Research Projects @ISAE-SUPAERO

Year 2026

Welcome to the student research projects at **ISAE-SUPAERO!**

Below, you will find the complete list of research topics available for the year 2026, covering formats ranging from short research projects (2 months) to full Master's theses.

These research projects are reserved for students from partner universities within the framework of established academic exchange agreements.

Applications must therefore be submitted through the following portal:
https://questionnaires.isae.fr/index.php/169798?lang=en

Students can select up to 10 projects, depending on availabilities.

Selected students will have the opportunity to carry out their research project within one of ISAE-SUPAERO's laboratories and to benefit from a high-level academic and scientific environment in Toulouse.

If you have some questions do not hesitate to send us an email:
international@isae-supaero.fr

The ISAE-SUPAERO International Office

List of projects

Methods for data reduction of double cantilever beam (DCB) test

Description:

The use of laminated materials leading to laminated composite structures for aircraft structural parts aims at increasing the strength to mass ratio: more strength at lesser mass. Laminated composite structures, including adhesive bonded joints, induce the presence of interfaces, subjected to debonding or delamination. For the designer, the strength prediction of composite structures including their interface is then crucial. During the presizing stages, analytical or semi-analytical based methods are preferred since they allow for a quick decision process. The stake associated is then to control the fidelity of models wrt the physical reality.This Research Project (RP) is focused on the delamination in mode I through the use of the double cantilever test (DCB) specimen for composite materials and adhesively bonded joints. The DCB test allows for the measurement of the fracture toughness of the interface (interlaminar or adhesive) in mode I. The use of enriched data reduction method can be used to represent the interface as a cohesive zone model (CZM): J-integral based method. This method makes use of the measurement the local opening at crack tip, which is difficult to measure during experimental test. In this context, the objective is to assess new data reduction scheme of DCB test to assess the CZM based on experimental measurement point easily to monitor and to simulate as the displacement at load point.literature review of data reduction scheme for DCB and analytical solutions for DCB tests (a detailed report will be provided) adaptation of J-integral based method to replace the opening displacement at crack tip by the load point displacement as function of simplified hypotheses used in the various data reduction schemes in the literature assessment of the sensitivity of the results of new data reduction schemes on the measurement capabilities validation of relevant new data reduction schemes by numerical and eventually experimental tests

In this context, the objective is to assess new data reduction scheme of DCB test to assess the CZM based on experimental measurement point easily to monitor and to simulate as the displacement at load point.
The work is composed by:
- literature review of data reduction scheme for DCB and analytical solutions for DCB tests (a detailed report will be provided)
- adaptation of J-integral based method to replace the opening displacement at crack tip by the load point displacement as function of simplified hypotheses used in the various data reduction schemes in the literature
- assessment of the sensitivity of the results of new data reduction schemes on the measurement capabilities
- validation of relevant new data reduction schemes by numerical and eventually experimental tests

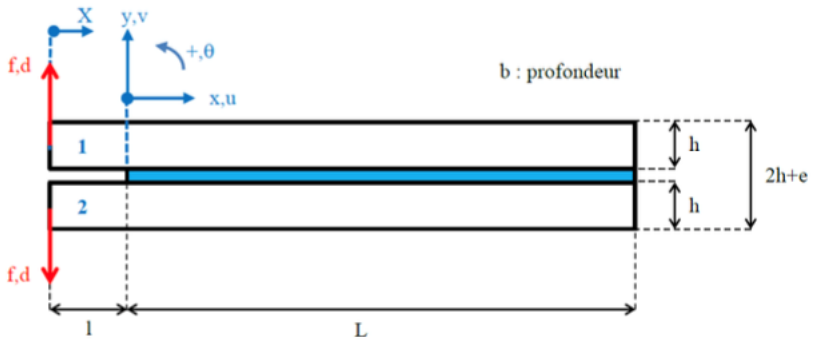


Figure 1 – DCB test.

Control of a wing-tip vortex by continuous steady forcing

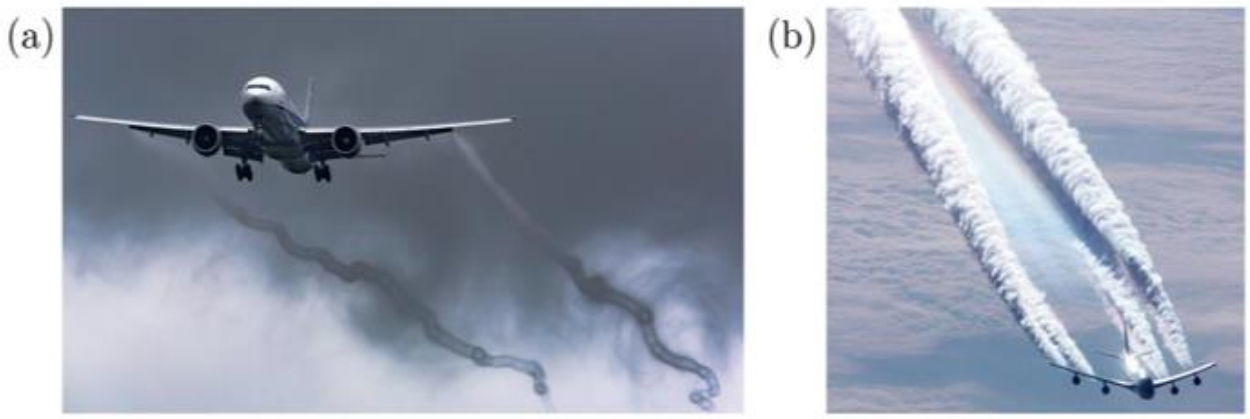


Figure 1: Condensation trailing vortices. (a) Photography taken in a high-lift configuration by Ryoh Ishihara and (b) photography taken by Joseph P. Williams in cruise flight where engine effluents enable the visualisation of these wake vortices.

The aim of this research project is to investigate the stability of vortices alike those shed downstream the aircraft wingtips when they are submitted to a continuous steady forcing. These condensation trailing vortices (*contrails*) illustrated in figure 1 play an important role both in the climate impact of aircraft by means of non-CO_2 effects and the generation of artificial cirrus clouds (Lee *et al.*, 2009) and in the aeronautical safety via the effect of the vortex wake on a neighbouring aircraft.

The vortex model used in this study is the q-vortex model, commonly used in the scientific literature (Fabre & Jacquin, 1992):

$$U_r(r) = 0, \quad U_\theta(r) = \frac{q}{r}\left(1 - e^{-r^2}\right), \quad U_z(r) = e^{-r^2} \tag{1}$$

where q is the vortex swirl number. In this project, we consider two strategies of control: one based on the injection of a light fluid at the wing tip and a second one through a continuous volumic forcing. These two types of controls aim at triggering instabilities of Rayleigh–Taylor

type (Joly *et al.*, 2005; Sablon *et al.*, 2023). The density profile associated to the light fluid injection is illustrated in figure 2 together with the azimuthal velocity component of the vortex and correspond to the following analytical expression:

$$R(r) = 1 + \left(\frac{2At}{1-At}\right) e^{-\left(\frac{r-r_0}{\sigma_\rho}\right)^2} \tag{2}$$

where the Atwood number At drives the intensity of the density variation induced by the injection, r_0 corresponds to the radius where the injection is located and σ_ρ controls the radial extent of the injection. This kind of injection can be generated either by hot air bleed from the engine for conventional aircraft or H_2 injection for future hydrogen-powered aircraft. The continuous forcing aims at representing any kind of perturbations that can be encountered naturally or generated by an actuation device. The idea is to identify the region of the flow where the steady forcing is the most efficient forcing for triggering the instabilities.

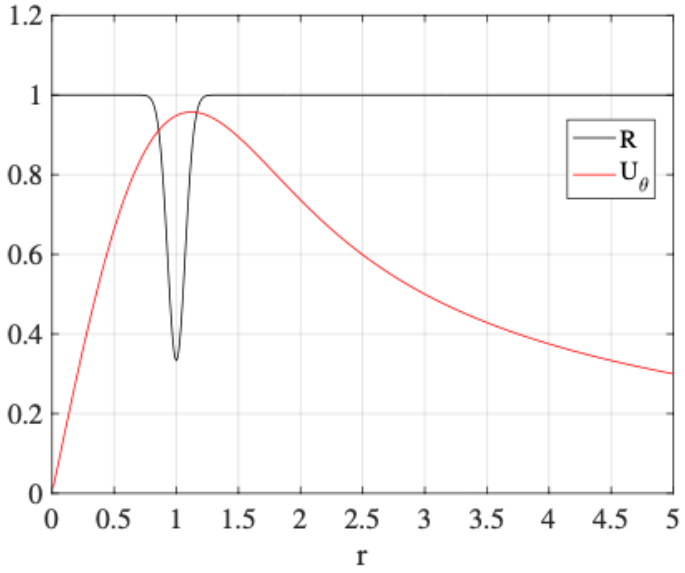


Figure 2: Azimuthal velocity profile of the q-vortex for $q = 1.5$ and density profile corresponding to the injection of the light fluid for $At = -0.5$, $r_0 = 1$ and $\sigma_\rho = 0.1$.

The research project is planned in three stages. The first step is to identify the flow regions where the continuous steady forcing is the most efficient. For that purpose, we adopt a methodology based on a variational optimisation method (Nastro *et al.*, 2023). The sensitivity to a steady force is obtained by adapting the in-house linear direct-adjoint stability code `dalsa`. Once the optimal forcing is obtained, the second step consists in performing nonlinear direct simulations, in which this forcing is introduced, in order to obtain a new solution corresponding to the forced vortex. At the end, the final stage is to verify and quantify the effect of the forcing on the amplification of instabilities by using again the `dalsa` stability code.

Teleoperation of a Robotic Arm for Space Applications

Description:

This Master's research project will focus on the teleoperation of a robotic arm for space applications, conducted jointly between IISc (Bangalore) and ISAE-SUPAERO (Toulouse). The objective is to establish a communication protocol enabling remote control of a CPS robotic arm at IISc from the Human Factors Lab at ISAE-SUPAERO, and to study human performance and physiological reactions in teleoperated payload relocation tasks. The experimental setup involves a 6-DoF robotic arm operating near a cylindrical space-module mock-up with docking ports and obstacles, while operators in Toulouse perform tasks such as picking up and docking a payload via a web interface. Performance metrics (time, collisions, docking success, corrective maneuvers) will be combined with workload assessments (NASA-TLX, ECG) and correlations with cognitive/perceptual tests.

Two MSc students will collaborate on complementary aspects: one will develop the web-based teleoperation interface using ROS2, while the other will implement task programming and control of the JetRover robotic arm on a Jetson Orin Nano platform. Both students should have a strong background and interest in robotics, programming, and human–machine interaction, and be capable of working autonomously within an international, interdisciplinary environment.

Delamination behavior of composite materials: bifurcation analysis of DCB test

Description:

The use of composite materials on aircraft structures aims at increasing the strength to mass ratio: more strength at lesser mass. Fort the designer, the strength prediction of composite structures is then crucial.

During the presizing stages, analytical or semi-analytical based methods are preferred since they allow for a quick decision process. The stake associated is then to control the fidelity of models wrt the physical reality.

This Research Project is focused on the delamination in mode I using the double cantilever test (DCB) specimen for composite materials and adhesively bonded joints (see Figure. 1). The DCB test allows for the measurement of the fracture toughness of the interface (interlaminar or adhesive) in mode I. Moreover, the nonlinearities present in the analytical equations open the door to more in-depth analysis, particularly regarding the multi-solution behavior.
In this context, the objective of this research project is to assess the ability of models to be representative for the physical reality at meso and macro-scale as function of their underlying hypotheses.

A step-by-step approach will be followed.
As a first step, the bibliographic review will lead to (i) the identification of classical methods to post-process DCB test specimen (area, compliance, J integral), (ii) their application of judicious test cases and (iii) the influence of geometrical and material inhomogeneities on the crack propagation.
As a second step, based on a pre-existing work done by the tutors on an analytical formulation involving the cohesive zone (CZM) modelling as well as the energy stress coupled criterion, the analysis for the existence and unicity of theoretical solution will be undertaken. This step will utilize the continuation method to conduct various parametric studies and investigate the formulation of "static" bifurcations in DCB specimens.
Within this step, a first approach could be to consider brittle failure, to uncouple the effect of damaging processes.
As a third step, an extension to a dynamic analysis could be suggested.

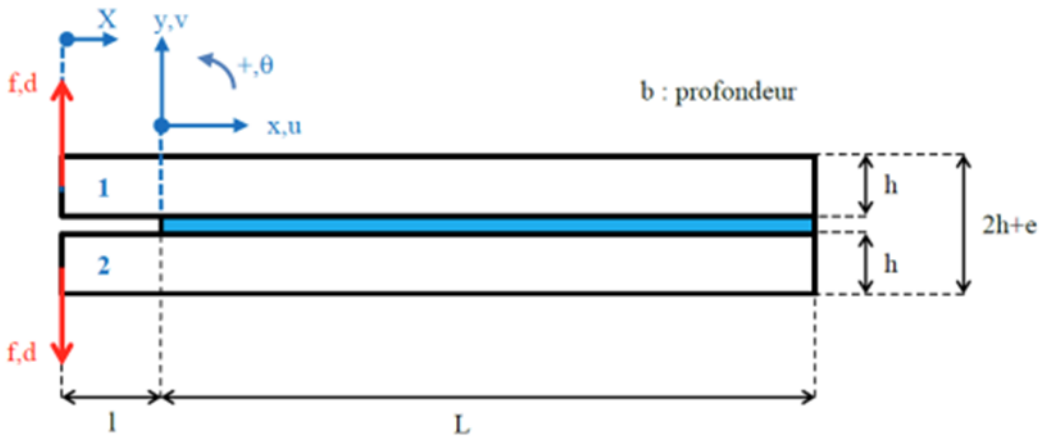


Figure 1 – DCB test.

Artificial General Intelligent Robot (AGIR) for Domestic Robotic Systems

Description:

This project addresses a frontier challenge in the domain of intelligent robotics: the development of an Artificial General Intelligent Robot (AGIR) capable of performing generalized domestic tasks with adaptive intelligence and robust control. The system will be designed to operate in realtime, respond intelligently to unstructured human environments, and execute tasks involving both physical interaction and context awareness. The central research axis involves the integration of embedded systems, real-time control architectures, and adaptive AI modules focusing not only on function but also on safe, stable, and human-intuitive behavior. This project is ideal for students aiming to contribute to the next generation of human-centric AI systems — merging advanced robotics, embedded control, and cognitive modelling The long-term research aim is to model and embed the decision-making behavior, task knowledge, and interaction style of a human subject into the AGIR system, creating an intelligent agent capable of replicating human-like responses and actions in domestic environments.

Research Objectives:

• To develop embedded, real-time control frameworks for humanoid robotics with dynamic motion capabilities.
• To design adaptive feedback control systems for compliant, safe, and context-responsive actuation.
• To study the integration of AI-based decision layers within safety-critical control loops.
• To validate motion and interaction strategies through simulation and perceptual feedback models.
• To investigate knowledge representation and learning methods that enable the robot to replicate human reasoning and respond with context-aware, personality-matched intelligence.

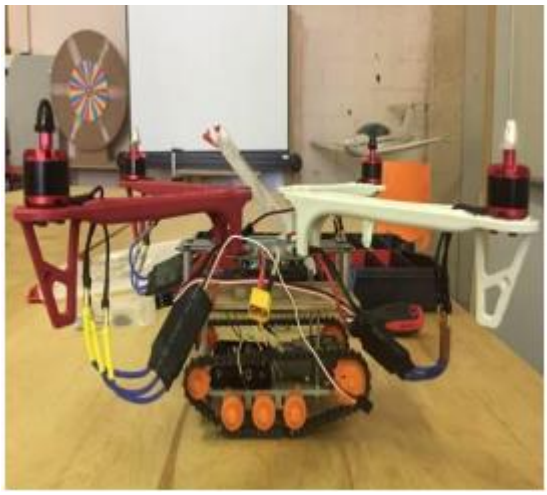
Edge AI Powered Autonomous Robotic Aerial Vehicle for BVLOS Disaster Missions

Description:

This research project explores the design and validation of a BVLOS capable Autonomous Robotic Aerial Vehicle (ARAV) enhanced with Edge AI for real time, mission critical deployment in disaster scenarios. The system is intended to function in environments where traditional connectivity is compromised, GPS signals are unreliable, and human access is limited or unsafe. The proposed ARAV platform will integrate embedded sensor fusion, onboard AI decision systems, and real-time control logic for remote operability to deliver intelligent autonomy. Key capabilities include navigating through collapsed structures, dynamically avoiding obstacles, and completing defined missions with minimal supervision. This project presents a high-impact research opportunity for embedded systems and robotics students, situated at the intersection of real-time computing, AI hardware-software integration, and autonomous aerial navigation.

