannels embedded within the suction-side cast wall. Inspired by mammalian capillary networks, the design aims to enhance heat transfer, reduce coolant pressure drop, and improve surface temperature uniformity. A parametric optimization was performed on branching angle and daughter channel length ratio, subject to constraints on Reynolds number and allowable pressure loss. The optimal configuration was found for branching angles of 53° and 56° at the first and second bifurcation levels, with a length ratio of 2.33:1 between successive branches. Three-dimensional CAD models of the baseline and optimized configurations were generated and analyzed using RANS CFD with a realizable k- ω turbulence model and conjugate heat transfer. For identical inlet mass flow and total pressure (3.8 MPa, 923 K coolant), the optimized design produced a more uniform suction-side wall temperature distribution, particularly at the leading edge, trailing edge, and mid-chord regions. The pressure drop at the minichannel exits was approximately 4.5 kPa, remaining within a typical 5% limit of the coolant supply pressure. Compared with the preliminary design, the optimized network reduced coolant exit velocity by about 46%, indicating lower kinetic-energy losses and improved flow distribution among branches. These results demonstrate that a biomimetic, hierarchically branched near-wall cooling network can provide effective and more uniform blade cooling while maintaining acceptable pressure losses, offering a promising route to support higher turbine inlet temperatures and improved engine efficiency in future gas turbine designs.



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sciforum-169888: Optimization of a Two-Stage Rocket for Low Earth Orbit Reconnaissance Payloads: Toward Fuel-Efficient Launch Systems

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Space and rocket-related projects are notoriously expensive, with costs that often exceed initial budgets, especially for government-funded projects. These high costs pose a substantial barrier to expanding the capabilities of space exploration, satellite deployment, and related scientific research. To overcome these challenges, this study presents the optimization of a two-stage rocket for low Earth orbit (LEO) at a maximum altitude of 450 km and a 300 kg payload, focusing on aerodynamic and propulsion optimization to enhance fuel efficiency.

A multidisciplinary framework was applied, incorporating propulsion system analysis, and thermodynamic properties of the rocket nozzles using NASA's Chemical Equilibrium with Applications (CEA) code. The Computational Fluid Dynamics (CFD) simulations were conducted in SolidWorks to refine the rocket's aerodynamic profile by optimizing fin geometries. The nozzle geometry was refined using Rao's method, with MATLAB calculations applied to determine the optimal nozzle expansion ratio. NASA's General Mission Analysis Tool (GMAT) was utilized to perform trajectory optimization and propellant mass calculations. The nozzle performance was validated through benchmarking against comparable-class small-lift launch vehicles.

The optimized launch vehicle achieves a total lift-off mass of 13,000 kg, including 11,200 kg of propellant and a 300 kg payload. The first stage produces 235 kN of thrust with a burn time of 155 s and a specific impulse of 265 s, while the second stage delivers 25 kN of thrust over 350 s with a specific impulse of 340 s. The combined two-stage propulsion system provides a total ΔV of 13.71 km/s, enabling a final orbital altitude of approximately 400 km. These findings contribute to more sustainable two-stage propulsion systems by enhancing fuel efficiency and sustainability in small-lift launch vehicles.



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sciforum-168350: Technological Advancements of Hybrid Rocket Engines for Sustainable and Competitive In-Space Propulsion Applications

Ryan Thibaudeau *, Stephen Whitmore, Jared Coen, Josh Sorenson, Logan Mecham and Ava Wilkey

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Hybrid rocket propulsion systems, utilizing liquid oxidizers in conjunction with solid hydrocarbon fuels, are recognized for their safety, environmental compatibility, operational simplicity, and capacity for precise control over thrust and impulse profiles. Thus, this emerging technology offers a promising alternative for future space propulsion applications. In the last decade, the Utah State University Propulsion Research Laboratory (PRL) has developed hybrid propulsion technologies for a diverse array of space mission applications. This paper summarizes key progress in the PRL's green-hybrid propulsion research, offers insights for scalable design future strategies, and presents a road map for future applications.

At the PRL, significant advancements in hybrid rocket technology have addressed both performance and sustainability requirements. Among the key technological advances are a patented low-energy arc-ignition system, which ensures reliable and consistent ignition, and a digital throttle control that enables precise and deep throttling. These advancements significantly enhance flexibility in missions requiring orbital transfer, attitude control, and rendezvous operations. These advances enable hybrid propulsion systems to serve as viable competitors to conventional chemical and electric propulsion methods for space applications.

PRL research also focuses on environmental sustainability alongside ignition and throttling improvements. A key objective is to substitute toxic and hazardous hydrazine-based propellants with safer, environmentally friendly options for in-space propulsion. By leveraging modern additive manufacturing methods, PRL research has enabled fast, affordable solid-fuel production by using recycled and bio-based plastics. These advances have optimized fuels, resulting in lowered production costs, minimized environmental impact, and increased motor efficiency. These advanced fuel blends exhibit advantageous regression rates, consistent mechanical strength, and compatibility with current ignition and oxidizer-feed systems. This research shows that sustainable materials can be used in propulsion without compromising performance, enabling hybrid rocket engines to be competitive in this market space.



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Session 3. Space Systems & Exploration

sciforum-168703: A Comprehensive Structural, Thermal, Solar, and Aerodynamic Analysis of a Mars Sub-surface Habitat

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Mars habitation is a highly challenging engineering problem due to its extreme environmental conditions, which make human habitation difficult. The Martian atmosphere is extremely thin, with a surface pressure of approximately 600 pascals, and the surface temperature stays very low, around 211 kelvins. The solar radiation keeps fluctuating, and dust storms create wind-driven surface flows. These conditions impose major design restrictions, which require structures to endure high pressure differentials, extreme cold weather and strong wind conditions. Therefore, it is necessary to address these coupled challenges through an integrated design strategy in the early stages of Mars surface habitat development. This work perform a complete numerical analysis using multiphysics approach to study a theoretical Mars sub-surface habitat system. Two habitat geometries, cylindrical and hemispherical, are modeled using CAD and analyzed using commercial finite element and computational fluid dynamics tools. The structural performance analysis assesses internal pressurization which meets human-rated conditions. Thermal behavior is analyzed using steady-state heat transfer analysis of a multilayer wall system comprising an aluminum structural shell, a regolith layer, and a low-conductivity insulation layer. The study includes solar radiation effects through solar flux analysis which considers four representative Martian years (MY48-MY51). Aerodynamic analysis is also performed to evaluate the habitat stability under Mars wind loading .The results demonstrate that habitat geometry and multilayer wall design significantly affect performance. The hemispherical design decreases structural deformation by more than ten times when compared to cylindrical geometries. The thermal analysis demonstrates insulation effectiveness, which results in 80-90% less conductive heat transfer, while regolith provides extra thermal insulation. The aerodynamic results demonstrate that the curved habitat remains stable when exposed to wind forces. The results create a practical base for initial Mars habitat development, which will later include radiation and dust assessment.