Research Objectives:

• To develop and optimize edge based AI algorithms for real time obstacle detection, classification, and avoidance.
• To evaluate multi sensor fusion techniques for autonomous spatial awareness in GPS denied and cluttered environments.
• To design a robust autonomy first communication framework that enables BVLOS mission control under bandwidth limitations.
• To simulate and validate disaster response scenarios using embedded autonomy in closed loop field conditions.



Stratospheric UAS under aerological perturbations

Description:

Ultra-high endurance unmanned aircraft systems (UAS) operating in the stratosphere, i.e. above the standard commercial airspace, are under consideration to complement high altitude satellites for missions of observations. Because of the local air density and their typical size and speed, stratospheric UAS operate in the transitional flow regime where the laminar boundary layer is prone to separation, transition and reattachment (see figure 1). This complex scenario influences aerodynamic forces experienced by the aircraft and is very sensitive to aerological perturbations.

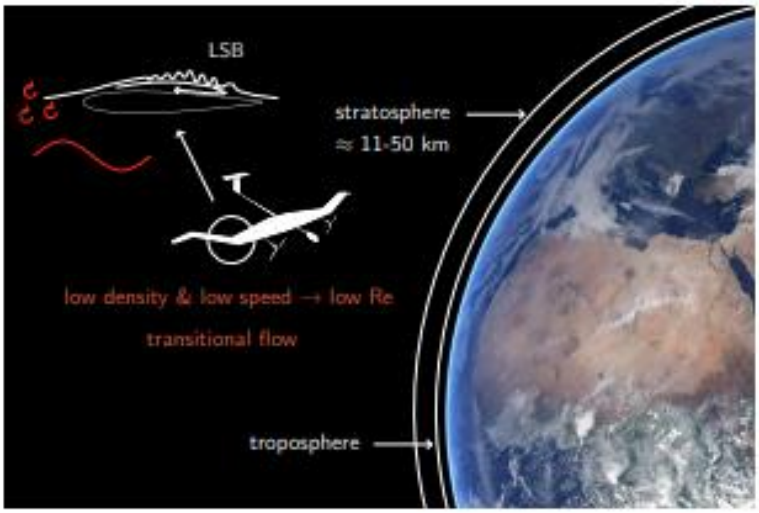


Figure 1: Illustration of the context

Here, we aim to conduct numerical simulations of the flow past a UAS wing under aerological perturbations (see figure 2) with flap control that counteracts the effect of perturbations on lift. The flap control law will first be defined using an analytical model based on unsteady thin airfoil theory and then implemented in the numerical simulation. Numerical data will be used for advanced analysis to understand the physical mechanisms behind the mitigation of lift fluctuations when actuating the flap.

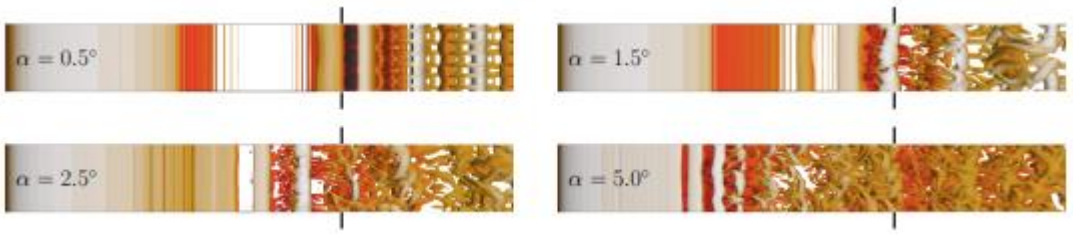


Figure 2: Transitioning flow past a NACA0012 airfoil (top view of Q-criterion isosurfaces) We seek undergraduate candidates with first experience in CFD (StarCCM+), unsteady thin airfoil theory and transitioning boundary layers.

SimWind - Development of a MATLAB/Simulink toolbox for the design and modeling of aerodynamic wind tunnels

Description:

The design of aerodynamic wind tunnels—whether for research, education, or industrial applications—requires a detailed understanding of flow behavior and pressure losses in each component. However, there is currently no simple, modular, and accessible tool to assist engineers in this process.

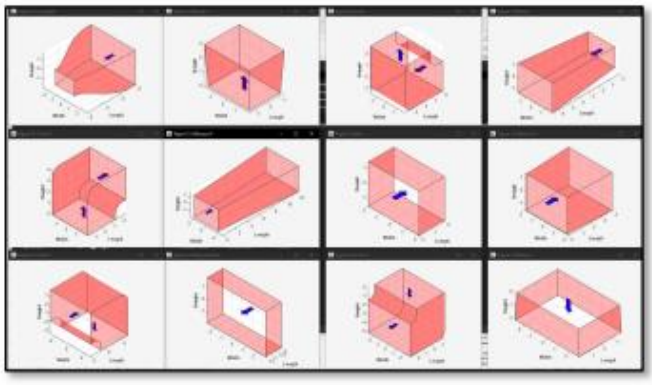
The **SimWind** project aims to develop a **MATLAB/Simulink** toolbox to model the main components of a wind tunnel (contraction, diffuser, test section, bends, fans, etc.) using a modular and scalable approach. This library will enable users to simulate different tunnel architectures (Eiffel type, closed loop, open/closed test section) and evaluate their global performance (flow velocity, pressure losses, required power).

Students will have access to:

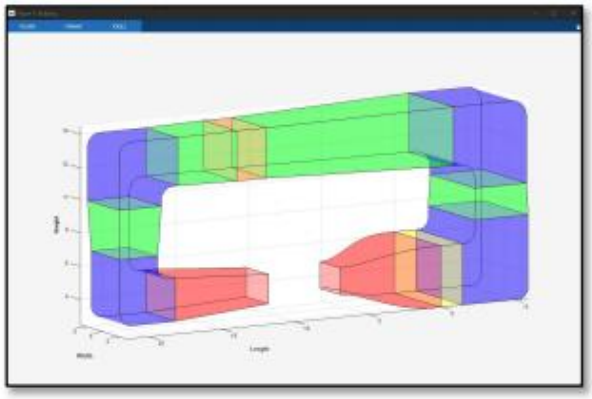
- an existing MATLAB code used for a real wind tunnel,
- a specialized bibliography and reference textbook,
- occasional technical support from a **MathWorks** expert.

Objectives:

- Design a Simulink block library modeling the main aerodynamic wind tunnel components.
- Integrate the relevant physical equations (1D flow, standard pressure losses) for each block.
- Simulate and evaluate various tunnel architectures and configurations.
- Ensure modularity, reusability, and clear documentation for professional or educational use.
- Validate the toolbox through case studies from the literature (Eiffel-type, closed-return tunnels, etc.).
- Optionally, develop a 2D/3D visualization tool to display assembled tunnel configurations.



Example illustrating the different components of a wind tunnel (contraction, test section, bend, fan, diffuser). Each sub-part will correspond to a model element in the future Simulink toolbox.
S. Prothin, 2020



MATLAB-generated geometric representation showing the complete tunnel configuration and the airflow path.
S. Prothin, 2020

WaGGner IV - Design and Modeling of a Flow Conditioner for the WaGGner Fan-Array Wall

Description:

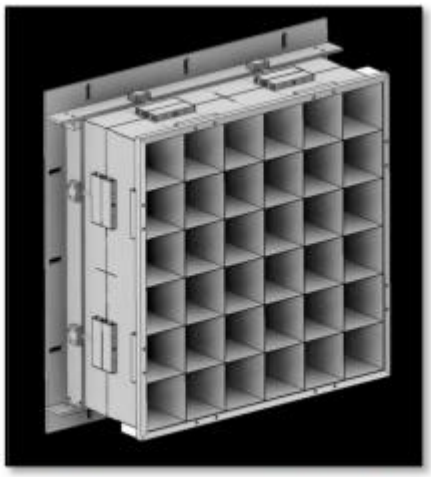
Multi-fan wall test benches offer a flexible and modular alternative to conventional wind tunnels for generating controlled wind conditions in the laboratory. By adjusting the speed and spatial distribution of each module, they can reproduce a wide variety of flow configurations — from uniform streams to complex spatial and temporal gradients. Such systems are particularly suitable for testing drones and small aircraft, where realistic wind disturbances, gusts, and turbulence are critical for assessing performance and robustness.
The **WaGGner** (Wall for Gust Generation) system is an experimental fan wall composed of 25 blocks arranged in a 5×5 grid, each block integrating two *SanAce 80* counter-rotating fans independently driven via PWM with tachometric feedback. This setup enables the generation of both spatial and temporal velocity gradients.
Available experimental resources include a **five-hole probe** for steady-state three-component velocity measurements, a **hot-wire anemometer** for time-resolved data in unsteady regimes, and a **three-axis automated traverse system** for flow mapping.

Objectives:

The goal of this project is to **design, model, and experimentally validate a Flow Management Device (FMD)** aimed at improving the quality of the flow produced by the WaGGner wall. Inspired by recent research (Di Luca et al., AIAA 2024), the proposed FMD will homogenize the mean flow, reduce residual turbulence, and limit pressure coupling between fan modules while maintaining the wall's ability to generate shear and dynamic gradients.

- Develop an FMD geometry suitable for WaGGner (honeycomb, mesh screens, channelized flow, or hybrid combinations)
- Model the internal boundary-layer growth and pressure losses
- Design and fabricate a prototype in collaboration with the InnovSpace
- Characterize experimentally the downstream flow quality (uniformity, turbulence intensity, velocity loss)
- Compare the results with analytical predictions and literature data

WaGGner platform



CAD image of the flow management device, Di Luca et al.

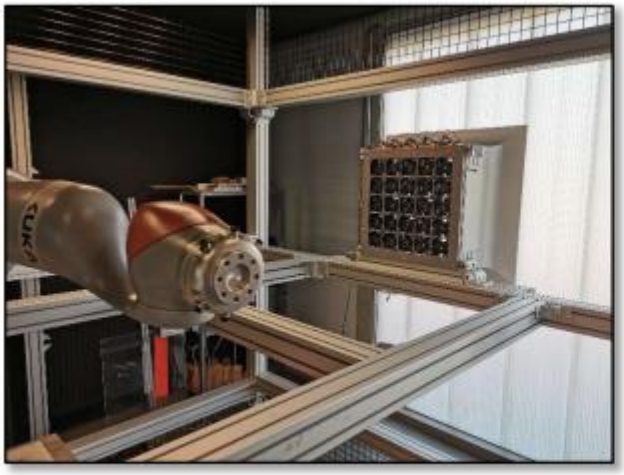
WaGGner II - CFD modeling and configuration study of a fan wall

Description:

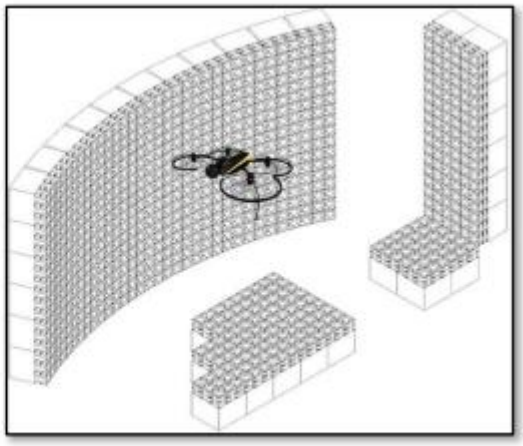
Multi-module fan wall test benches offer a flexible and modular alternative to classical wind tunnels for generating controlled wind conditions in the laboratory. By adjusting the speed and spatial distribution of each module, they can reproduce a wide variety of flow configurations, from uniform flows to complex spatio-temporal gradients. These devices are particularly well suited for testing drones and small aircraft, where the reproduction of gusts, turbulence, or wind variations is essential to evaluate system performance and robustness.
The **WaGGner** system (**W**all for **G**ust **G**eneration) is an experimental wall composed of 25 blocks in a 5×5 grid, each block integrating two SanAce 80 fans independently controllable via PWM and equipped with tachometric feedback. This device enables the generation of spatial or temporal velocity gradients.
Students will rely on **CFD simulations using StarCCM+** to build numerical models of the WaGGner wall, validate them against experimental measurements (Subject A), and explore new prospective configurations such as curved walls, lateral fan walls, or integration into a classical wind tunnel.

Objectives:

- Develop a CFD model of a single fan block and extend it to the complete wall.
- Compare CFD predictions with experimental measurements from Subject A.
- Assess the ability of CFD models to reproduce wake uniformity and gradients.
- Perform a prospective study of advanced configurations (curved walls, lateral fan walls, fan wall inside a conventional wind tunnel).
- Analyze advantages, limitations, and feasibility of each configuration.



WaGGner platform



Wind modules can be stacked into arbitrary shapes and sizes, thus enabling the testing of drones of various dimensions

WaGGner I - Experimental characterization and modelling of a fan wall for gust generation

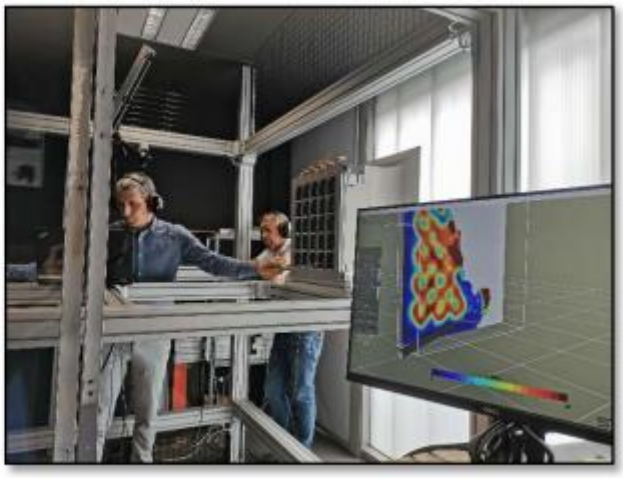
Description:

Multi-module fan wall test benches offer a flexible and modular alternative to classical wind tunnels for generating controlled wind conditions in the laboratory. By adjusting the speed and spatial distribution of each module, they can reproduce a wide variety of flow configurations, from uniform flows to complex spatio-temporal gradients. These devices are particularly well suited for testing drones and small aircraft, where the reproduction of gusts, turbulence, or wind variations is essential to evaluate system performance and robustness.
The **WaGGner** system (**W**all for **G**ust **G**eneration) is an experimental wall composed of 25 blocks in a 5×5 grid, each block integrating two SanAce 80 fans independently controllable via PWM and equipped with tachometric feedback. This device enables the generation of spatial or temporal velocity gradients.
The experimental resources available to the students include: a five-hole probe providing the three velocity components (u, v, w) in steady conditions; a hot-wire probe providing two components (u, w) with temporal resolution suitable for unsteady conditions; and a 3-axis traverse system to perform wake cartographies.

Objectives:

- Experimentally characterize the PWM ↔ mean velocity (steady) relation for a single block and for the full wall.
- Assess the homogeneity of the wake.
- Implement and calibrate analytical models.
- Compare these models with experimental data, analyze errors, nonlinear effects, and couplings.
- Measure turbulence intensity in the wake.
- Measure the time response (unsteady) to PWM variations (step, ramp).
- Propose control recommendations based on the models.

WaGGner platform



Wake measurement on WaGGner platform

Automatic discovery of aerospace metamaterials for impact protection layer

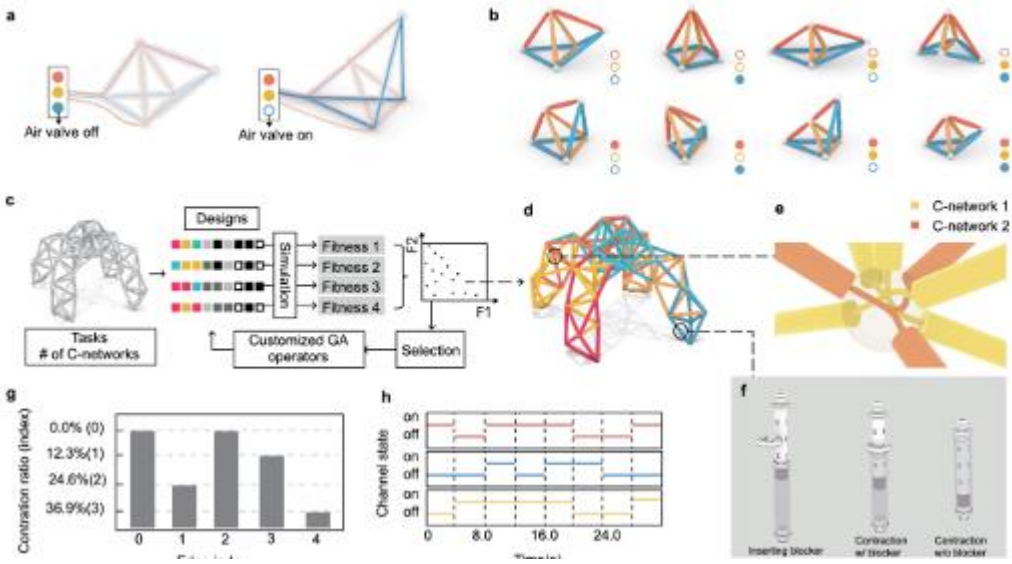
Description:

Mechanical metamaterials have demonstrated exceptional impact performance while remaining lightweight. Impact resistance has traditionally been investigated using quasi-static simulations, often with the assumption that performance will translate to high-velocity impact scenarios. However, critical crash protection parameters—such as peak stress and absorbed energy—are highly sensitive to impact velocity, leading to inconsistent performance under dynamic loading. To address this, we introduce a strain-rate-aware, active deep learning framework that enables multi-objective optimization of impact protection metrics across a wide range of impact velocities. Our framework captures the strain-rate sensitivity of architected lattices by learning to control spatial gradation in cellular metamaterials, resulting in over 200 % enhancement in impact protection relative to state-of-the-art designs such as Voronoi and re-entrant lattices. We demonstrate its practical utility by designing next-generation lattice structures for automotive bumper systems that satisfy multiple, velocity-specific safety criteria—capabilities beyond those of conventional designs. More than just a predictive tool, this framework marks the first step towards enabling adaptable impact-resistant structures across dynamic regimes.

Optimization and control of actuator truss networks using BO

Description:

A robot's morphology is pivotal to its functionality, as biological organisms demonstrate through shape adjustments – octopi squeeze through small apertures, and caterpillars use peristaltic transformations to navigate complex environments. While existing robotic systems struggle to achieve precise volumetric transformations, Variable Geometry Trusses offer rich morphing capabilities by coordinating hundreds of actuating beams. However, control complexity scales exponentially with beam count, limiting implementations to trusses with only a handful of beams or to designs where only a subset of beams are actuable.



Multimaterial topology optimization framework for sustainable aerostructures

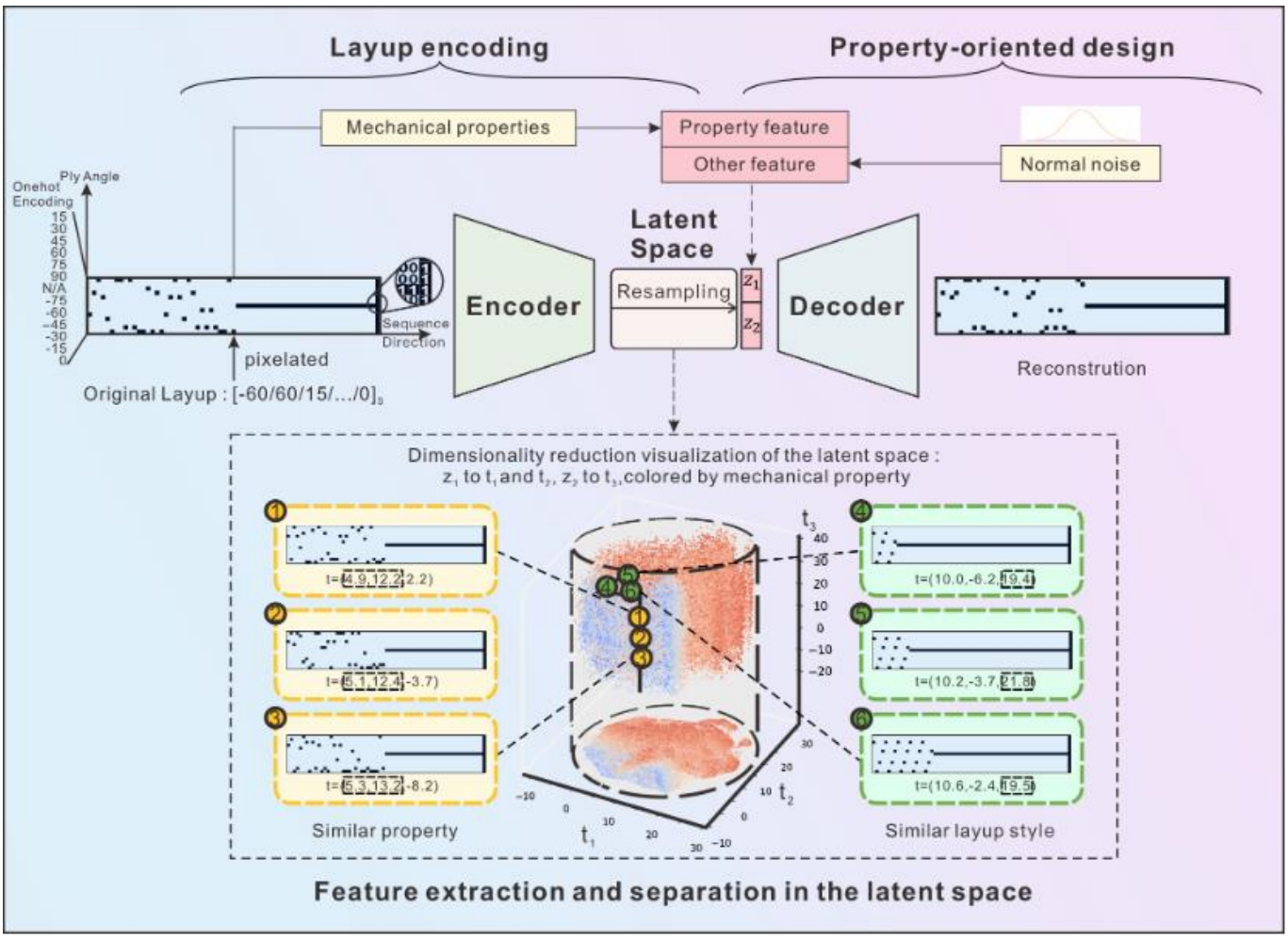
Description:

We propose a multimaterial topology optimization framework for sustainable infrastructure design with substantial mechanical and economical advantages. The framework optimally harnesses the mechanical superiority of steel and the environmentally sustainable properties of biomaterials, such as laminated bamboo and timber, to design stiff, strong, and sustainable structures. The fibrous characteristics of biomaterials are incorporated using the transversely isotropic constitutive relation and Tsai–Wu failure criterion, while steel is assumed isotropic with von Mises yield criterion. Two sustainability-oriented formulations are proposed to accommodate different design scenarios, accounting for performance, environmental impacts, and economic costs. Both formulations are capable of designing optimized steel-biomaterial hybrid structures with significant sustainability improvements. Through 2D and 3D example problems, we demonstrate that the proposed framework effectively leverages the unique advantages of steel and different biomaterials to strive an ideal balance among diverse mechanical, economic, and environmental design requirements. The results indicate that both steel and biomaterials are essential to achieve cost-effective sustainable design solutions with enhanced mechanical performance.

Composites structures Optimization using VAE

Description:

Fiber-reinforced composites provide substantial tailoring potential, while the extensive parameters and complex coupling mechanisms pose formidable challenges to layup designs. This paper presents an efficient inverse design framework for composite layups utilizing a variational autoencoder (VAE), which is applicable to non-conventional laminates. By leveraging the VAE's exceptional feature extraction and generative capabilities, the decoder rapidly produces layups with desired properties through controllable feature vectors. Based on the stacking characteristics of layups, multi-scale one-dimensional convolutions precisely extract sequence features relevant to mechanical properties and specific manufacturing constraints. A customized loss function is formulated to constrain the latent features, while addressing the non-uniqueness problem for layups with certain mechanical properties.



Safety-security methodology for UAV/UAS case study

Description:

Unmanned Aerial Vehicles (UAV) are widely used for various missions (surveillance, transport, maintenance/overhaul) in the civil and military domains. Therefore, an UAV is prone, in operation, to undesired events such as attacks and flaws. According to the nature of these events, a specific methodology is applied to mitigate their effects on the UAV itself and its environment. An attack-threat implies a security approach, whereas a fault relies on a safety analysis [1].

RQ.1: Is it possible to merge safety and security approaches?
RQ.2: How can the lack of a joint safety-security methodology lead to inappropriate security choices thus, threaten safety objectives?

The safety certification process enables to tackle these issues. Also, the U-space regulatory framework (EU 2021/664) provides a set of guidelines for the management of drones, which impacts the UAV's embedded systems. The implementation of these guidelines in terms of Acceptable Means of Compliance and Guidance Material (AMC/GM) is of the upmost importance for the certification of drones designed to share the airspace with other aircraft. The guidelines address all aspects of the development and the operation for the drones and the stakeholders. Thus, the Specific Operations Risk Assessment (SORA) methodology defines about twenty-one Operational Safety Objectives (OSOs) for various risks such as the Air Risk Class (ARC) [2]. OSOs require high-level properties of the Unmanned Aerial Systems (UAS), which encompass not only the UAV but also the ground control station, communication links, and any supporting infrastructure needed for operation. For instance, OSO #11 states that "procedures are in-place to handle the deterioration of external systems supporting UAS operations"[3].

As for the security, the MITTRE ATT&CK1 database provides us with a set of tactics et techniques used by attackers. The standard NIST Cybersecurity Framework [4] defines the five main properties for data and services in the field of information processing systems (namely systems that embed computers): confidentiality, integrity, availability, authenticity, 1 https://attack.mitre.org/ accountability [5,6].

To ensure the security of an information system, we aim to guarantee the triad of properties. Regarding UAV/UAS, this triad is as follows:

• Confidentiality: Preserves authorized restrictions on information access and disclosure, including means for protecting personal privacy and proprietary information. A loss of confidentiality is the unauthorized disclosure of information.
• Integrity: Guards against improper information modification or destruction, including ensuring information non-repudiation and authenticity. A loss of integrity is the unauthorized modification or destruction of information.
• Availability: Ensures timely and reliable access to and use of information. A loss of availability is the disruption of access to or use of information or an information system. In the context of the research project, our main objectives are : o to define a merged methodology for the security and safety of an UAV/UAS, o to propose a methodological framework based on models, o and to validate it on an UAV's architecture integrating Paparazzi2 system.

Plasma measurements in the Jovian polar region with Juno/JADE

Description:

Jupiter's main auroral oval provides a window into the complex magnetospheric dynamics of the Jovian system. The Juno spacecraft entered orbit about Jupiter on 5 July 2016 and carries on board the Auroral Distributions Experiment (JADE) that can directly sample the auroral plasma structures. Here we identify five distinct regimes in the JADE data based on composition/energy boundaries and magnetic field mappings, which exhibit considerable symmetry between the northern and southern passes. These intervals correspond to periods when Juno was connected to the Io torus, inner plasma sheet, middle plasma sheet, outer plasma sheet, and the polar region. When connected to the torus and inner plasma sheet, the heavy ions are consistent with a corotating pickup population. For Juno's first perijove, we do not find evidence for a broad auroral acceleration region at Jupiter's main auroral oval for energies below 100 keV

1. Introduction

Many of the auroral signatures observed throughout the solar system are attributed to accelerated electrons interacting with a planet's atmosphere. Aurorae have been most extensively studied at Earth, with sounding rockets and multiple orbiting spacecraft [Evans, 1974, Mozer et al., 1977, Carlson et al., 1998]. At Earth, a host of auroral phenomena have been observed including parallel electric fields (double layers), perpendicular electrostatic shocks, accelerated electrons, anti-earthward ion beams, strong wave activity, and deep density cavities [Mauk and McIlwain, 1975; Sharp et al., 1975; Klumpar et al., 1976; Ergun et al., 1998, 2000, 2002, 2004]. While Jupiter's plasma environment is significantly different from Earth's, similar auroral processes have been posited to occur at Jupiter [Barbosa et al., 1981; Cowley and Bunce, 2001; Nichols and Cowley, 2004; Clarke et al., 2004; Ray et al., 2009, 2010, 2012].

In the Jovian magnetosphere, neutrals are emitted from Io; a large fraction of these neutrals are subsequently ionized via charge exchange and electron impact, generating fresh plasma that is picked up and moves with the corotating plasma. These iogenic plasma populations make up the Jovian plasma sheet, a reservoir of plasma mostly confined to a region near the magnetic equatorial plane. In situ measurements in the plasma sheet showed the ionic composition to be dominated by M/q = 16, with O+ and/or S++ ions as the dominant population [e.g., McNutt et al., 1981]. As plasma is transported radially outward, conservation of angular momentum dictates that it must slow down relative to corotation. Maintaining rigid corotation requires Jupiter's ionosphere to provide the needed angular momentum. It is argued this is done through a current system whereby a J × B torque acts on the equatorial plasma. This process begins to break down at large radial distances, where the finite ionospheric conductivity inhibits the generation of large currents required to fully transfer the angular momentum needed to bring rotating plasma up to full corotation [Hill, 1979]. It is hypothesized that the region of corotation breakdown (or flow shear) is linked to auroral emissions [Hill, 2001]. The aurorae at Jupiter provide a window into this complex current system. The Juno mission is a polarorbiting spacecraft, which entered orbit about Jupiter on 5 July 2016 (UTC). One of Juno's primary mission objectives is to explore the polar magnetosphere and aurorae [Bagenal et al., 2014]. On board, it carries the Jovian Auroral Distributions Experiment (JADE), an instrument suite that consists of a single ion detector, JADE-I (0.01–50 keV/q), and two electron detectors, JADE-E (0.1–100 keV) [McComas et al., 2013]. Prior to Juno's first science perijove pass, JADE measured the inbound solar wind, magnetosheath, and magnetosphere [McComas et al., 2017], observed a hot flow anomaly [Valek et al., 2017], found evidence for magnetic reconnection at the magnetopause [Ebert et al., 2017], observed mass transport across the magnetopause [Gershman et al., 2017], and found evidence for a connection between solar wind inputs and auroral emissions [Nichols et al., 2017].

Here we describe the JADE measurements taken during Juno's rapid transit between the northern and southern regions of Jupiter's polar magnetosphere on the dusk side during Juno's first science perijove. In section 2, we briefly describe the magnetic field mapping schemes used. In section 3, we characterize the plasma measurements taken on close approach by relating them to their magnetospheric sources and auroral mappings. We conclude in section 4 with a discussion of the contrast between our expectations of the structure of the Jovian auroral current system and the JADE measurements.

2. Magnetic Field Mapping

The Jovian literature commonly uses "L shell" to identify the equatorial crossing distance of a dipolar magnetic field line. This value is convenient for relating spacecraft measurements at high latitudes to their equatorially mapped

source regions. Since the Jovian field is very stretched, the use of a dipole L shell for organizing measurements can be misleading. To reduce ambiguity, we adopt the terminology "M shell" (M for magnetic) to describe the equatorial crossing distances for any given field line. We use the VIP4+CAN magnetic field models [Connerney et al., 1981, 1998], a synthesis of a multipole internal field model (VIP4) and current sheet model (CAN), to determine M shells for magnetic field lines crossing through Juno in this work. This model is typically applicable for mappings to 6 < M < 30 RJ and less accurate in mapping field lines very near to the northern auroral kink region [Vogt et al., 2015]. We note that M shell mapping is not strictly constant in time, changing with variations in the plasma conditions within the magnetosphere [Nichols, 2011; Nichols et al., 2015]; however, we assume time-invariant mappings for simplicity in this work.

M shell ranges for the Jovian auroral oval have been estimated via a variety of techniques. One of the more stringent constraints on the oval mapping distance is the observation of Ganymede's auroral foot point, which typically occurs equatorward of the main oval. Since Ganymede orbits at 15 RJ, this puts an approximate lower limit on the inner M shell of the oval at M > 15 RJ [Clarke et al., 2002], though the latitudinal gap between the foot point and edge of the auroral oval suggests an inner edge closer to 20–30 RJ. We note that there have been outlying events during which the Ganymede footprint was transiently equatorward of the main auroral emission [Bonfond et al., 2012]. Separate modeling efforts have also concluded that the source region for the auroral oval begins around M = 20–30 RJ and extends to several tens of RJ beyond that distance [e.g., Hill, 2001; Cowley and Bunce, 2001; Nichols, 2011; Vogt et al., 2011].

3. High-Latitude Observations

During the 6 h centered about Juno's perijove, JADE took measurements in its high-rate science mode, with 1 s resolution for JADE-E and 2 s resolution for JADE-I. Approaching the northern pole from the dawnside, JADE was magnetically connected to the polar auroral region. Here JADE experienced large intermittent bursts of penetrating radiation and, with the exception of a few periods, measured ion and electron populations with very low densities within the JADE energy range. However, as Juno's planetary footprint moved equatorward, JADE observed a diverse and complex plasma environment, with significant structure on a variety of timescales. Here we identify five distinct boundaries in the JADE data, corresponding to five separate plasma regimes that exhibit considerable symmetry between the northern and southern passes. To identify boundaries, we analyze the electron and heavy ion data. Unlike protons, heavy ions such as O and S, in high relative numbers, suggest magnetospheric (i.e., not Jovian, sheath, or solar wind) populations. We therefore favor these populations over the proton data to identify distinct plasma boundaries relating to the magnetic field mapping. Figure 1 summarizes the JADE measurements during closest approach, with the separate regions discussed below in order of increasing M shell. Note, in this work, that we performed a preliminary background subtraction to the JADE-I and JADE-E data based on the use of the background anodes [McComas et al., 2013].