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sciforum-163646: Enhanced Trajectory Prediction of Satellites and Space Debris Using Machine Learning and Kalman Filter

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The increasing proliferation of space debris poses a significant and growing threat to operational spacecraft and future space missions. Our research aims to address the growing concern about space debris and the need for accurate trajectory predictions to ensure the safety and sustainability of space operations. Our approach combines machine learning for space object classification with classical filtering techniques for trajectory prediction, resulting in an interactive visualization of the spatial environment. The initial phase of our research consisted of applying a Random Forest Classifier for the accurate detection and classification of space objects, distinguishing between active satellites and space debris. Subsequently, our research used a Kalman filter to predict the trajectories of both active satellites and space debris. This allowed us to obtain dynamic and precise position informations for these space objects. Finally, a 3D visualization has been developed to illustrate the behavior and movement of both debris and active satellites. Preliminary results, obtained by extracting orbital parameters such as semi-major axis, inclination, right ascension of the ascending node (RAAN), argument of perigee, and mean anomaly from Two-line element (TLE) data, indicated a good classification accuracy of approximatively 98% for distinguishing between different types of space objects during the training phase.



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sciforum-163846: Reliable and cost-effective design of the temperature conditioning module for a scientific LEO microsatellite

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In recent years, there has been a proliferation in the launch of small satellites or low-cost constellations for operations related to the Internet of Things (IoT), the measurement of conditions in the space environment, and the testing of commercial instruments in the New Space sector. Controlling the internal temperature of the satellite plays a key role in the durability of the on-board electronics for the success of these missions, making the components responsible for this task a critical part of the space platform. The module developed selects and conditions the temperature signals from the sensors of a satellite in Low-Earth Orbit (LEO) for reading by the on-board computer (OBC), as well as implementing the power supply interface for the internal temperature stabilisation heaters. The design is characterised by its small size and optimal cost, as well as being manufactured with commercial electronic components which have been manufactured under IPC inspection and testing quality standards and UNE-EN standards for the aerospace sector. The preliminary flight model (PFM) has been characterised through electronic tests at room temperature, vibration tests and tests in a thermal-vacuum chamber (TVAC) to simulate space environment conditions, obtaining initial results with average temperature errors of less than 0.25-0.5 °C, with good stability and repeatability. Based on these satisfactory results, the flight module (FM) is expected to undergo qualification testing in a clean room together with the rest of the satellite's avionics and instruments, and to be integrated into the flight platform for launch into space in the near future.



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sciforum-169525: A Hybrid Hardware–Software Power Conservation System for Small Satellite Platforms

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Nanosatellites and CubeSat platforms require power management techniques which function effectively because their size and weight limitations together with their power budget restrict their operational abilities until their mission duration finishes. The existing small satellite system design maintains continuous operation for all onboard equipment, which leads to excessive power consumption and decreased mission duration. The research presents a hybrid power conservation system which combines hardware and software components to solve power conservation issues present in small satellite systems. The system integrates hardware-based power management components which consist of power distribution networks and load switching equipment with onboard microcontroller systems that execute intelligent power management through software. The system establishes three operational modes, which include normal operation power-saving mode and survival mode, to control power consumption based on battery status, mission demands and subsystem operational status. The system disables all non-essential subsystems during low-energy operations while keeping necessary functions active to protect mission security. The system operates under evaluation through simulation analysis, which uses actual subsystem power models together with orbital illumination patterns for assessment. The results show that the system achieves a 25-35% reduction in average power consumption, which leads to longer mission time because traditional systems maintain continuous operation of their subsystems. The proposed approach demonstrates an affordable lightweight solution which enhances energy efficiency for nanosatellite missions, making it appropriate for upcoming long-duration CubeSat and small satellite missions.



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sciforum-169725: A Novel Small Satellite Mission for Antarctic Ice Shelf Monitoring Using Molniya Orbits

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Antarctic ice-shelf movements are essential for controlling sea-level rise and global climate patterns. Continuous monitoring of the region poses substantial challenges due to the vast spatial extent, remote location, and harsh environmental conditions of Antarctica. The Antarctic Ice Exploration Experiment (AICE) mission concept is designed to address these challenges by tracking changes in Antarctic ice shelves using a satellite positioned in a highly elliptical orbit. The mission employs a Synthetic Aperture Radar (SAR)- equipped 12U-class small satellite to effectively monitor designated areas of interest (AOI) over a nominal two-year mission period.

The proposed mission utilizes a single-satellite-single-maneuver (SSSM) configuration to reduce the overall mass of the satellite while minimizing the Δv budget, thereby maintaining the possibility of accessing a high-inclination orbit without any plane-change maneuvers, thus maximizing polar region observation capability. Synthetic Aperture Radar (SAR) was selected as the primary scientific payload for the satellite to collect measurements of ice shelves for its ability to deliver high-resolution imagery in all-weather, day-and-night conditions, ensuring reliable coverage of Antarctic ice shelves. The radar payload features a 30° field of view to maximize the swath exceeding 400km during each pass.

To extend the observation time, the spacecraft is placed on a Molniya orbit with an inclination of 63.4°. It provides over 75% of the mission lifetime worth of observation window dedicated to Antarctic observations. The AICE mission demonstrates the feasibility of a single-satellite, single-maneuver spacecraft with SAR-enabled imagery, enabling sustained monitoring of the Antarctic region in highly elliptical orbits. The approach highlights a scalable and efficient solution for earth observation and information-gathering missions in long-term climate modeling, polar science, and the understanding of ice-sheet dynamics.



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sciforum-161150: A Standardized 3U Common Bus Architecture for Scalable 6U CubeSat Missions

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CubeSat development has historically been mission-specific, with each spacecraft built as a unique integration of avionics, structure, EPS, and ADCS hardware. While this enables tailored optimization, it also increases non-recurring engineering effort, extends integration schedules, and complicates qualification and acceptance testing for every new flight article. As small satellite missions expand beyond academic demonstration toward sustained science and commercial services, the lack of a standardized, reusable bus architecture has become a limiting factor for program throughput and cost efficiency. This work presents a 3U common CubeSat bus designed to interface directly with a 3U payload, forming a complete 6U spacecraft without requiring new bus-level avionics layout, system harnessing, or mechanical redesign for each mission.

The architecture establishes consistent mechanical mounting features, power distribution topology, thermal sink paths, compute resources, and safe-to-mate inhibit logic, enabling payloads to integrate through defined electrical and structural interfaces rather than bespoke bus adaptation. Ten 6U missions launched between 2018 and 2025 were evaluated to derive power, pointing, mass, and data-rate envelopes that guided sizing of solar generation, battery capacity, OBC throughput, and ADCS accommodation. Results indicate that a single, openly defined 3U bus can support multiple payload classes including imaging, RF communications, atmospheric science, and technology demonstration with minimal configuration changes.

This paper argues that the primary value of the proposed bus is not reliability as an outcome, but architectural standardization as the mechanism enabling repeatable manufacturing, faster ATP flow, and reduced development friction across mission sets.



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sciforum-169617: AURORA-HFSM: Autonomous Ultrasound & NIRS Rig for Orbital Redistribution Assessment – Headward Fluid Shift Monitor

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Despite advances in space medicine, astronauts currently lack tools to comprehensively monitor their health in microgravity. This study aimed to demonstrate the potential of multimodal monitoring technologies to track physiological changes in space. The AURORA-HFSM experiment investigates headward fluid shifts and cerebrovascular dynamics during short-term weightlessness.

Healthy volunteers underwent multimodal monitoring during a parabolic flight campaign on the Airbus A310 Zero-G. Measurements integrated ultrasound (US), near-infrared spectroscopy (NIRS), indocyanine green (ICG) impedance tracking, and inertial measurement units (IMU) for motion synchronization. Signals were recorded continuously during each parabola (~22 s microgravity) across three gravity phases: 1.8 g pull-up (baseline), 0 g microgravity, and 1 g recovery. Each flight included 31 parabolas in three blocks, with short intermissions, providing ~11 minutes of cumulative 0 g exposure. This protocol enabled characterization of venous and arterial flow, tissue oxygenation, and thoracic fluid redistribution.

The study will provide the first synchronized multimodal dataset quantifying jugular, cerebral, and thoracic fluid dynamics during parabolic flight. Correlations between US, NIRS, and ICG indices will inform ESA research on intracranial fluid redistribution and guide the design of compact astronaut health-monitoring systems for long-duration missions.

AURORA demonstrates a feasible, safe, and operationally robust platform for multimodal physiological monitoring in microgravity. Medically certified components, low-voltage operation, mechanical robustness, and redundant data acquisition ensure ESA compliance and minimal residual risk. Expected outcomes include novel integrated biomarkers of cerebral hemodynamics, improved diagnostic accuracy, and enhanced monitoring for spaceflight and clinical applications, establishing AURORA as a translational platform bridging space physiology and astronaut health monitoring.



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sciforum-169776: Autonomous Modelling Analytics for Space Ground Vehicles with Multidisciplinary System Design Framework

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Aerospace engineering applications for air and space solutions have been becoming increasingly complex. They are required to provide high performance while keeping sustainable safety in place, particularly when human beings are involved in their operations. Multidisciplinary development teams of engineers, system architects, and other stakeholders typically work together to design such sophisticated man-made systems. They use computer models that have different views of the same aerospace system under development. However, technical collaboration between interested parties becomes a deadlock when representations from each collaborator must be cross-checked across multiple models (from other developers) to assess the impact of diverse viewpoints, e.g., how changes in the software design models affect control design models. Later changes in modelling augment risks and costs as they require synchronization of blueprints by updating, and then re-verifying as well as re-validating each of the model representations.

This paper presents details of the design process of a planet rover in which diverse stakeholders deal with aspects of the space ground vehicles. It includes preliminary results from requirements analysis and system design that are used to interlink system models to set an autonomous crosschecked-model design process. The approach is carried out by a multidisciplinary design framework for development of aerospace systems that is meant to reduce collaborative design efforts by enabling multiple developers to minimize potential design inconsistencies (that ultimately produce downtimes) by means of interconnecting their system models. The framework methodology is based on an Artificial Intelligence (AI) support to autonomously link the parametrical notations from different models for modelling analytics, and for further advice on dependencies between models and actions to be taken. Concluding remarks and future research are also presented.



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sciforum-169829: Clustered Small Satellite Constellations with Inter-Satellite Communication for Enhanced Global Coverage

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The operational capacity of single nanosatellite missions is restricted because they can only cover limited ground areas and have infrequent satellite passes, and their missions stop when any subsystem fails. The increasing demand for Earth observation and environmental monitoring capability requires satellite systems which can deliver extensive coverage, operational resilience and flexible sensing capabilities at economical costs. The paper describes a satellite constellation system which uses cluster operations to enable satellites to work together in small groups instead of functioning as separate units. The cluster contains four nanosatellites which each operate their own dedicated payload system that includes optical imaging and environmental sensing and communication relay and navigation and health monitoring. The mission function distribution across the cluster enables operators to achieve space mission objectives while minimizing operational footprint through system complexity, power needs and satellite weight requirements. The system establishes inter-satellite communication links to support its three operational functions, which include real-time data sharing, collaborative task performance and system fault recovery capabilities between different clusters. The system uses multiple clusters stationed in low Earth orbit to achieve complete Earth surface coverage while maintaining enhanced time resolution capabilities. The paper presents system architecture details together with the payload distribution method, inter-satellite communication system and orbital coverage study, which uses actual nanosatellite specifications. The proposed approach to nanosatellite platforms provides scalability and redundancy together with adaptability to upcoming Earth observation, disaster monitoring, climate studies and space-based sensing operations.



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sciforum-163847: More FLOPS, less mass: enabling future AI missions in Space

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Space-based artificial intelligence (AI) is advancing rapidly with compute efficiency rapidly becoming a critical factor in measuring system capabilities. This abstract analyzes AI compute efficiency—measured in floating-point operations per second per kilogram (FLOPS/kg)—across platforms from 3U CubeSats (~4 kg) to 1000 kg satellites. Historically, larger spacecraft relied on radiation-hardened processors that had very limited compute (a couple hundred MIPs). Recent advances in edge compute have led to the ability of nanosatellites to have gigaflop to teraflop compute capabilities. This comparison of onboard edge AI compute will evaluate the tradeoff with size and compute, demonstrating the closing gap of FLOPS/kg. Space-based missions often evaluate design trade-offs such as form factor power, thermal management, and compute architecture; this work seeks to find the appropriate compute solution for workloads and then compare those to missions capable of running those loads. Early benchmarks show small-satellite GPUs achieving ~14× speedups over legacy processors. Overall, low-mass platforms in LEO are approaching the AI performance per mass of larger systems, enabling new autonomous capabilities and specialized compute workloads. At the end of this work, sample workloads for missions will be explored and will demonstrate how multiple satellites can autonomously carry out larger missions. This work seeks to demonstrate that AI capabilities including increased autonomy and onboard edge computer vision are possible on the smallest space-based platforms.