Boundary (a) maps to M shell values of 5.7 RJ (north) and 6.5 RJ (south), with boundary (b) mapping to 8.4 RJ (north) and 10.5 RJ (south). When connected to M shells inside of (a), JADE experienced large fluxes of penetrating radiation due to the radiation belts [Paranicas et al., 2017] with little indication of a low-energy plasma population within the JADE energy ranges above noise levels. Between (a) and (b), JADE measured heavy ion populations dominated by M/q = 16, corresponding to O+ and/or S++ that spanned an energy range of a few hundred eV to tens of keV, up to the top of the JADE-I measurement range (Figure 2). There are no distinct electron populations in the JADE-E instrument range measured in the northern pass for this region, with evidence for a very low density electron population with energies between 0.1 and a few keV in the south. The heavy ion time-energy spectrograms show a large degree of spin modulation during this time interval, indicating that these ion populations are highly directional. The compositional dominance of M/q = 16 and dearth of electrons >100 eV is consistent with previous spacecraft measurements in the Io torus [Bagenal and Sullivan, 1981; Sittler and Strobel, 1987]. Additionally, the M shell mappings for this region are consistent with the Io torus boundaries. Therefore, we interpret this region physically as being connected to the Io torus. We note that a high-energy population of heavy ions with characteristic energy of 10–20 keV was observed on the northern pass when transitioning past boundary (b), yet not in the southern pass.

Near boundary (b), JADE observed a rapid increase in the total count rates of heavy ions. Based on the trend line, this is the location where the plasma electrons become hot enough to be observed by JADE-E; presumably, they are cooler in region between (a) and (b). The ions are notably more isotropic, as the spin modulation signature is less pronounced. As (b) maps to M shells consistent with the outer edge of the Io torus, we interpret the region bounded by (b) and (c) to be connected to the inner plasma sheet (boundary (c) described below). The heavy ion panels in Figure 1 show twice

the equatorial corotation energy (dotted line) for the dominant M/q = 16 species, which correlates well with the peak in the count rate spectrogram between (b) and (c). For a subthermal Maxwellian distribution, the peak in the count rate spectrogram will occur at twice the thermal energy (with minor energy-dependent corrections). Therefore, the heavy ions observed in this period are preliminarily consistent with a corotating population from the inner plasma sheet, heated via a process that scales with corotation energy. Additionally, significant energetic populations of O++, S+++, O+ , and/or S++, and a smaller contribution from S+ , were observed, consistent with an inner plasma sheet source (Figure 2).

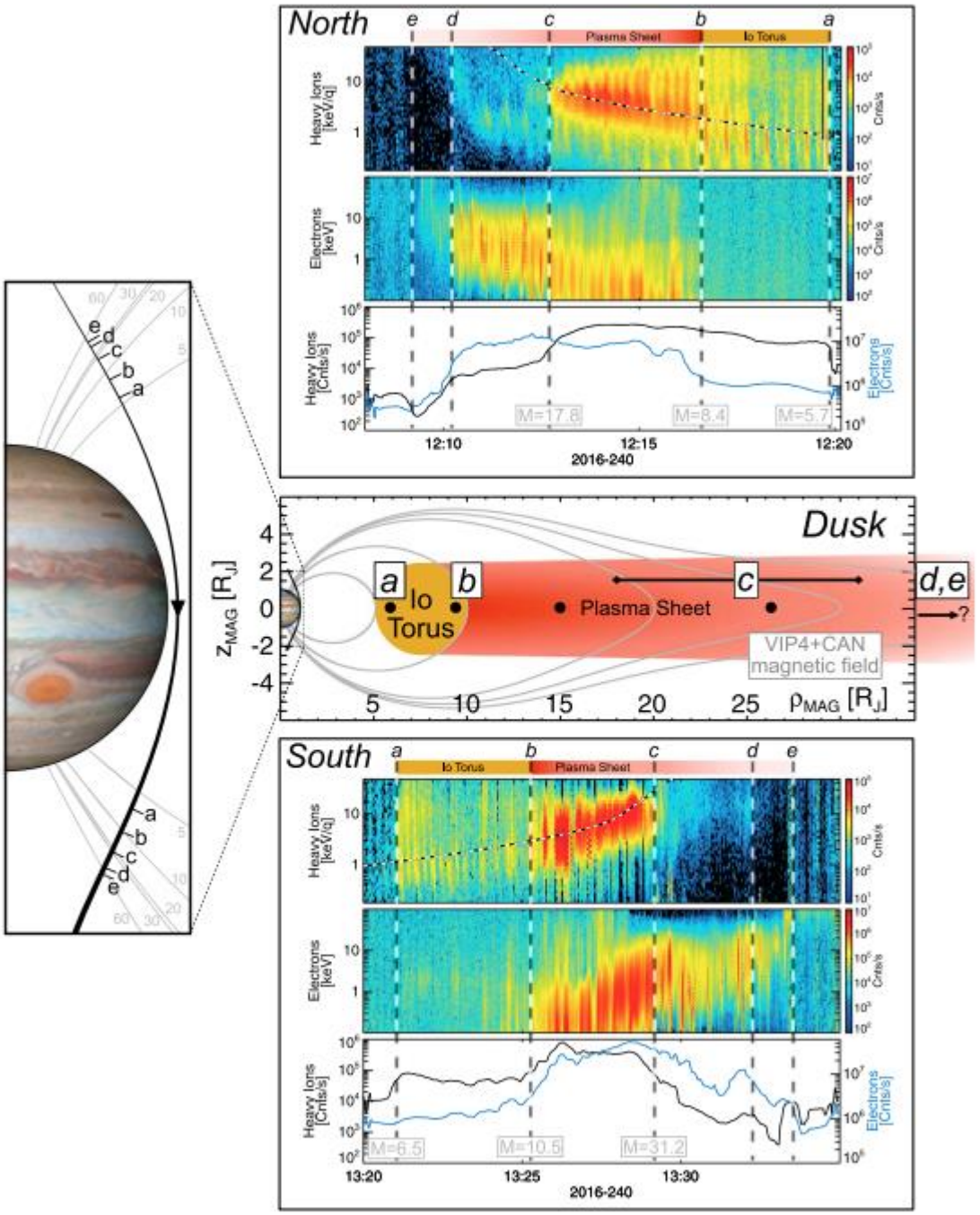


Figure 1. Summary of the JADE heavy ion ($M/q \geq 8$) and electron measurements, with energy versus time spectrograms and total count rates, taken during the northern and southern (N/S) polar passes of Juno's first science perijove. We identify distinct periods for both the N/S passes in which Juno was connected to the Io torus and plasma sheet. The heavy ion panels indicate twice the equatorial corotational energy for M/q = 16 (dashed line). The left and middle panels show the overall measurement geometry and VIP4+CAN magnetic field model [*Connerney et al.*, 1981, 1998]. Black dots indicate the locations of the four Galilean moons, in order of increasing radial distance from Jupiter: Io, Europa, Ganymede, and Callisto.

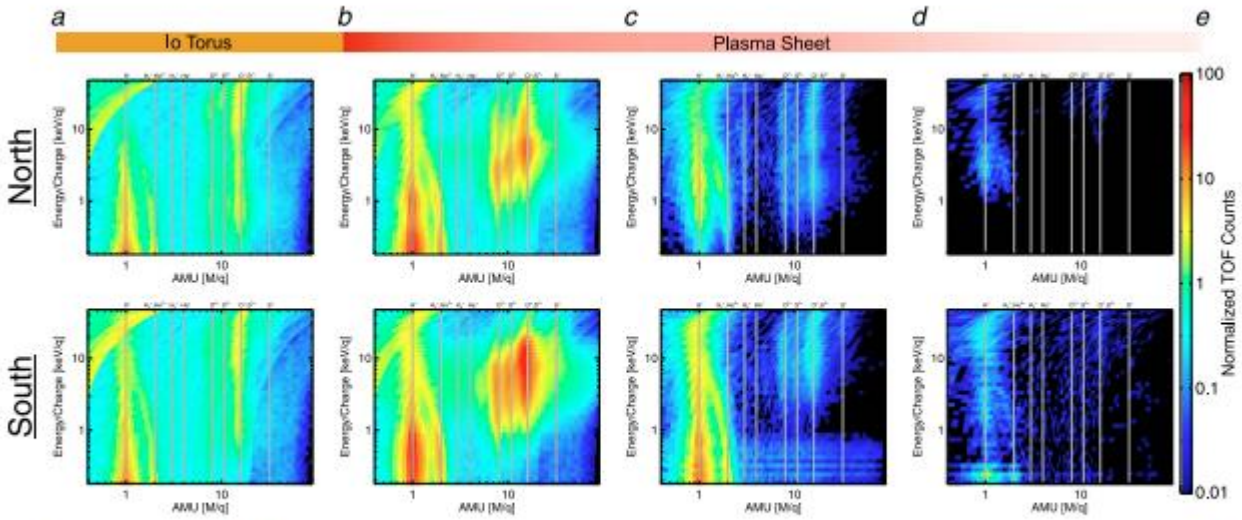


Figure 2. *M/q* versus energy from JADE-I for the northern and southern inner magnetosphere measurements near Juno's periojove. Count rates are all normalized to the same scale. The Io torus populations observed at high latitudes exhibit broad energy structures with the majority of heavy ion counts dominated by $M/q = 16$ corresponding to O^+ or S^{++}. JADE plasma sheet measurements show significant energetic populations of O^{++}, S^{+++}, and O^+/S^{++} and a smaller contribution from S^+.

Table 1. Locations and Geometric Information for the 10 Boundaries Identified in the JADE PJ1 Close Approach Data[a]

	N/S	Time (UTC)	R (R_J)	LT (hh:mm)	M (R_J)	λ_{III} (deg)	θ_{III} (deg)	θ_{MAG} (deg)	θ_{CEN} (deg)
a	N	2016-240T12:19:53	1.47	17:51	5.7	77.5	67.8	61.6	63.9
a	S	2016-240T13:21:03	1.45	17:53	6.5	113.9	−59.6	−57.8	−58.7
b	N	2016-240T12:16:36	1.54	17:50	8.4	75.6	72.1	65.4	67.9
b	S	2016-240T13:25:16	1.55	17:53	10.5	116.3	−65.1	−62.6	−63.8
c	N	2016-240T12:12:43	1.63	17:50	17.8	73.4	76.6	69.4	72.1
c	S	2016-240T13:29:09	1.63	17:54	31.2	118.6	−69.6	−66.4	−67.9
d	N	2016-240T12:10:13	1.68	17:49	52.0	72.0	79.3	71.8	74.5
d	S	2016-240T13:32:15	1.71	17:54	58.8	120.4	−72.8	−69.1	−70.8
e	N	2016-240T12:09:12	1.71	17:49	57.3	71.5	80.3	72.7	75.5
e	S	2016-240T13:33:32	1.74	17:54	62.9	121.2	−74.1	−70.1	−71.9

[a]Columns show the boundary label, northern/southern hemisphere, time in UTC, radial distance of Juno from the center of Jupiter, local time (LT) of Juno, M shell, System III longitude (left handed), System III latitude, VIP4 dipole magnetic latitude, and VIP4 dipole centrifugal latitude.

Boundary (c) is of particular interest as it maps to the middle plasma sheet, with M shells of 17.8 RJ (north) and 31.2 RJ (south) where the literature would suggest the inner edge of the main auroral oval maps to [e.g., Hill, 2001; Cowley and Bunce, 2001; Clarke et al., 2002; Nichols, 2011; Vogt et al., 2011]. We note that the lower of the two M shells for boundary (c), 17.8 RJ, is the mapped value from the northern hemisphere near the kink region. Given the putative magnetic anomaly in this region [Grodent et al., 2008], M shell mappings near it are particularly error prone [Vogt et al., 2015]. We therefore favor the southern mapped boundary for (c) of 31.2 RJ and suggest that this is closer to the true equatorial mapping distance. In general, we expect all of the given M shells to be more accurate for the southern pass during these observations for the same reason. In transitioning past boundary (c), the heavy ions are observed to have a rapid decrease in total counts, with peak energies that no longer follow the corotational energy and consistent with increasingly large corotation lag. Some part of the reduction in heavy ion counts in the (c)-(d) region may also be attributable to the much increased influence of the centrifugal confinement at the large radial distances to which this region maps. Additionally, the electron energies are marked by a sharp jump in energy to a few keV at boundary (c). We hypothesize that the region bounded by (c) and (d), which maps to the middle plasma sheet and is characteristically different than the adjacent inner plasma sheet connected region, corresponds to the main auroral oval region (see also the ionospheric mapping discussion below). More detailed analysis of the JADE-E data indicates that the low-energy electron population in this region is primarily moving upward (small local pitch angle) [Allegrini et al., 2017]. While the tentative identification of the main oval region is based on geometric constraints discussed throughout this work, we note that the character of the electrons measured by JADE is not conclusively consistent with the presence of a population of primarily downward accelerated electrons [Allegrini et al., 2017].

The region bounded by (d) and (e) is characterized by an additional decrease in the heavy ion and electron counts by an order of magnitude. The electrons' energies continue to increase up to boundary (e) at which point there is an abrupt cutoff of the electron population that is also observed in the high-energy plasma populations by JEDI [Mauk et al., 2017]. We interpret this region to be connected to the outer plasma sheet, past the main auroral current system, with boundary (d) defining the poleward edge of the main auroral oval. Past (e), the JADE measurements for both ions and electrons are dominated by penetrating radiation, which manifests itself in JADE measurements as vertical strips with similar count rates throughout the energy range. Aside from these radiation signatures, the ion and electron populations exhibit very low densities. Table 1 summarizes the five boundaries and gives relevant geometric quantities.

In addition to identifying how these measurements relate to magnetospheric sources, we now discuss the mapping of Juno's magnetic footprint onto the Jovian ionosphere. Figure 3 shows Juno's trajectory mapped onto the ionosphere using the VIP4 model. The blue dotted/solid lines show the mean auroral boundaries/center from a statistical study of Hubble Space Telescope (HST) observations from 2007 [Nichols et al., 2009; Bonfond et al., 2012]. We have also included a grid (grey) that runs tangent to the mean oval to provide a reference to the distances traversed. In this figure, we have identified the five boundaries for both the northern and southern passes.

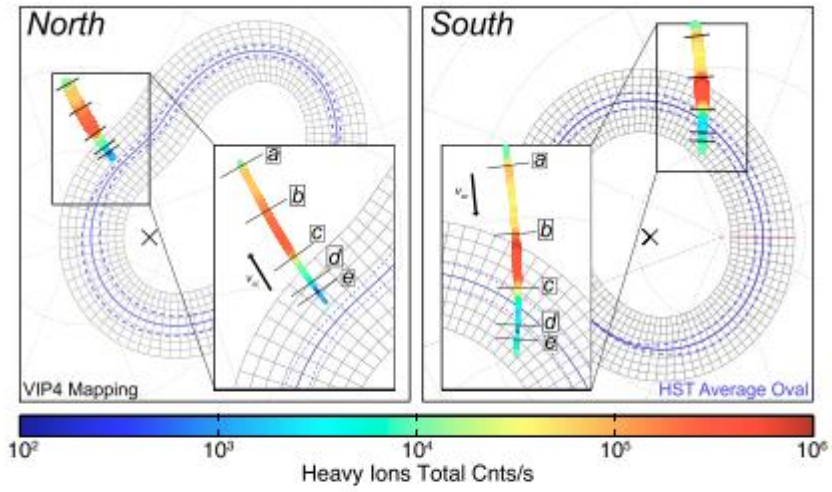


Figure 3. Mapping of the Juno trajectory during the PJ1 close approach with the VIP4 magnetic field model [*Connerney et al.*, 1998]. Both projections are shown as viewed from above the north pole. The blue solid/dotted lines indicate the average center and boundaries for the auroral oval based on HST observations [*Bonfond et al.*, 2012]. The longitudinal gridlines (grey) parallel to the mean oval are spaced in increments of 1250 km on the 1 bar level from the mean oval. The intersection of the north and south VIP4 magnetic dipole moment with the Jovian surface is marked with a cross.