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sciforum-168594: On the feasibility of a lighter-than-air platform for Martian exploration

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Lighter-than-air platforms are currently gaining the attention of engineers for diverse applications. Beside their superior endurance performance granted by buoyancy as a means for countering weight, electric motors coupled to propellers, with their high thrust-to-weight ratio and small size, allow designers to deploy them within the topology of a novel airship, thus mitigating the inherent controllability issues of these platforms.

Among the missions currently envisaged for airships on Earth are high-altitude pseudo-satellite (HAPS) applications, where the ability of the airship to reposition, further increase its own flight time through solar energy harvesting, and return to base after a long-endurance flight, constitute an interesting alternative for surveillance and intelligence gathering missions traditionally associated with space satellites. Furthermore, the atmospheric and irradiance conditions encountered in the layers of the atmosphere at 18–20 km of altitude are partly similar to those found on non-terrestrial bodies. This naturally suggests an application of airships for non-terrestrial exploration especially on planets where a sufficiently dense atmosphere is present.

Lighter-than-air applications (notably, uncontrolled balloons) have already been attempted on Venus, along with preliminarily studied in the past for both Venus and Mars. However, most of the literature is less recent than the latest developments in technology, especially in solar cells and envelope material, besides that of electric motors and batteries, which nowadays can be exploited to reduce the weight and size of an unmanned airship.

This study, grounded on a pre-existing method for the preliminary sizing of airships already employed for several terrestrial applications, tries to fill this gap by analyzing the sizing solution of an airship for Martian exploration through a parameterized approach. This allows us to study the effect of different technological choices on the sizing solution, highlighting the most relevant bottlenecks towards the feasibility of this concept, dictated by constraints on geometrical dimension and mass.



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sciforum-163356: Optimizing Large-Area Coverage for the LT-4A GEO SAR Satellite: A Hybrid Genetic Algorithm with Adaptive Maneuver Time Control

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This paper introduces a computationally efficient mission planning framework tailored for the Ludi Tance-4A (LT-4A), the world's first operational GEO SAR satellite. The LT-4A's unique figure-8 ground track and large-scale imaging capabilities present complex scheduling challenges. Conventional planning methods often rely on fixed maneuver durations, leading to inefficiencies due to the satellite's evolving orbital geometry.

To address this, we propose an Orbital-Window-Aware Hybrid Genetic Algorithm (OW-HGA) integrated with an adaptive maneuver time calculation method. The approach utilizes a two-phase optimization strategy. An offline preprocessing phase exploits geosynchronous periodicity to identify "Optimal Imaging Windows" (OIWs) and dynamically calculates maneuver times based on real-time attitude adjustments. This converts a complex continuous search into a discrete set of opportunities. Subsequently, an online Genetic Algorithm determines the optimal sequence for these OIWs using rapid database lookups rather than time-consuming orbital calculations.

A case study focusing on the Yangtze River Basin validates the proposed method. Comparative results demonstrate a 19.6% reduction in total mission time against greedy algorithms and a 42% reduction in solution variance compared to standard genetic algorithms. Most notably, the framework achieves a 17-fold improvement in computational efficiency. These findings confirm the algorithm's suitability for real-time mission planning and dynamic replanning for next-generation space-based observation systems.



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sciforum-169867: Staged Excavation for Dust Prevention in Lunar Regolith: Design and Preliminary Results

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Introduction: Dust generation during lunar regolith excavation presents a major challenge for sustained surface operations, with implications for mechanical wear, optical degradation, thermal control, and crew safety. Most current excavation approaches address dust through mitigation techniques applied after particle liberation. In this work, we investigate an alternative strategy focused on dust prevention by design, using a staged excavation architecture intended to limit particle release at the source during material interaction.

System Design: We present the design of a dual-stage excavation and containment subsystem developed as the core functional element of a small-scale experimental platform. The architecture integrates material engagement, controlled internal transport, and temporary storage within a single enclosed cylindrical volume. This configuration is intended to minimize exposure of disturbed regolith to the surrounding environment during insertion and excavation, thereby reducing opportunities for particle entrainment and dispersion.

Experimental Methods: Preliminary experimental testing was conducted in open-air conditions using LMS-1E lunar regolith simulant. The excavation subsystem was mounted on a fixed test jig to isolate excavation behavior from vehicle dynamics, vibration, and wheel-terrain interactions. Dust dispersion was evaluated using gravity-collected particles captured on adhesive sampling pads placed at fixed locations around the excavation zone. Following each test, sampling pads were photographed and weighed to estimate relative dust deposition patterns. Ambient humidity was not controlled during testing.

Results and Discussion: Observations indicate reduced visible dust during both insertion and excavation phases, with dust deposition patterns suggesting localized particle release and limited spatial dispersion. Collected particles on sampling pads were concentrated near the excavation interface, consistent with the staged excavation hypothesis. While the results are preliminary and qualitative, they support the potential of staged excavation architecture as a viable approach for reducing dust generation during lunar regolith operations.



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sciforum-163565: State-Constrained Aeropropulsive Control for Air-Breathing Hypersonic Vehicles

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Samsun University

State-Constrained Aeropropulsive Control for Air-Breathing Hypersonic Air-breathing hypersonic vehicles operate in an extremely challenging flight environment characterized by strong coupling between aerodynamic behavior and propulsion system performance. In such vehicles, aerodynamic maneuvers directly influence inlet shock structures, mass-capture efficiency, combustion stability, and overall engine safety. At high Mach numbers, even small variations in angle of attack, flight path angle, or fuel-air equivalence ratio can cause significant disturbances in inlet flow, leading to reduced pressure recovery, degraded thrust performance, and, in severe cases, engine unstart. These tightly coupled aeropropulsive interactions significantly limit the usable flight envelope and cannot be effectively managed using conventional aerodynamic control strategies that neglect propulsion-related constraints.

To address this limitation, this study presents an integrated aeropropulsive modeling framework that explicitly captures the coupling between the longitudinal flight dynamics of a hypersonic vehicle and key propulsion performance parameters. The proposed model links vehicle motion with inlet total pressure recovery, mass-capture ratio, and combustion stability indicators, providing a unified representation of aerodynamics and propulsion dynamics. Based on this coupled framework, a state-constrained control architecture employing barrier functions is developed to ensure safe operation during flight-condition tracking. The barrier-function-based controller dynamically modifies control authority as critical system states approach predefined propulsion safety boundaries, thereby preventing violations of inlet and engine operating limits.

Simulation results demonstrate that the proposed control strategy effectively suppresses unsafe inlet shock excursions, limits fuel-air equivalence ratio deviations, and maintains stable thrust generation under aggressive maneuvering conditions. Compared to classical control approaches, the proposed method significantly expands the safe operating envelope while preserving aerodynamic performance. These findings emphasize the importance of propulsion-aware and constraint-enforcing control architectures for the reliable operation and future design of air-breathing hypersonic vehicles.



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sciforum-169547: Steady-State Modelling of a Dual Active Bridge Converter for Bidirectional Energy Flow in Space Electrical Power Systems

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AAST

The dual active bridge (DAB) DC–DC converter serves as the primary choice for bidirectional energy conversion systems because it provides galvanic isolation, delivers high power density and enables users to control power flow flexibility, which makes it suitable for advanced aerospace and space power systems. The DAB converter requires precise steady-state modeling to perform performance evaluations and current stress assessments, which lead to control system development for energy-efficient systems. While the use of harmonic-based models is widely found, they often lack a clear connection to time-domain operating principles.

This research establishes a complete steady-state modeling system for dual active bridge converters which begins with time-domain waveform evaluation and ends with basic analytical models. The first part of the analysis establishes the inductor current behavior and power transfer mechanism under steady-state conditions to show how circulating current emerges physically from phase-shift parameters. A fundamental harmonic approximation is then employed to obtain closed-form expressions for power transfer, which are subsequently used to derive a reduced-order, control-oriented model. The proposed modeling approach enables direct connections between time-domain operation and analytical power expressions while maintaining low computational needs.

The paper presents numerical evaluation results and simulation data to prove the accuracy of the developed models, which operate from minimum to maximum operating points of isolated bidirectional converters. The developed framework establishes a solid base which enables researchers to study and create power processing units for spacecraft electrical power systems and energy storage interfaces and other bidirectional aerospace energy conversion platforms.



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sciforum-169541: Study on the development of a propellant tank that enables propellant refilling in microgravity (Verification of the gas-liquid separation mechanism during liquid filling through a short-term microgravity experiment)

Ryoji Imai * and Hiroto Shonai

Muroran Institute of Technology

In recent years, the utilization of space has expanded rapidly across communications and broadcasting, positioning, meteorological observation, and remote sensing, resulting in a sharply increasing demand. Under these circumstances, the number of satellites has surged, elevating the risk of collisions and raising concerns about the growing amount of space debris generated by such collisions. Satellites use liquid propellants for orbital insertion and attitude control, but they reach the end of their operational life when propellant is depleted. Many satellites remain in orbit for extended periods after the end of life, and the need to launch replacement satellites further increases the number of objects in orbit, contributing to the growth of space debris. Conversely, if on-orbit propellant refilling can be realized, it may be possible to extend satellite lifetimes and thereby suppress both the need for replacement launches and the associated increase in space debris.

The ultimate goal of the present study is to establish on-orbit propellant resupply technology, and the objective of this work is to develop in-tank gas-liquid separation techniques during propellant transfer under microgravity conditions, which constitute one of the core enabling technologies for achieving that goal. As the first step in the development of this technology, the behavior of liquid in a small, spherical mock-up tank equipped with a vane-type propellant acquisition mechanism utilizing surface tension was observed during filling with simulated propellant under short-duration microgravity conditions generated using a drop tower. Additionally, a variant of the vane-type propellant acquisition mechanism, with baffles added to the central and top sections of the support rods that install the vanes, was also fabricated and tested. It was found that the gas-liquid separation performance of the configuration with top-mounted baffles was superior to that of the other designs.



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sciforum-169813: VOYCE-M1: An AI-Enabled Nanosatellite Mission for Autonomous Human Voice Transmission and Interplanetary Communication from Mars

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VOYCE-M1 (Voice-Oriented Yielding and Communication Experiment – Mars Mission 1) is an interplanetary technology demonstration satellite intended to validate autonomous, voice-based communication from Mars-distance environments under realistic deep-space constraints. The mission is centered on the concept of “voice as data,” treating human speech not merely as an audio signal but as a structured, time-delayed communication artifact capable of being processed, prioritized, and transmitted autonomously across interplanetary distances. Operating at Earth–Mars ranges, VOYCE-M1 addresses key challenges including extreme signal latency, limited bandwidth, intermittent ground contact, and strict power availability. The spacecraft incorporates an AI-enabled communication system that performs onboard voice encoding, compression, noise filtering, and content management prior to store-and-forward transmission to Earth. This architecture allows voice messages to be generated, curated, and transmitted without continuous ground control, reflecting future human–robot interaction scenarios around Mars. The transmitted voice content may include predefined human messages, autonomous system-generated narration, or mission-status audio summaries, demonstrating both cultural and operational use cases of voice in deep space. In addition to voice transmission, VOYCE-M1 supports context imaging and symbolic messaging experiments to enhance mission validation and outreach. The mission is designed for operational resilience, enabling meaningful voice and data demonstrations during interplanetary cruise and Mars-proximal operations. VOYCE-M1 serves as a precursor to future Mars communication infrastructure, offering critical insights into AI-assisted autonomy, low-power interplanetary communications, and the role of human-centric voice interaction in sustained planetary exploration. This paper outlines, mission and operational planning, technical overview, mass budget, payload systems, and satellite infrastructure.



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sciforum-168831: When Cyber Becomes Physical: Assessing the Impact of Space Cyberattacks on LEO Collision Risk.

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The rapid growth of satellite activity in low Earth orbit (LEO), especially driven by large constellations, has increased the frequency of close approaches and the operational burden of collision avoidance. In this context, cybersecurity incidents are not only an information technology problem but can translate into physical safety risks in orbit. This paper presents a high-level assessment of how representative cyberattack scenarios can affect orbital safety by reducing situational awareness, limiting control authority, or triggering unintended spacecraft behavior.

We frame the problem through an “attack-to-impact” chain linking cyber events to operational degradation and, ultimately, to increased conjunction and collision risk. The discussion covers typical pathways such as loss of communications that shortens the available response window, manipulation of tracking or orbit data that leads to incorrect risk assessment, and unauthorized command execution that can alter trajectories and create secondary close approaches. Rather than focusing on implementation details of specific attacks, we emphasize the resulting operational consequences relevant to satellite operators and mission designers.