For the southern hemisphere, the predicted oval crossing times coincide remarkably well with our identified auroral region, as evidenced by the proximity of boundaries (c) and (d) to the statistical average oval boundaries. However, in the northern hemisphere, the JADE identified that auroral region is well equatorward of the main average oval. We attribute this offset to two reasons. First, the VIP4 model is less reliable when mapping magnetic field lines near the kink region, which Juno flew directly over, making estimation of the true footprint less accurate. Second, both the northern and southern passes were made very near to the dusk terminator. The auroral emissions have been observed to be asymmetric in local time, with the dusk emissions notably variable and more extended [Bonfond et al., 2015], due to the local time dependence in Jupiter's magnetospheric plasma structures. Additionally, during the time leading up to the flyby, HST measurements observed the dusk northern auroral oval to be equatorward of the 2007 statistical average oval [Nichols et al., 2017], qualitatively consistent with the JADE measurements. We suggest that these explanations account for the discrepancy between the northern and southern auroral mappings. The pattern and sequence of features in the north and south are very similar, lending credence to the interpretation that these periods map to similar magnetospheric regions. Our position is that the data are more indicative of regions than model-dependent mappings. Given the more accurate mapping to the main oval in the south, which well correlates to specific features in the JADE data, we therefore infer the oval location in the north based on the strong symmetry in data features.

Quantum Machine Learning

Description:

Quantum computing is a new emerging filed of activity. Quantum computers are not yet fully operational, but this new technology has the potential to change the world. Following the creation of a new teaching course in the field of quantum programming, the Department of Complex System Engineering (DISC) wishes to explore the possibility of creating new research activities. As for computer programming in the 50's, quantum programming needs to be explored to find areas that matches its possibilities.

Objectives:

Quantum machine learning seems to be a promising area for quantum computing [1][2]. This domain associates quantum computing and artificial intelligence (AI). The objective of this proposition is to implement and test a classification algorithm proposed in [3]. Since this project aims to create a new research activity within the DISC, it is a long-term project. It will therefore last the 2 years of the MAE.

Reinforcement Learning for AeroSpace Vehicule

Description:

The RL-AERO project aims to develop robust reinforcement learning (RL) algorithms capable of piloting three classes of aerospace vehicles in extreme aerological conditions: guided parachutes, glider drones, HALE drones, and atmospheric reentry systems.
The objective is to ensure that control is maintained and missions are accomplished despite severe atmospheric disturbances (strong turbulence, gusts, wind shear, jet streams).

Year 1: Simulation environments integrating high-fidelity aerological models, turbulence profile database, first operational RL agents in simulation
Development of turbulence profile database (mountains, urban areas, jet stream, re-entry)
Multi-platform simulation environments
First RL agents per platform

Year 2: Robust agents validated over a wide range of extreme conditions, integration of weather predictions, hardware-in-the-loop testing, initial real-world testing on parachutes and drones
Training across a wide spectrum of wind conditions
Coupling with NWP models (AROME, ARPEGE)
Anticipation of disturbances 10 seconds to 5 minutes in advance thru RNN or LSTM coupled with RL.

RISC-V for space

Description:

Most processors used in the space industry are fully or partially from the US. So they are subjected to International Traffic in Arms Regulations (ITAR) rules, which is a set of United States government regulations that control the export and import of defense-related articles and services. As the space technologies cans also be used for weapon production (missiles, warheads…), the US government can unilaterally decide to block the export of US technologies and then prevent European countries from developing their space program. The European Space Agency (ESA) and the French National Space Agency (CNES) have tried to develop a processor based on the Specification for Processor Architecture (SPARC), the LEON processor. But this project led to a dead end, mainly because of the lack of a strong community around it. The emerging RISC-V processor and its growing community seem to be an answer to that problem [1][2].

Objectives:

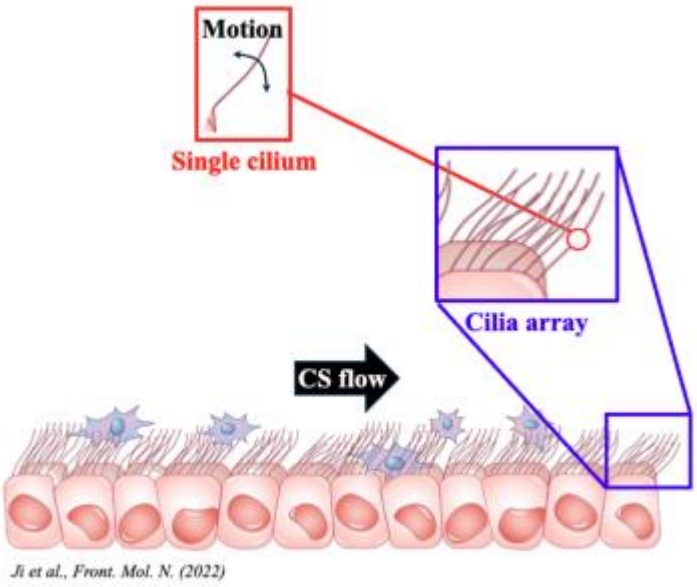
The RISC-V processor is an open source and modifiable processor, supported by a non-profit organization based in Switzerland. However, the RISC-V processor is not adapted for the space environment. The objective of this project is then to study mitigation techniques for space and apply them to the RISC-V processor [3]. We also consider publishing a scientific article.

Simulations of the CerebroSpinal Fluid (CSF) flows

Description:

Cerebrospinal fluid (CSF) flow (fig. 1) is essential for brain since it facilitates nutrient transport, waste clearance, as well as mechanical protection of neural tissue. Altered CSF circulation is linked to various neurological conditions, including hydrocephalus and neurodegenerative diseases. Yet, the fine-scale mechanisms driving the CSF flow remain poorly understood. Computational models can help bridge this gap by providing detailed insight into flow features that are challenging to measure experimentally.
CSF dynamics in the brain ventricles is strongly influenced by (i) the whole-body motion, (ii) the heart beating which yield flow pulsation, and (iii) the forced motion of numerous motile cilia lining the ventricular walls. Recent studies (RSI 2022, PubMed 2022) have demonstrated that not only the presence, but the coordination, orientation, and density of beating cilia significantly affect the near-wall flow and mixing.

This project aims to simulate and analyze the effect of beating coordination patterns (e.g. in-phase, anti-phase, metachronal waves etc.) in a very simplified configuration using the CFD solver STAR-CCM+. The objective is to move beyond static or averaged force models and to assess how temporally resolved - spatially patterned ciliary motion can modulate fluid transport, pressure distribution, and shear stress in confined geometries.



Sketched ventricular system

Plasma leakage through the magnetospheric boundaries of Jupiter and Saturn

Description:

Jupiter and Saturn, the largest planets in our solar system, present complex and rich magnetized environments. Their magnetospheres, which form in the interaction between the solar wind and their intrinsic magnetic field, are characterized by the existence of a plasma disk fed by the production of particles coming from either the volcanic activity of Io or the geysers of Enceladus, and put in rotation by a magnetic interaction with Jupiter or Saturn itself, respectively. The plasma created deep inside the magnetosphere of Jupiter and Saturn is then transported radially, redistributed throughout the whole magnetosphere, before to be lost down tail or at the boundaries of the magnetosphere.

The NASA Juno mission, in orbit around Jupiter since July 2016, provides us with an excellent opportunity to conduct a precise study of the processes leading to the leakage of charged particles from the magnetosphere of Jupiter. Juno, with its JADE and JEDI particle spectrometers, together with its MAG magnetometer and WAVES plasma wave instrument, is ideally suitable for this type of analysis. The NASA/ESA Cassini mission, in orbit around Saturn during 13 years, provided a large datasets of bow shock and magnetopause crossings which have also been largely unexplored to date.

Objectives of the proposed work:

The proposed internship consists of an observational study using all available in situ datasets from Juno and Cassini in order to characterize the charged particle environments at the boundaries of the magnetosphere of Jupiter and Saturn, and their link with plasma losses from the magnetosphere. The tools developed by the french space plasma data center (CDPP, https://cdpp.eu) such as AMDA (http://amda.cdpp.eu) will be used in order to build catalogue of events that will be subsequently analyzed with routines to be developed in the language of choice (python, ...).

Wind power (really) differently, now!

Description:

The company “Collaborative Energy” is introducing a true alternative concept for wind turbines for carbon-free energy production, while striving to demonstrate the public acceptability and benefits of its technology through concrete pilot projects. It consists of a comprehensive approach, employing the most efficient technology on the market, with a guaranteed social acceptability, respect of biodiversity and natural resources, and a significant reduction of land use for parcs of wind turbines, or even shared with photovoltaics.

Some key features bringing positive impact throughout the lifecycle: manufacturing, installation, and maintenance:
- Reduced manufacturing costs - simple blade shapes (constant profiles without twisting), low mast height, simple design and limited number of parts
- Fast installation - reduced intervention time and teams
- Excellent maintainability - "Zero maintenance"

In addition, one can note a positive impact on the planet:
- Acceptability - significantly reduced operating noise and visual impact
- Respect for natural resources and biodiversity - generator without rare earth elements, very little impact on birds and bats

That being said, several parameters come into play for the design/development and the finally obtained performance. The goal of this research project is therefore to
- Revisit the approach using a systems engineering approach, identifying the needs, the parameters, and assessing the design
- Revisit the design and performance parameters, identifying what limiting factors exist and how they can be addressed
- Trade-offs to be made so to obtain an optimal result

This multi-disciplinary system approach should lead to an optimization of the real-time control software taking into account all of parameters aero/mechanical/electromechanical/sensor/electronic variables and the aerodynamic/anemological constraints of a wind farm.

It will be a multi-disciplinary project, bringing in several technical disciplines as we go along.

Design of functionally graded materials (FGM) for shock absorption

Description:

Systems of protection against high-velocity impact (bird strike on aircraft, impact of space debris, terminal ballistics, etc) often consist in stackings of layers, sheets or plates made of materials with individual properties aiming at ensuring different functions in the protection process. The performance of the protection system depends not only on the materials at stake but also on the assembly technique. In order to free oneself from the latter, the idea is to use materials with properties gradient, called functionally graded materials (FGM).

The objective of the research project is to numerically design an FGM capable of meeting requirements related to shock absorption. A parametric study employing the commercial finite element computation code Abaqus will be conducted in view of optimizing the architecture of a shock-resistant FGM. Depending on the research project progress, the FGM will be fabricated using the metal additive manufacturing or/and polymer 3D printing machines available at the Lab., and tested using standard testing machines and impact set-ups.

Experimental and numerical study of molten metal droplet projection

Description:

During welding, additive manufacturing and electric arcing, molten metal droplets can be projected. These droplets then exchange mechanical and thermal energy with the support they impact and can cause damage to the support in question. The objective of the research project is to carry out, on the one hand, a numerical study of the impact of molten metal droplets on a support using a commercial computation code (Abaqus, COMSOL multiphysics) and, on the other hand, an experimental study of this same impact.

Microwave dielectric characterization of 3D-printed artificial dielectrics for antenna applications

Description:

Additive manufacturing (AM), or 3D printing, is a new way of producing materials with high mechanical precision and reduced material waste [1]. Contrary to the subtractive manufacturing which realizes a product by subtracting a material from a larger piece of material, it makes a product layer by layer additively.
AM of metals or thermoplastics has already been successfully applied to the fabrication of microwave antennas [2]. It not only makes possible the production of very complex shapes, but also the control of electromagnetic properties of these 3D printed materials, such as their heterogeneity and anisotropy.
ISAE-SUPAERO is currently studying with ENAC the potential of AM of artificial dielectrics for the design of innovative antennas. For example, we have recently proposed original dielectric resonator antennas (DRAs) manufactured by a subcontractor from 3D printed ceramics [3-5].
Recently, ISAE-SUPAERO acquired a 3D printer, several rolls of RF-compatible material, and an oven dedicated to ceramic manufacturing. These new facilities now require a learning phase to define the 3D printing and firing characteristics needed to obtain the desired artificial dielectric behavior.

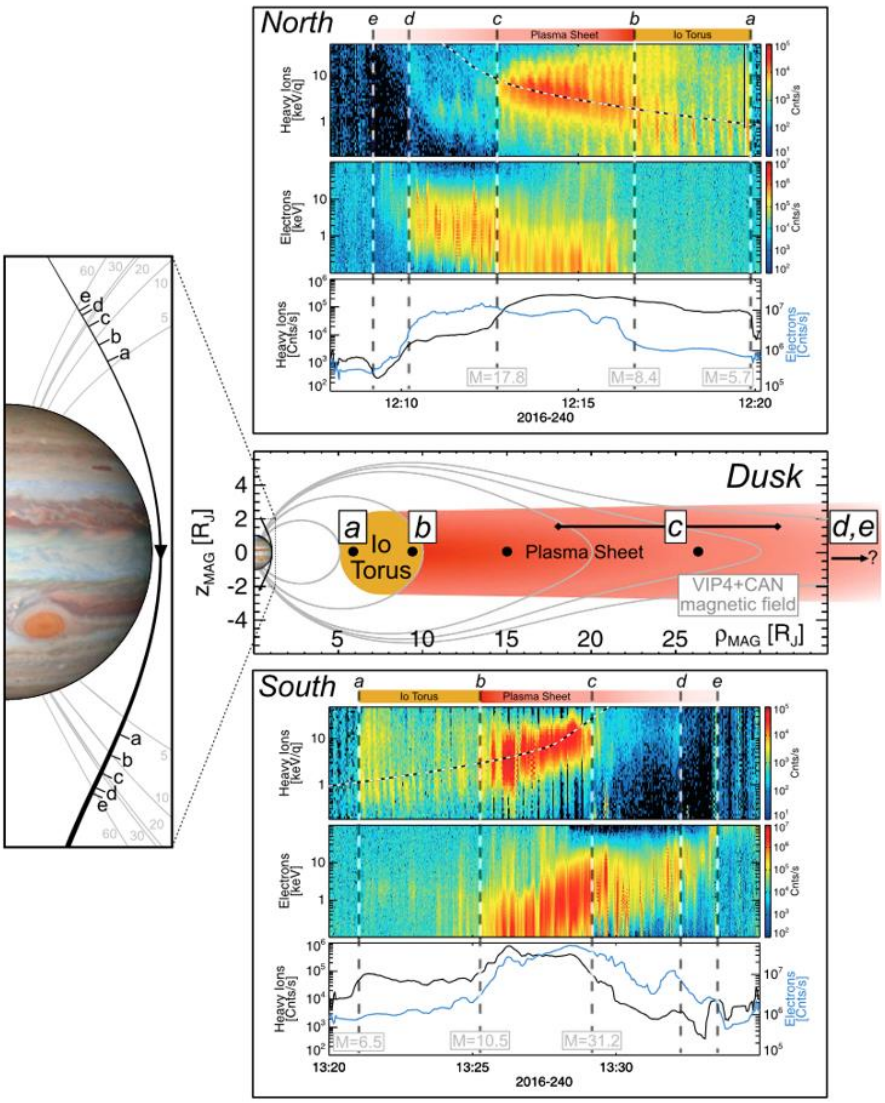
Objective:

The objective of this project is to design several samples of 3D-printed dielectrics with different characteristics and evaluate their electromagnetic responses. This work should enable the establishment of design rules that guarantee the reproducibility of parts in the future.
To do this, it will also be necessary to familiarize oneself with techniques for characterizing the dielectric constant at microwave frequencies, and even to develop new techniques that are compatible with the samples produced.

North-south asymmetries of Jupiter's magnetosphere

Description:

Jupiter has the strongest magnetic field in our Solar System and its interactions with the flow of matter coming from the Sun, the plasma wind, creates a magnetosphere surrounding it. This magnetosphere is filled with charged particles coming from the volcanic activity of the moon Io, that diffuse outwards and create a magnetized disc of plasma. The Juno spacecraft entered orbit about Jupiter on 5 July 2016 and carries on board the Auroral Distributions Experiment (JADE) that can directly sample the structure of Jupiter's magnetosphere. In this project we propose to analyze plasma and magnetic field from all available orbits (70) of Juno around Jupiter and identify potential asymmetries between the northern and southern hemispheres of the magnetosphere.
The tools developed by the french space plasma data center (CDPP, https://cdpp.eu) such as AMDA (http://amda.cdpp.eu) will be used in order to survey the data that will be subsequently analyzed with routines to be developed in the language of choice (python, ...).



Hierarchical Classification of Wildlife Images

Description:

Implementation and Comparison of Deep Neural Networks Incorporating Species Taxonomy

In the context of species classification one can observe both strong diversity and high complexity. In France for example, around 1,000 species of wild bees have been recorded to date. When attempting to classify a bee image, that is, to identify the species of the individual shown in an image, a major challenge arises: many species share similar features and look alike.

We will aim to organize species based on their taxonomic tree, the hierarchical structure that organizes species into nested groups based on their evolutionary relationships and shared characteristics. This tree makes it possible to classify bees in an ordered way, starting from the most general categories, such as families or genus, and moving toward specific species.

Unlike other classification tasks (such as distinguishing a table, a phone, or a plane), the hierarchical order of species can serve as additional information for a deep learning model. By leveraging this taxonomy, one can better differentiate closely related species by taking into account their similarities at different levels. The goal is not only to improve classification performance but also to limit the severity of errors: if the model predicts the wrong bee species, it should at least predict the correct family, and so on.

The objective of this project is to implement hierarchical loss functions proposed in the literature and to evaluate them by training a model on two different image datasets (the bees dataset depicted on the first figure, and the Deep Sea Debris Database, see below).

Stability analysis for n-periodic fluid systems

Description:

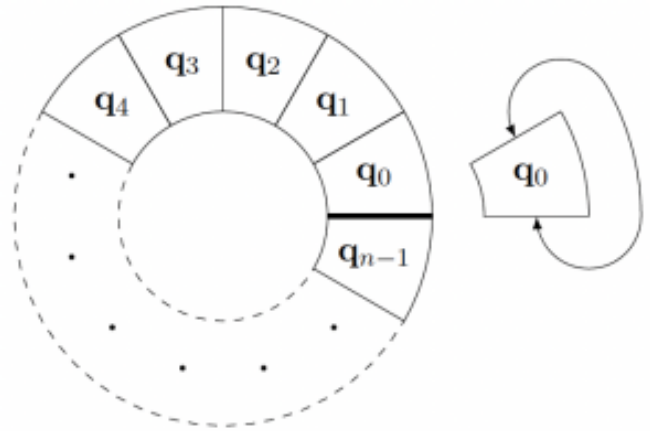


Figure 1: Sketch of an n-periodic fluid system which consists of n identical sub-units described by the corresponding state vector $\boldsymbol{q}_j$, $j = 0, ..., n-1$. From Schmid *et al.* (2017).

Fluid systems composed of arrays of identical sub-units are widely encountered in industrial applications. The ubiquity of fluid systems characterised by an n-periodic arrangement of identical sub-units or by multi-periodic geometric features (see figure 1) has spawned a great deal of analyses and simulations: flow in wavy or grooved channels (Ghaddar *et al.*, 1986; Szumbarski *et al.*, 2007) or past arrays of roughness elements and vortex generators (Choudhari *et al.*, 2009), acoustics in periodic wave-guides (Adams *et al.*, 2008), energy extraction from an buoy array (Garnaud & Mei, 2010) and, of course, flow in turbomachines (Erdos *et al.*, 2023; Gerolymos *et al.*, 2002) and combustors (Campa & Camporeale, 2014; Mensah *et al.*, 2016; Patil *et al.*, 2016; Staffelbach *et al.*, 2009) are but a few examples that fall under this category. Studying the stability of these n-periodic systems can be highly complex, as it involves solving a discretised system of excessive or even prohibitive size.

In this context, several methods have been introduced to address such problems by exploiting periodicity in order to reduce the computational cost required to solve the corresponding system. In addition to Floquet analysis, Schmid *et al.* (2017) have recently proposed a formulation that employs block-circulant matrices to reduce the resolution of n-periodic problems

to that of a single sub-unit (see figure 1). This approach ensures that the interaction of the remaining $n-1$ units with the single one is correctly modelled. Moreover, the decomposition into a single sub-unit and its subsequent linear analysis exhibit ideal scalability on parallel computing architectures, demonstrating further advantages of this type of analysis.

The aim of this research project is to investigate the linear stability of a row of wakes (see figure 2), where each individual sub-unit is modelled as a Bickley wake with a base-state profile given by the following relation:

$$U(y) = 1 - A\,\mathrm{sech}^2\left[a\left(y - \frac{1}{2}\right)\right] \tag{1}$$

with $0 \leq y \leq 1$. The parameter a governs the wake's width, while A defines the corresponding velocity deficit. Together, these parameters allow the streamwise evolution of the wake profile behind bluff bodies to be accurately represented. The temporal evolution of two-dimensional

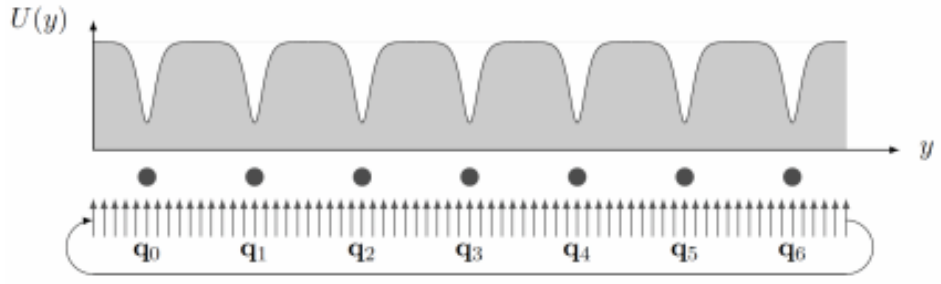


Figure 2: Sketch of a 7-periodic configuration of Bickley wakes (Schmid *et al.*, 2017).

perturbations $\boldsymbol{q}'(x,y,t) = \hat{\boldsymbol{q}}(y)\exp(i\alpha x)\exp(\lambda t)$ superimposed on the base flow of equation (1) is governed by the Orr-Sommerfeld equation:

$$\lambda\left(\frac{d^2}{dy^2} - \alpha^2\right)\hat{v} = -i\alpha U\left(\frac{d^2}{dy^2} - \alpha^2\right)\hat{v} + i\alpha U''\hat{v} + \frac{1}{Re}\left(\frac{d^2}{dy^2} - \alpha^2\right)^2\hat{v} \tag{2}$$

where $\hat{v}$ is the shape function of the perturbation normal velocity v', α the streamwise wavenumber, Re the Reynolds number based on the free-stream velocity and the distance between the individual wakes, and λ the eigenvalue whose real part constitutes the exponential growth or decay rate. Formulating the stability problem for a global problem consisting of n sub-units, a block-circulant global stability matrix results (Schmid *et al.*, 2017). The in-house solvers for the Orr–Sommerfeld equation, implemented in Python or MATLAB, are designed to perform linear stability analysis on the classical Poiseuille base flow. The objective of this research project is to modify the existing code to first adapt it to the new base flow (1), and subsequently extend it to handle the n-periodic system illustrated in figure 2.

The research project is thus planned in three stages.

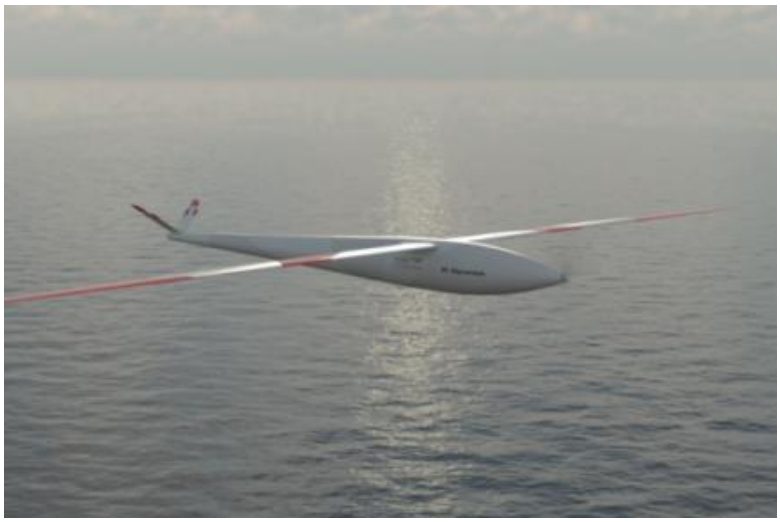
- The first phase involves becoming familiar with stability theory and the in-house stability solver for the Orr-Sommerfeld equation (2). To this end, preliminary analyses will be performed on the Poiseuille flow profile. Then, the students will focus on modifying the base flow by introducing a single wake profile (1).

- The second phase will address the core objective of the research, namely the implementation of the method proposed by Schmid *et al.* (2017) to solve the n-periodic problem via a parallel computing architecture and reproduce their results.

- The third phase will consist of a parametric analysis of the problem, in which the student will vary the governing parameters to assess the sensitivity of the system to both geometric and physical factors.

A Comprehensive Study of Stability, Flight Quality, and Aerodynamic Coefficient Identification for the MERMOZ Drone

Description:



This project will analyze the **stability, flight quality, and aerodynamic performance** of the MERMOZ drone through a structured five-step approach:

1. **Aerodynamic Coefficient Estimation and Validation**: Estimate lift, drag, and moment coefficients using **AVL (Athena Vortex Lattice)** and analytical methods. These results will be refined and validated through **participation in flight tests**, ensuring high-fidelity modeling.
2. **Flight Dynamics Simulation**: Implement the drone's aerodynamic model in **JSBSim** to simulate its dynamic behavior. This step will validate stability and control characteristics under nominal conditions, providing a baseline for further analysis.
3. **Longitudinal and Lateral Stability Analysis**: Assess the drone's **static and dynamic stability** in both longitudinal (pitch, speed) and lateral (roll, yaw) axes. This analysis will identify potential instabilities or coupling effects, which are critical for safe and efficient flight.
4. **Response to Atmospheric Perturbations**: Evaluate the drone's resilience to **severe atmospheric disturbances** (e.g., strong winds, wind shear, gusts). Performance metrics such as recovery time, deviation from trim, and control effort will be analyzed to assess robustness.
5. **Identification of Typical Flight Perturbations Using High-Resolution Atmospheric Models** Utilize **high-resolution atmospheric models (e.g., AROME or ICON)** to identify and characterize typical perturbations encountered during the drone's flight envelope. This will involve extracting realistic wind, turbulence, and thermal profiles specific to the drone's operational conditions, enabling accurate simulation and analysis of perturbation effects.

Flight Testing: Flight tests will be conducted during the project to collect real-world data, enabling the identification and refinement of aerodynamic coefficients.

Future Work: This project will serve as a foundation for next year's research, focusing on **in-flight energy recovery**. The validated aerodynamic and stability models will inform the development of control strategies to optimize energy harvesting from atmospheric disturbances and dynamic flight maneuvers.

Expected Outcomes:

- A validated aerodynamic model of the MERMOZ drone.
- Insights into stability and flight quality under nominal and perturbed conditions.
- Recommendations for design or control improvements.
- A framework for integrating flight test data into aerodynamic and stability analyses, setting the stage for energy harvesting research.

Improving paragliding back impact protection

Description:

Back injuries are among the most common paragliding related injuries. Appropriate back protection is thus an essential safety item in paragliding harnesses. Traditionally this back protection has been either foam or airbag based, both technologies having their corresponding advantages and drawbacks. Recent years have brought new developments in paragliding back impact protection with the arrival of the Neo-Koroyd based protectors. These use polymer tubes to create cubes that crumple under the impact, thus dissipating energy. This behavior allows for significantly thinner back impact protection, making the harnesses less bulky and improving their aerodynamic efficiency. There has been however some controversy whether the Koroyd behavior, which has maximal energy absorption, but in this process leads to high acceleration jerk is actually able to reduce the injuries following a back impact. This project seeks to explore ways to further improve this type of back impact protection through multiple leads : selective stiffening of the microtubes, designing more complex architected microstructure that further improve injury prevention, etc.

To achieve this, the project can address (depending on time and interest) following:

1. Litterature review of back impact injury prevention, notably based on medical studies on fighter jets ejector seats 2. Definition of the most relevant design criteria for a paragliding back protector based on the findings of the literature review
3. Numerical exploration of the back protection behavior and possible improvements through selective stiffening of certain areas
4. Design and optimization of an architected material that best achieves the previously defined design criteria
5. 3D printing of the architected material 6. Impact testing of Koroyd and of alternative or 3D printed material to compare real and expected performance.

Figure 1: Neo-Koroyd paragliding back impact protection (left); Neo-Suspender paragliding harness (right)

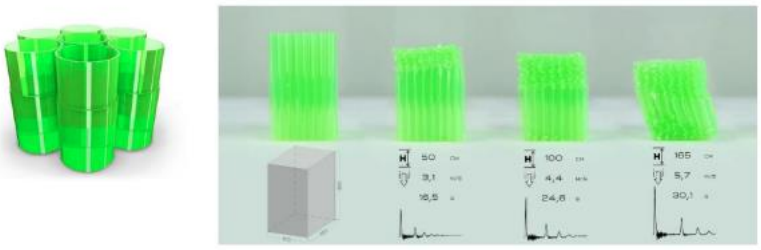


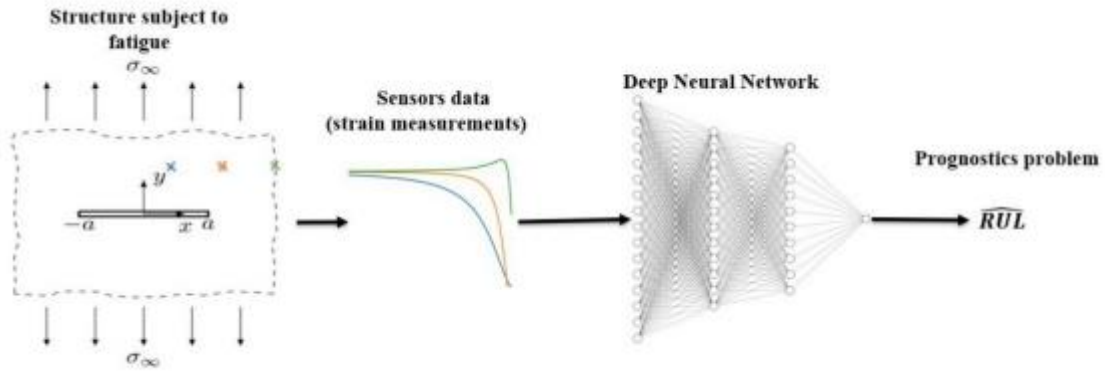
Figure 2: Koroyd tubes concept (left); crumpling behaviour under impact of the Koroyd cubes (right)

Deep learning for fatigue damage prognostics

Description:

Safe and efficient operations of aircraft is a persistent challenge in the aeronautical industry. One main current pillar for their continual improvement is through prognostics frameworks. Prognostics involves prediction of some relevant quantity (e.g. operational parameters, damage index) into the future. It can be particularly relevant for optimizing aircraft maintenance in order to significantly reduce lifetime operating costs while maintaining safety. Recent developments in deep neural networks (a.k.a deep learning) have led to numerous resounding successes in various fields, where large amounts of data are available (big data). Due to stringent safety requirements, aviation has always been at the forefront of recording vast amounts of sensory data. However, relating this sensory data to relevant quantities such as remaining useful life of the part is still an expensive and time-consuming task.

Recent work done within the superviser's team has shown the potential of a new self-supervised deep learning approach which is able to directly relate sensory data to remaining useful life of aircraft components subject to fatigue damage. The approach was based on a GRU network but various other neural networks (e.g. transformer, GPT, TRM) appear very competitive in other fields based on the literature. The objective of this research project is thus to investigate various available architectures for the deep, self-supervised learning framework developed for fatigue damage prognostics.



GUSTY project - Advanced control of a multirotor UAV in disturbed environments

Description:

Studying and simulating drone flights in disturbed aerological environments is of major importance, particularly for critical applications such as offshore wind turbine inspection. These environments, characterized by strong winds, velocity gradients, and unpredictable turbulence, create significant challenges in terms of stability, accuracy, and flight safety. Offshore wind turbines, located in high-wind regions, maximize energy production but expose maintenance teams to substantial risks during inspection operations. The use of drones makes it possible to perform observation and diagnostic missions without direct human intervention, thereby reducing safety hazards and operational costs. Understanding and predicting UAV behavior under aerodynamic disturbances is essential to: • Optimize control laws: design robust controllers capable of adapting the flight dynamics to sudden gusts or unsteady flows. • Ensure operational safety: identify stability limits and anticipate critical behaviors before flight testing. • Improve mission accuracy: preserve sensor and imaging quality even in complex aerological conditions. • Reduce maintenance costs: minimize unplanned shutdowns and extend system lifetime. In this context, an initial project conducted at ISAE-SUPAERO (Kristiyan Goranov, MSc Aerospace Engineering, 2nd years) developed a multirotor UAV simulator in Matlab/Simulink, including a realistic aerodynamic model and a full-state feedback PID controller. This simulator now provides a robust foundation to explore advanced control strategies capable of anticipating and compensating wind effects through predictive models or disturbance observers. The present project extends this work by integrating a spatio-temporal wind field derived from CFD and by developing advanced control methods (MPC, adaptive control, or disturbance observer) to enhance UAV robustness and reliability in disturbed environments.

Objectives:

The project aims to develop and assess advanced control strategies for a multirotor UAV operating in disturbed aerological environments, building upon the existing simulator enhanced with a detailed aerodynamic model.