The main contribution is a structured viewpoint that connects cybersecurity resilience with orbital safety metrics and highlights why cyber preparedness should be considered part of sustainable LEO operations. We conclude by outlining practical mitigation directions at a conceptual level, including stronger command authentication, safe operational modes, redundancy in critical links, and procedures prioritizing rapid recovery of control and trusted state estimation during elevated conjunction risk periods. This approach supports cross-domain risk thinking and helps bridge the gap between space cybersecurity and debris mitigation discussions.



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Session 4. Digitalization, Autonomy & Airspace Management

sciforum-163609: State-Based Estimation of Future Mission Capability for Degrading Unmanned Aerial Vehicles

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Reliability assessment in complex technical systems often involves capturing the interdependency between multiple subsystems and the gradual loss of their functional effectiveness. This challenge becomes particularly critical in the context of unmanned aerial vehicles (UAVs), where sustained operational capability is essential for the safe execution of autonomous missions. This work presents a state-based methodology to estimate the future mission capability of UAVs subject to progressive component degradation. To generate a representative dataset, numerous simulated flight missions are conducted with randomly varying degradation profiles across multiple actuators. A hidden semi-Markov model (HSMM) is trained on this data to characterize the progressive reduction in system performance over time. To improve model tractability and generalization, raw flight data is first reduced to a concise set of performance-related parameters, from which critical sensor signals—such as roll, pitch, yaw, horizontal and vertical airspeeds, and current consumption—are estimated. The proposed approach enables the identification of system-wide dependencies between degradation patterns and mission-relevant behavior. By linking current operational states to the likelihood of meeting future performance requirements, it offers a quantitative basis for predictive reliability assessment. Looking ahead, this framework may support extensions toward forecasting sensor trends and in-flight anomaly detection, contributing to more anticipatory and resilient UAV operations.



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sciforum-167937: A Compact Multi-Sensor System for Real-Time Micro-Debris Impact Detection in Nanosatellites

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The swift growth in the number of nanosatellites and CubeSats in orbit around the Earth has noticeably amplified the danger of collisions with micrometeoroids and orbital micro-debris. While these particles are tiny, the high relative speeds at which they move can inflict serious damage to the structure, impair the sensors, or render the whole subsystem non-functional, especially in small satellites that have little redundancy. A majority of the current nanosatellite missions do not have specially designed real-time impact detection hardware on board and instead depend on post-mission inspection or indirect signs like telemetry anomalies for their detection. This article describes a system consisting of several sensors that is compact, uses less power, and is able to detect micro-debris impact on the satellites in real time, which was the main reason for its development. The entire system is made up of several sensing elements, such as piezoelectric sensors, MEMS accelerometers, acoustic sensors, magnetic field sensors, and temperature pressure sensors, which respectively take up the different physical signatures produced by debris impacts. The sensor outputs are then directed to the signal conditioning stage, where filtering and normalization are performed. After this, a threshold-based event detection logic combined with a weighted multi-sensor data fusion method is applied to enhance detection reliability and lower the number of incorrect triggers caused by normal satellite operations. The system deploys event-driven logic for independent and low-power surveillance. Impact occurrences are recorded, sent, or kept with time stamps. The combination of the sensors increases the dependability, separates the background noise from the impacts, and makes possible the logging, power management, and integration of the nanosatellite without interruption, supporting the safety of long-term missions.



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sciforum-169784: Acoustic sensor-based runway health monitoring system

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This work presents the development of an Advanced Runway Health Monitoring System (ARHMS) that combines acoustic sensors with machine learning-based computer vision to enable real-time runway condition assessment. The proposed system addresses critical safety issues such as surface defects, foreign object debris, and structural integrity that are often overlooked during conventional manual inspections. By employing YOLOv8 for accurate object detection and OpenCV for image processing, the prototype was trained on over 600 images from Kaggle datasets and evaluated using a scaled physical runway model. The results demonstrate strong accuracy in hazard detection and highlight the system's potential for mobile deployment and future predictive capabilities. Key contributions include a hybrid acoustic-vision monitoring framework, analysis of real-world runway incidents, and practical recommendations for preventive maintenance. Despite challenges such as daylight dependency and occasional false positives, this study establishes a promising proof-of-concept for non-intrusive, AI-assisted runway monitoring aimed at significantly enhancing aviation safety.

The results showcase impressive accuracy in hazard detection, with exciting potential for mobile deployment and advanced predictive capabilities in the future. Key contributions of this research include the development of a hybrid acoustic-vision workflow, in-depth analysis of real-life incidents, and actionable recommendations for preventive maintenance. While we acknowledge challenges such as daylight dependency and the occurrence of false positives, we also outline a clear roadmap for scaling this system to operational use. This work not only serves as a compelling proof-of-concept for AI-assisted runway safety but also underscores the critical need for non-intrusive, real-time monitoring to significantly reduce runway-related accidents.



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sciforum-131814: Cognitive Offloading: A Human-Centered Gap in Interface Design Standards

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In high-complexity systems such as aerospace interfaces, operational forgetting is a silent but critical challenge, particularly under time pressure, multitasking, or cognitive fatigue. Existing standards for user interfaces emphasize fixed color codes for alerts and status indicators, but they offer limited support for memory scaffolding, contextual grouping, or functional proximity visualization.

This paper introduces a human-centered design concept: symbolic color grouping as a cognitive offloading mechanism. Drawing from personal workflow strategies and cognitive theory, the approach uses shared symbolic color logic, visual proximity, and functional clustering to help operators recall, prioritize, and navigate information more intuitively. Unlike rigid alert-based systems, this method does not replace existing standards, but adds a dynamic layer of visual organization that supports memory and reduces overload without increasing risk.

As the research methodology, this study presents a comparative analysis of current interface standards, i.e., ISO 9241, MIL-STD-1472, and ARINC display protocols, and reveals the gap in addressing visual memory support and symbolic association in system design. The proposed concept addresses this absence by offering a scalable, minimally disruptive enhancement methodology, suitable for cockpit interfaces, space systems, and autonomous mission dashboards. While designed to complement and not replace the existing alert systems, this approach is especially effective during non-critical or transitional phases of operation, where operators rely more heavily on memory and intuitive navigation. In such contexts, symbolic color and spatial grouping enhance recall, reduce effort, and support task continuity. Its potential for broader integration remains open to future validation.