Specific objectives are:
1. Analyze and understand the current dynamic and aerodynamic models (quadcopter and rotor–flow interaction).
2. Study and compare different advanced control approaches suitable for UAVs under disturbances:
- Model Predictive Control (MPC),
- Disturbance Observer (DOB),
- Adaptive Control (optional),
- Reinforcement Learning (exploratory).
3. Select and justify one or two promising strategies for detailed implementation.
4. Implement and validate the selected controller(s) on representative flight scenarios (vertical climb, translation, helical trajectory) with varying wind conditions.
5. Quantitatively compare the new approaches against the existing PID controller in terms of:
- tracking error (position and attitude), o robustness and stability under gusts,
- computational cost and real-time feasibility.
6. Evaluate onboard feasibility of the developed algorithms for small UAVs with limited computing resources.

Geometric and Semantic Traversability estimation for a rover in harsh environment

Description:

Context Space and terrestrial rovers are often deployed in unstructured, non-cooperative environments characterized by limited visibility, challenging localization, unpaved paths, and the presence of various obstacles. The mission constraints further restrict possible trajectories, while the terrain may include both positive and negative obstacles, slopes, and uneven surfaces — all of which pose significant risks to the robot.

These risks must be accurately identified and quantified in order to plan safe and efficient missions for autonomous systems. However, the sensors used to perceive such environments are often sparse or limited in their field of view — for example, 3D LiDARs with incomplete coverage or stereo-vision systems sensitive to lighting and texture conditions. Consequently, new methods taking into account the lack of information for environment mapping and traversability analysis are required. Moreover, on earth, purely geometric perception may incorrectly interpret some features as obstacles — for instance, tall grass or soft vegetation might appear as impassable objects, even though they pose no real traversal risk for the rover. This highlights the need to integrate semantic understanding into the traversability estimation process, enabling the system to differentiate between genuine obstacles and benign terrain elements. This project aims to explore advanced perception and machine learning approaches to estimate traversability by combining geometric features (such as slope, roughness, and obstacle height) with semantic understanding (such as terrain type, material, or deformability). The outcome will be a robust traversability estimation framework capable of guiding rovers in harsh and uncertain conditions.

Work to be done Several studies have already been conducted by our research team on this topic, and these previous results will have to be extended and improved :
• a LiDAR-based traversability mapper relying solely on geometric features,
• an image segmentation network for terrain classification. The main goals of the project are :
• Literature Review : Study existing approaches for traversability estimation, including geometry-based, appearance-based, and learning-based methods.
• Sensor Data Processing : Analyze and preprocess in a probabilistic way raw data from sensors such as LiDAR, stereo cameras, or RGB-D sensors.
• Feature Extraction : Identify relevant geometric features (slope, roughness, height variation) and semantic features (terrain type classification).
• Traversability Mapping : Design a method to fuse geometric and semantic cues into a single traversability map.
• Evaluation and Validation : Test the proposed approach on simulated and/or real datasets then with the rover to assess performance, accuracy, and robustness.

FIGURE 1 – CORTEX robot that will be used for the real experiment

Design of Aerial Firefighting aircraft

Description :

This work will be conducted as a continuation of the work currently carried out on the evaluation of the performances of an aerial firefighting aircraft. Said work, conducted in conjunction with Positive Aviation, aims at evaluation the performances of a retrofit ATR72 aircraft to which floaters were attached. Previous work, however, only focus on the evaluation of an already fixed configuration which is known to show more limited performances than a design from scratch.
Within the context of dramatic increase of fires and their environmental impact, the aim of the project is to explore the ability of the FAST-OAD simulation platform (https://github.com/fast-aircraft-design/FAST-OAD) to reproduce and size a firefighter aircraft, based on a regional aircraft. Therefore, a key output from the project is to enrich the current level of disciplinary models, considered at OAD level, required to describe floater (or similar) configurations.

Objectives:

- Extensive state of the art on: (a) floating concepts, with emphasis on floaters, (b) floater hydrodynamics, (c) structural, mass and handling qualities impacts of floater like devices
- Second, to set-up elementary lift & drag floater performance models, and associated mass breakdown;
- To evaluate the new models allocated to floater devices through implementation within the open source OAD platform (https://github.com/fast-aircraft-design/RTA);

Efficiency of a fan with water injection

Description:

The application of water injection in aeroengines has the well-known benefit of increasing the compression efficiency through evaporative cooling. Recent studies show that the entropy reduction through evaporative cooling is in competition with entropy creation due to the water phase change, and increased friction in the fluid. The studies use 3D numerical simulation of the two-phase flow through the compressor blades.
The aim of this project is to replicate these observations using a simpler, 2D-axisymmetric numerical model with a body-force (source-term) model for the fan (in StarCCM+), and discuss different system-level models of compression efficiency with water injection in the literature. We will begin with a literature review and comparison of existing system-level models before eventually proposing a theoretical model, then a numerical model based on a proposed test case. We will discuss the ability of the proposed test case to serve as a validation experiment, and possibly discuss the influence of the fan design and pressure ratio by reproducing the simulations on a second fan design.

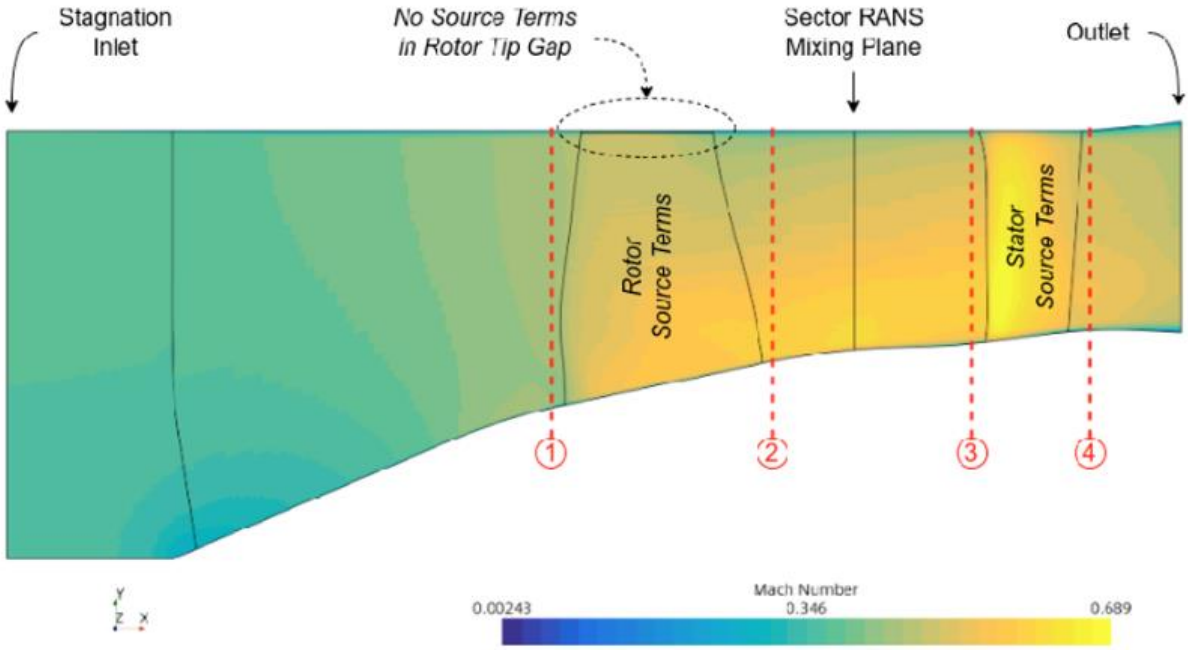


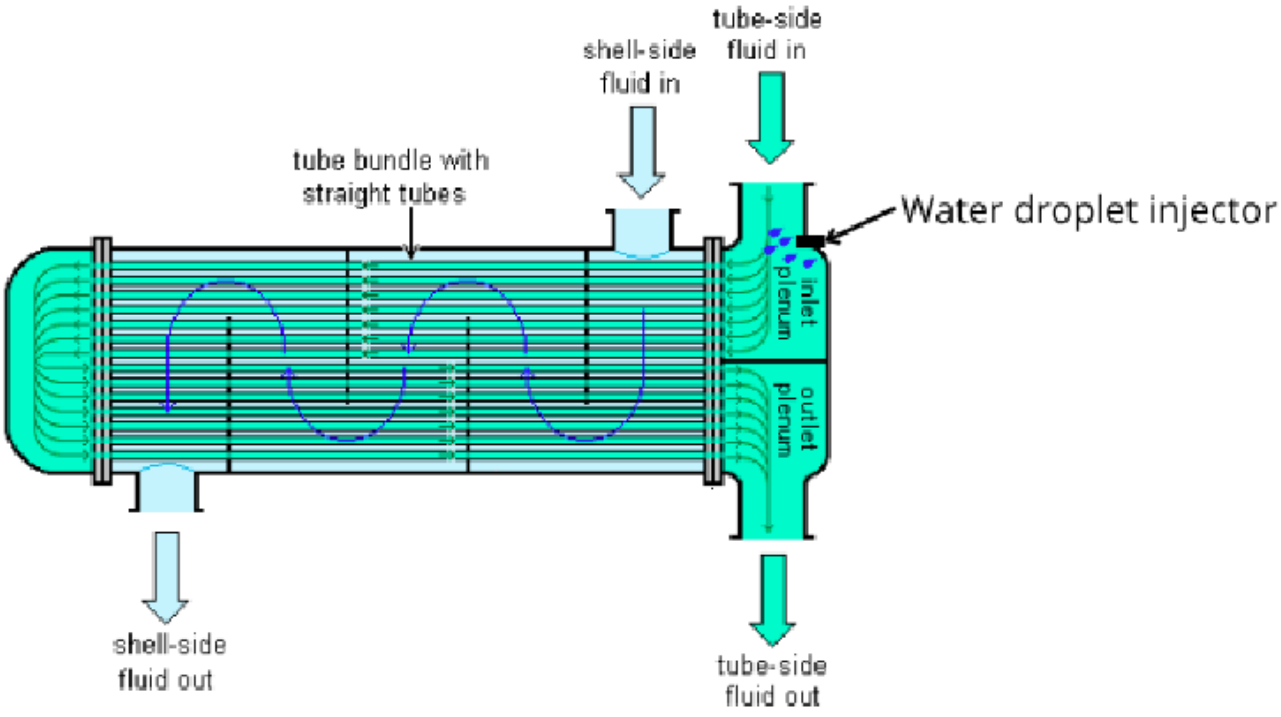
FIGURE 2: 2D AXISYMMETRIC DOMAIN

Droplet Injection in steam injected turboprop heat exchangers

Description:

Water droplet injection can enhance the performance of a heat exchanger through evaporative heat transfer, but may introduce further pressure loss through increased flow friction (droplet drag and higher flow speed). The objective of this project is to propose a 0D/1D model of heat exchanger with water injection, and to verify this model using numerical simulation (with Fluent) of the two-phase flow across a proposed heat exchanger geometry. Results will be compared to bench tests conducted in parallel at Viraj Aero. Expected outcomes include improving our understanding of heat exchange phenomena in droplet-laden flows, verify correlations used in system-level models, and establish practical design guides to maximise heat transfer for a minimal additional pressure loss (injector type and location, liquid-to-air ratio ranges).

Viraj Aero is a startup based in Toulouse developing a new generation of turboprop based on steam injection, enabling high fuel-efficiency gains and NOx reduction.



Steam-injected turboprop model for regional aviation

Description:

This Research Project aims to develop a comprehensive understanding of the performance gains and optimisation opportunities achievable through steam injection on the engines of a regional aircraft. This technology is expected to impact both the engine performance, but also the aircraft performance, through added weight, volume and potentially drag.
We will develop, in parallel, system level models for

- The performance model of a PW127-type engine (used on the ATR-72) as well as a model or steam injection to predict the influence of steam injection in the burner.
- The performance of an ATR72-type aircraft, to assess the impact of additional volume required, and the drag of the required air intakes

Finally, we aim to assess the expected benefits and optimal operating strategies depending on route length, cruise altitude, and other parameters to be determined.
The project will involve bibliographic research and 0D modeling and optimization, but also possibly CAD pre-designs and low-fidelity CFD studies. The working hypotheses will be defined in collaboration with Viraj's engineering team and can be validated through numerical simulations or targeted experimental tests organised jointly with the company.
Viraj is a startup based in Toulouse developing a new generation of turboprop engines using steam injection technology, which enables significant improvements in fuel efficiency and reductions in NOx emissions [1]. After light aviation, Viraj aims to extend steam injection to all aviation segments, starting with regional aircraft.

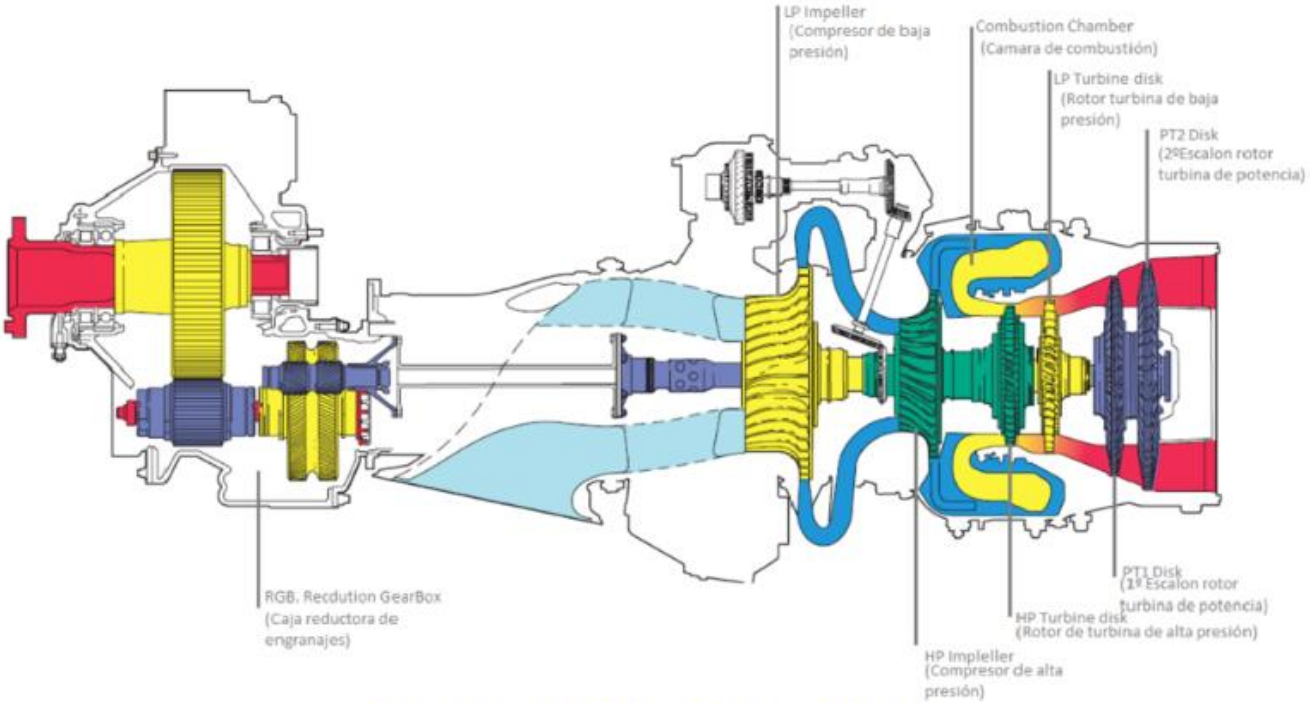


Figure 1 – PW127 – Section cut [2]

Modelling of a cryogenic fuel distribution system for a LH2-burning turbofan

Description:

Hydrogen-burning turbofan cycles have recently gained interest in civil aviation applications. Since liquid hydrogen is stored at cryogenic temperatures, it must undergo a large temperature variation on its way to the combustion chamber. This can be exploited as a heat sink to improve the propulsion system thermal efficiency, for example, through pre-cooling and inter-cooling in the compression phases.
The aim of this project is to model a cryogenic fuel distribution system for the DGEN380 turbofan engine (in the test bed at DAEP), and to couple it with the engine cycle via different heat management strategies, replicating the work of [1]. First we will model the jet-fuel-based cycle (using Python, PROOSIS or Pycycle), and compare with experiments at different operating points. Then we will calculate the cycle burning H2, model the fuel distribution system (Fig. 4 below) and discuss different heat-management strategies (Fig. 1 below) to couple the two. Finally, we will perform a preliminary design of heat exchangers to assess the feasibility of the coupled cycle.