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sciforum-166452: Free Vibration Analysis Of a Pre-Twisted Composite Beam

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This project deals with the numerical analysis of a composite cantilever beam that represents a section of a helicopter propeller blade. The analysis is carried out using ANSYS software, with the beam modeled using Fiber-Reinforced Polymer materials such as Carbon Fiber-Reinforced Polymer (CFRP) and Glass Fiber-Reinforced Polymer (GFRP). Since helicopter blades are usually pre-twisted to improve their aerodynamic performance, this study considers both the pre-twisted geometry and the anisotropic nature of composite materials. Modal analysis is performed to understand the natural frequencies and vibration modes of the beam.

Torsional vibrations are especially important in rotating blade structures, as they can lead to problems such as flutter, stall-induced vibrations, and structural instability. The interaction between axial forces and torsional motion, known as tension-torsion coupling, is examined to understand effects like blade untwisting and torsional stiffening. These phenomena are important in modern rotor blade design, where passive twist control is achieved through proper material tailoring.

The finite element model includes bending, torsion, shear deformation, and material directionality to accurately capture the dynamic behavior. The results show that pre-twist and material anisotropy significantly influence the vibration response. Overall, this study highlights how composite materials and structural tailoring can be effectively used to improve vibration control and performance in helicopter rotor blades.



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sciforum-163533: From Ground-Centric Control to On-Orbit Intelligence: Enabling Autonomous Satellite Constellations with Edge AI

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The rapid expansion of satellite constellations has fundamentally transformed space operations, resulting in unprecedented volumes of onboard data and increasing dependence on limited downlink capacity and ground-based processing. This traditional ground-centric paradigm introduces latency, scalability challenges, and operational inefficiencies, particularly for time-critical applications such as anomaly detection, Earth observation, and constellation-level coordination. As the number of satellites continues to grow, these limitations pose significant risks to the sustainability and responsiveness of future space systems.

This paper proposes an edge AI-enabled framework for on-orbit intelligence that shifts key decision-making processes from ground stations to the satellites themselves. Lightweight machine learning models are deployed onboard to perform real-time data filtering, prioritization, and anomaly detection, allowing only high-value information to be transmitted to Earth. By reducing unnecessary data transmission, the proposed approach alleviates communication bottlenecks while improving operational agility.

A conceptual system architecture is presented to illustrate how edge AI can be integrated into resource-constrained space environments. Design considerations such as power limitations, radiation exposure, fault tolerance, and model update strategies are discussed to highlight practical deployment challenges. The framework emphasizes scalability and resilience, making it suitable for large and heterogeneous satellite constellations.

This study demonstrates how relocating intelligence from ground control to orbit can enhance system autonomy, reduce downlink dependency, and support more sustainable space operations. By advancing the digitalization and autonomy of space systems, this work contributes to the development of next-generation aerospace architectures and provides actionable insights for AI-enabled satellite constellation design.



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sciforum-144984: Geometric MPC for Robust UAV Flights using a 2-Manifold approach

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As Unmanned Aerial Vehicles (UAVs) are increasingly deployed in complex, cluttered, and dynamically changing environments, conventional Euclidean control architectures based on Euler-angle parameterizations exhibit fundamental limitations. These include representation singularities, gimbal lock, and degraded control performance during aggressive maneuvers such as high-speed turns, rapid attitude changes, and near-hover transitions under actuator saturation. To address these challenges, this paper proposes a unified navigation and control framework that models the multi-rotor UAV configuration directly on the Special Euclidean group $SE(3)$. By exploiting the intrinsic geometric structure of the configuration manifold, the proposed formulation provides a singularity-free representation of coupled translational and rotational dynamics, thereby avoiding the drawbacks associated with local attitude parameterizations and under-actuation-induced singularities. Building upon the $SE(3)$ modeling framework, an $SE(3)$ -consistent Model Predictive Control (MPC) scheme is developed for trajectory tracking and obstacle-aware navigation. The proposed MPC explicitly incorporates physical and operational constraints, including actuator saturation limits, vehicle dynamics, and safety margins with respect to static and dynamic obstacles. This allows the controller to generate dynamically feasible control inputs while maintaining robustness in challenging flight regimes. The overall framework is implemented and evaluated using high-fidelity simulations in the MATLAB/Simulink UAV Toolbox, enabling realistic modeling of aerodynamics, sensing, and actuation. Simulation results obtained across aggressive, high-curvature flight scenarios demonstrate that the proposed geometric MPC approach achieves improved tracking accuracy, smoother control inputs, and enhanced robustness compared to conventional cascaded position-attitude control architectures. Furthermore, the computational performance remains suitable for real-time receding-horizon execution. These results indicate that geometric manifold-based control provides a principled and effective foundation for constraint-aware autonomy and reliable sim-to-real transfer in advanced multi-rotor UAV applications.



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sciforum-169347: Ground-Based Estimation of Low-Altitude Turbulence Over Milan for Safer Airship and UAV Operations

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Reliable characterization of atmospheric turbulence in the urban boundary layer is critical for the flight safety and structural integrity of light aerial platforms operating below 300 m. For unmanned airships, in particular, turbulence represents a well-known complication factor due to their large aerodynamic surfaces and low-speed flight regimes. An accurate understanding of near-ground conditions is essential for these vehicles, especially in Milan, where experimental activities are scheduled as part of the IPROP project. However, conventional high-resolution sensing infrastructure is often too costly or spatially sparse for real-time deployment. This study proposes a low-cost turbulence-intensity proxy, T_b , derived from standard 10-minute ground-based meteorological data. The metric is defined as $T_b(t) = \alpha|dU/dt| + \beta\sigma_U$, capturing both impulsive shear transients and stochastic fluctuations.

The methodology was evaluated using data from two Milanese stations during April–May 2025: Lambrate (suburban) and P.zza Zavattari (dense urban core). The results show that the suburban site exhibits higher dynamic activity, with a mean T_b of 0.142 and peak excursions exceeding 0.36, indicating frequent shear-driven bursts. Conversely, the urban core shows a smoother environment with a mean T_b of 0.097. This work maps these proxies to three operational risk categories—Nominal, Elevated Workload, and Caution—providing a practical heuristic for mission planning. The findings underscore the necessity of localized hazard mapping for Urban Air Mobility (UAM) and experimental airship operations in complex metropolitan airspaces.



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sciforum-163830: Interpretable Machine Learning for Nonlinear Control via Kolmogorov–Arnold Decomposition

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Introduction

The increasing use of machine learning in aerospace control systems poses critical questions related to explainability, verification, and certification. While black-box approaches can achieve high performance, their limited transparency remains a major barrier for deployment in safety-critical applications. This work addresses this gap by focusing on interpretable machine-learning methods for nonlinear control, aiming to balance learning-based performance with the explainability and analysability required in aerospace engineering.

Methods

An interpretable control framework is considered, based on a deliberate separation between optimal control generation and control-law learning. Open-loop optimal trajectories are first computed for nonlinear systems and subsequently used to identify closed-loop feedback laws via symbolic regression. Two complementary approaches are employed: (i) genetic programming with integrated continuous parameter optimisation, enabling compact symbolic controllers, and (ii) Kolmogorov–Arnold-based decompositions that reduce high-dimensional learning problems into structured combinations of univariate functions. This decomposition is particularly attractive for explainability, as it exposes the functional role of individual state variables within the control law.

Results

The approach is demonstrated on textbook nonlinear control problems, where fully interpretable feedback laws achieve performance comparable to reference optimal solutions and classical controllers. For aeronautical applications, the framework is applied to stability augmentation and tracking tasks on a nonlinear aircraft model, with emphasis on controller transparency rather than aggressive performance tuning. Results indicate that Kolmogorov–Arnold representations offer improved scalability and readability compared to direct symbolic regression, enabling meaningful inspection of control structure and sensitivities. Initial closed-loop validations and limited robustness analyses support the practical relevance of the method.

Conclusions

This work contributes to the development of explainable learning-based control for aerospace systems, offering a viable pathway toward controllers that are not only effective but also interpretable and verifiable. By prioritising transparency and structural insight, the proposed approach aligns with emerging certification and assurance needs for autonomous and highly nonlinear aerospace systems.



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sciforum-169380: Laser-Based Satellite Debris mitigation system

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The rapid increase in satellites and spacecraft has led to a critical rise in orbital debris, posing severe risks to active missions and long-term sustainability in space. Defunct satellites, spent rocket stages, and collision fragments threaten to trigger cascading collisions, making active debris mitigation an urgent priority. This project investigates a space-based laser debris mitigation system as a proactive solution to reduce orbital debris hazards.

The proposed system employs high-powered lasers mounted on space-based platforms equipped with precision pointing, advanced optics, and real-time tracking technologies. Unlike ground-based systems, space deployment eliminates atmospheric interference and enables direct access to debris across multiple orbital regimes, including LEO, MEO, and GEO. The operational principle involves directing focused laser pulses at debris surfaces to induce localized ablation, generating a recoil force that alters the object's velocity and trajectory. This controlled perturbation enables orbital decay or relocation to less congested regions.

Integrated debris tracking, adaptive control algorithms, and optimized laser parameters ensure effective engagement across a wide range of debris sizes and materials. The system's versatility allows mitigation of both large trackable objects and smaller high-risk fragments.

Key challenges include high power demand, energy storage, thermal management, system integration, and international regulatory concerns related to the dual-use nature of directed-energy technologies. Future work will focus on improving laser efficiency, compact power systems, advanced tracking algorithms, and simulation-based validation, alongside international collaboration.

Overall, space-based laser debris mitigation offers a scalable and effective approach to enhancing orbital safety and ensuring the long-term sustainability of space operations.



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sciforum-168706: Robust AI-Assisted HPC Borescope Inspection: Evaluating Stage-Level Decisions and Viewpoint Generalisation

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Borescope inspection of aircraft engine high-pressure compressors (HPCs) is safety-critical yet remains highly manual because inspection footage is noisy (blur, glare, occlusion), viewpoints vary across blade regions, and decisions must be traceable for audit. While deep learning has been applied to aero-engine defect detection, most studies focus on curated single-frame “snapshot” evaluation and accuracy, with limited attention to workflow-level decisions, evidence traceability (frames/timestamps), shortcut learning from on-screen UI overlays, and generalisation under real inspection view shift. This research proposes an audit-friendly decision support approach for HPC borescope inspection that outputs stage/segment-level decisions (AUTO_PASS/ NEEDS_REVIEW/AUTO_FLAG) together with evidence frames and timestamps. Using borescope videos from seven engines, covering early, mid, and late segments of the HPC, we construct a real-workflow dataset, exclude frames with unmaskable overlay states, and evaluate generalisation with engine-holdout, stage/segment-holdout, and view-holdout protocols. As a baseline, we train a ResNet-18 classifier using stage-level defect labels, then develop an event-window evidence model that learns from temporally localised defect windows and aggregates Top-K supporting frames (with timestamps) to form stage/segment-level decisions. UI overlays are neutralised to reduce shortcut learning, and leakage control is verified via UI-only “cheat tests.” Across engine-holdout folds, the proposed evidence-frame approach is expected to deliver high defect sensitivity with improved specificity compared with stage-label baseline, by leveraging temporally localised event learning and Top-K evidence aggregation to suppress UI- and noise-driven false positives. Robustness will be assessed by the stability of stage/segment-level decisions under realistic degradations, with low flip rates anticipated at the chosen operating point. In view-holdout transfer (Root-to-Platform vs. LE/Upper-Blade-to-Tip) and stage/segment-holdout, a measurable performance shift is anticipated, motivating explicit viewpoint validation when claiming inspection coverage. Overall, this work reframes borescope AI from image classification to audit-ready decision support aligned with real inspection workflows.



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sciforum-169655: Telemetry-Driven Predictive Maintenance of Satellite Electronics for Nanosatellite Applications

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Nanosatellites and small satellites use multiple compact electronic systems to execute their essential functions of power control and communication and data processing. The entire mission can be affected if electronic components fail because satellites become unrepairable after reaching orbit. Current satellite health monitoring systems depend on fixed threshold values which use telemetry data to monitor temperature and voltage levels. The methods which exist at present can identify problems only after actual damage has begun to occur. The current situation requires development of predictive maintenance methods which can detect early signs of equipment failure before actual breakdowns happen. This research introduces a predictive maintenance system which utilizes telemetry time-series data to monitor satellite electronic equipment. The study analyzes major system components through temperature measurements, voltage readings, current flow data and reset events from essential onboard electronic systems. The process starts with telemetry data cleaning and normalization while the data extraction process begins with essential feature identification. The machine learning models are developed to identify normal and degraded operational patterns which enable them to predict potential system failures. The study demonstrates that the proposed method outperforms traditional threshold-based monitoring systems through its enhanced ability to predict faults. The developed system is well suited for nanosatellite platforms because it requires low computational resources and can be implemented either onboard or at the ground station. This method will enable future satellite operations to perform autonomous health monitoring and extend mission duration while enhancing the dependability of nanosatellite networks.



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