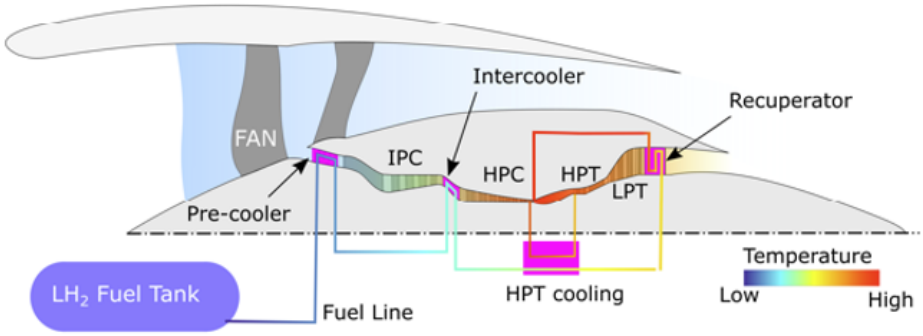


Figure 1. Cross-sectional meridional cut of a turbofan engine, including possible locations for core heat rejection to the hydrogen fuel. The fuel is stored at its boiling point in the cryogenic tank. The temperature of the hydrogen in the fuel line is increased by the different core-installed heat exchangers on its way to the combustion chamber. IPC: Intermediate-pressure compressor; HPC: High-pressure compressor; HPT: High-pressure turbine; LPT: Low-pressure turbine.

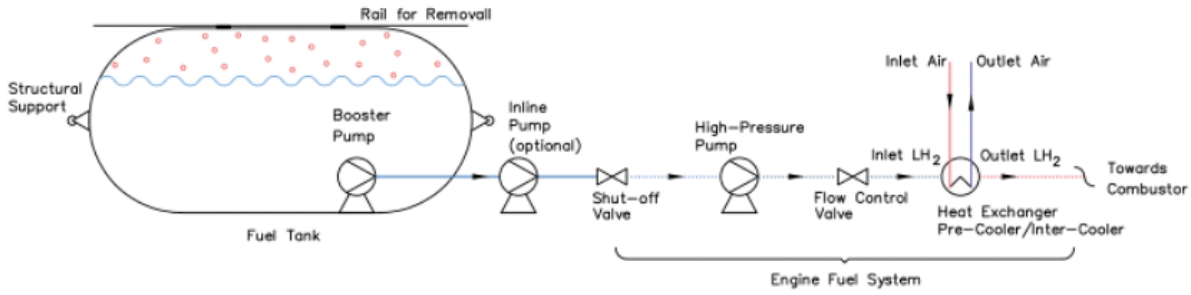


Figure 4. Schematic of cryogenic fuel distribution system connected to the structurally non-integrated tank.

MELiSSA-gym: a Reinforcement Learning framework to Optimize the Execution of Regenerative Life Support Systems

Description:

For sustaining human presence on extended space voyages, where resupply logistics from Earth are often unfeasible or unreliable, an essential requirement is the implementation of a closed-system solution. This necessity mandates the use of Regenerative Life Support Systems (LSS), which independently provide critical functions like atmosphere revitalization, water recovery, food production, and waste processing. The MELiSSA (MicroEcological Life Support System Alternative) project [6] has been initiated in 1987 by the European Space Agency and is the European project of circular life support systems. The physical realization of the MELiSSA loop [4], represented in Figure 1, is the MELISSA pilot plant [5] tested at the Universitat Autonoma de Barcelona, currently hosting laboratory rats as a crew mock-up mimicking the respiration of humans [2].

Objectives:

The MELiSSA loop has recently been modeled precisely (see Figure 2) for the purpose of controlling it using a Model Predictive Control approach [1]. This work has been published, but the associated code is not publicly available and uses a proprietary language. The objective of this research project is to develop a simulator of this loop in the form of a gymnasium environment [10], such as farm-gym [7], gym-DSSAT [3], or wofost-gym [8]. This environment will enable reinforcement learning [9] agents to be trained in order to optimize the execution of the MELiSSA loop. After a literature review on the MELiSSA loop and Reinforcement Learning, the simulator will be developed by creating increasingly refined versions: starting with a simplified version involving a finite set of states and actions and simple equations, the model will be improved until a version close to that defined in [1] is obtained, allowing comparison with the methods presented therein. For each version of the simulator, several reinforcement learning algorithms will be developed in order to train agents and compare their performances. The progress made in this work may be published in conferences or journals on AI applications or space research. All the work done during the internship will be made reproducible and open-source, following an open-science and open knowledge philosophy.

Figure 1: The concept of the MELiSSA loop with its five compartments and their interconnections. Picture from [11].

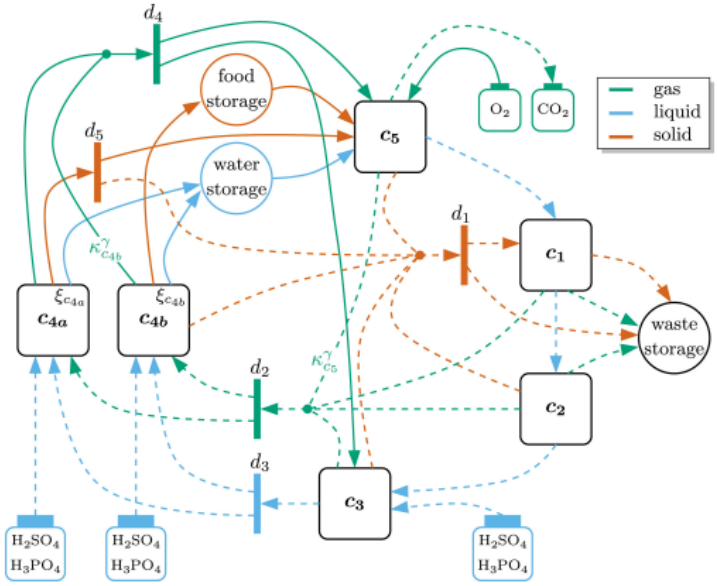


Figure 2: Precise representation of the MELiSSA loop.

Computer Vision for Space Farming

Description:

Advances in space exploration require human presence in space for extended periods. Indeed, permanent settlement on other planets is now very much on the agenda, as are long space travels. However, supplying these missions from Earth would be too costly, if not impossible. A promising solution is to consider closed-loop systems and bioregenerative Life Support Systems (LSS) to ensure and maximize recycling of resources, in particular oxygen, water and food. Therefore, plant cultivation is an essential aspect that must be ensured while using resources as efficiently as possible. In future missions, astronauts will have limited time for crop cultivation, as their main focus will be on completing mission objectives. Therefore, upcoming space cultivation systems must be designed to require the least crew intervention, incorporating more automation to streamline the process. Monitoring plant growth and health throughout their life cycle is crucial to ensure the proper operation of the closed-loop system. Advanced imaging techniques can gather essential data enabling non-invasive and automated assessments of the state of the plants and requiring minimal crew involvement. Swiftly identifying signs of nutrient deficiencies, drought or infections enables early response, and ultimately the success of long-term space missions. In this context, the University of Adelaide (Australia), member of the Plants for Space ARC of Excellence, and ISAE-SUPAERO, hosting the ALICE (AI for Life In spaCE) project, are interested in the development of Computer Vision algorithms for plant cultivation monitoring.

Objectives:

The objective of this research project is to develop computer vision algorithms that can estimate quantities of interest relating to cultivated plants from images of them. More specifically, it aims to estimate fresh weight, plant height, leaf area, diameter, and dry weight of lettuce (outputs, also called target) from RGB-(D) images (input) taken from above. A dataset comprising 391 images, which will be provided at the start of the project, has been collected and labeled with actual outputs and can be used to evaluate the performance of the developed methods.
The aim of this project is to conduct a benchmark, i.e. a comparison of several methods from the literature based on the same (provided) dataset and regression metrics. Once the literature review on computer-vision and vision-based plant monitoring has been completed, the first steps in developing this benchmark will be as follows:
• The first method is a two-step process: it begins with raw image processing using OpenCV [1] to estimate leaf area, then continues with regression (classical supervised learning, e.g. Random Forests) using Scikit-Learn [6] to estimate the targets 2 Figure 2: Phenobench image segmentation dataset [8]. (outputs) mentioned earlier. Priority should be given to predicting fresh weight and plant height.
• The second method consists of directly using deep learning models (e.g. CNN) with Pytorch [5, 3] to predict the targets (mainly plant height and fresh weight).
• Next, more recent techniques will be developed: based on publicly available pretrained models, such as SAM [2] or YOLO [7], and using online databases, such as the Plant Phenotyping Dataset [4], Phenobench [8] or the datasets mentioned in [9]. The performance of the developed methods will be evaluated using Cross-Validation on the provided dataset. The code and documentation will be hosted on a repository (e.g. github) allowing remote testing during the project.

Planning and Reinforcement Learning for Precision Agriculture in Life Support Systems

Description:

Now that humanity is able to go to other planets, the next challenge is to send human there, and to be able to settle there permanently. Since supplying the future settlers from Earth would be far too expensive, if not impossible, one of the major problems in achieving space exploration is the lack of resources and favorable local conditions. Moreover, according to the latest work of the Intergovernmental Panel on Climate Change (IPCC), sustaining life on our own planet also seems to be a challenge. Contexts that support life will be more difficult to access on Earth, mainly because of climate change itself, and maybe in the shorter term as a consequence of the policies to fight it, and the depletion of resources. Finally, on Earth or in space, it is necessary to find solutions to ensure the sustainability of life despite the lack of resources and unsuitable environments.

The research in bioregenerative life support systems (BLSS) [16, 1] aims at allowing a long term settlement of the human being in such environments. This is why ESA is interested in the implementation of BLSS: “For more than 30 years, the European Space Agency (i.e. ESA) is active in the field of regenerative life support system. MELiSSA (Micro-Ecological Life Support System Alternative) is the European project of circular life support system. It was established to gain knowledge on regenerative system, aiming to the highest degree of autonomy and conse1 quently to produce food, water and oxygen from mission wastes.”1 . Within the framework of the MELiSSA project, design studies for greenhouses [13, 2, 17] and prototypes have been developed (e.g. for cultivation of tuberous plants [8] in the ESA Project “Precursor of Food Production Unit”), and many research works have been carried out (e.g. on hydroponic systems [6] or potatoes in controlled environments [7]).

The SpaceShip FR project of the CNES (Centre National d’Etudes Spatiales), that started in 2019 in Toulouse FRANCE, plans to build a lunar or martian type base in order to demonstrate the solutions implemented in various fields, such as health, energy, robotics, digital, plant cultivation and recycling. Regarding the issue of nutrition, the SpaceShip FR project considers hydroponic greenhouse, as well as circular aquaponic system whose fish can be used to diversify the astronauts’ daily nutrition and create fertilizers from their waste.

Many experiments have already been carried out in space, one of the most recent being the production of chili peppers in the ISS by NASA three years ago, which of course also conducts a lot of research on systems growing plants for food production [4]. It was also the first fruit in space and the longest experimentation with plants. For his part, the ESA astronaut Thomas Pesquet has been named Food and Agriculture Organization (FAO) Goodwill Ambassador in April 2021, on the occasion of the International Human Space Flight Day. Finally, a french start-up has succeeded in growing lettuce in lunar regolith. Although this experiment was not in space, it represents a big step towards space agriculture.

ALICE Project:

As explained and highlighted in [9, 14, 10], space crop production needs for advanced automation, robotics, modeling, and machine learning. With the support of the Innovspace (Fablab of ISAE-SUPAERO), the ALICE (AI for Life In spaCE) project also contributes to the research domain of Precision Agriculture in Life Suport Systems (LSS) with the general goal of using Artificial Intelligence (AI) for maximizing production and minimizing ressource consumption. In this context, the ALICE project focuses on 4 main interrelated issues, namely the optimization of:
1. the design of plant cultivation systems using Multi-Disciplinary Analysis and Optimization (MDAO) frameworks taking into account various models and criteria,
2. the plant and environment state estimation using Machine Learning and Computer Vision algorithms to derive informed decisions from data,
3. the sequential decisions using Planning and (Offline) Reinforcement Learning algorithms to compute efficient and economical autonomous cultivation strategies,
4. the data transmission between systems using low power, wide area communication protocol (e.g. LoRa).

The related studies paves the way towards autonomous plant growing systems capable of analyzing and even reacting to the growing process in order to quickly obtain healthy plants while optimally use space and resources (nutrient, water, energy, etc.). Twenty students are taking part or have taken part in this project since 2019.

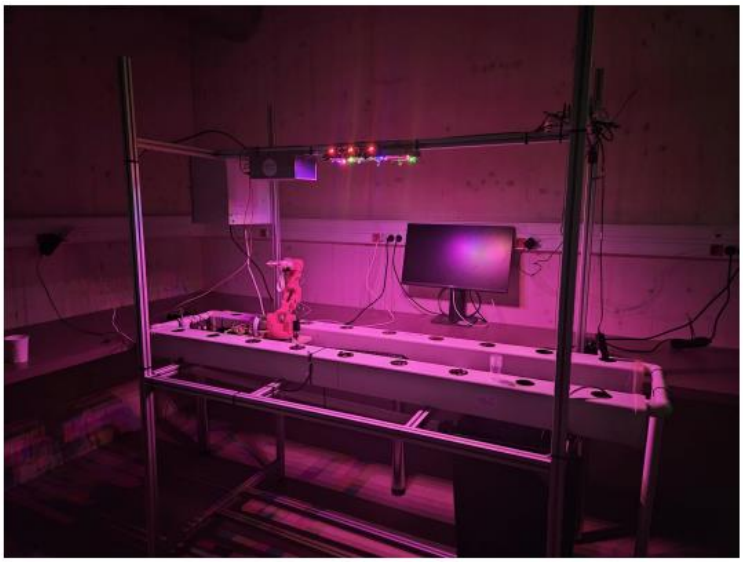


Figure 1: Robotic hydroponic system.

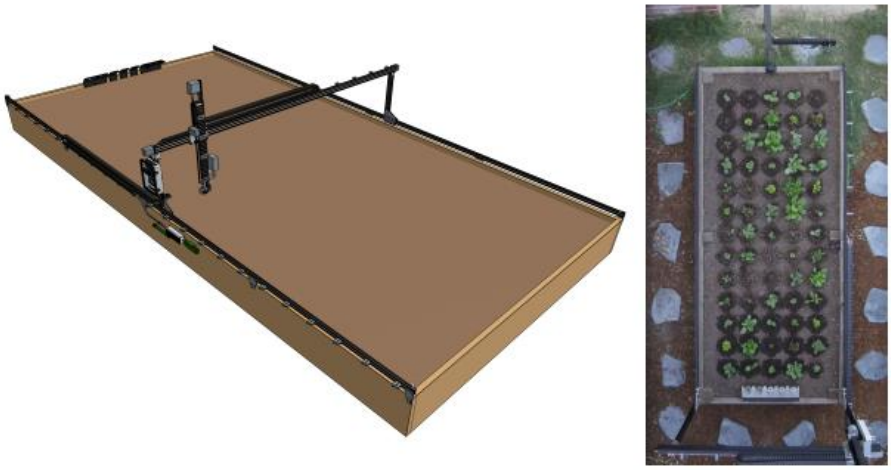


Figure 2: Farmbot Genesis XL robotic system.

The ALICE project also sets up test beds to collect plant cultivation system data useful for the 4 main issues, and to ensure that the tools developed work in practice. One of them is a robotic hydroponic system (see Figure 1) developped and improved by previous students. This robot controls the intensity and the frequency of the light, as suggested by [12, 11], the flow of the water and the nutrients level, measures the temperature, the pH of the water, and with its robotic arm fixed on a rail, it is able to take pictures of each plant and to move them.

Another test bed of the ALICE project is the Farmbot Genesis XL2 (see Figure 2), an open source Cartesian coordinate robot farming machine that has been set up next to the ISAE restaurant. This robot can plant seeds, water plants, remove weeds, take pictures, and measure the soil moisture. The hydroponic system as well as the Farmbot may be used for this research project addressing the third main issue, namely the optimization of the sequential decisions using Planning and (Offline) Reinforcement Learning algorithms to compute efficient and economical autonomous cultivation strategies.

Objectives:

The objective of the presented research project is to use Planning [3] and Reinforcement Learning [15] to optimize the execution of plant cultivation systems.

• The first step in any research project is to begin a literature review of the subject. For this project, it will concern plant cultivation systems, precision agriculture, planning and reinforcement learning.

• In parallel, it will be necessary to learn how to use planning algorithms (e.g. MetricFF3 or Prost4) with associated languages (e.g. PDDL or RDDL), and Reinforcement Learning algorithms trained on simulators (e.g. Gymnasium5) or on a large dataset [5]. A test bed of the ALICE project (the robotic hydroponic system or the Farmbot) will be also studied and tested, listing accessible data and possible actions of the system on the environment, to ensure accurate modelling. The measurement tools needed to estimate the criteria used for optimization may be added on the system.

• Once the state of the art has been sufficiently analyzed, a first planning or reinforcement learning task will be proposed, minimizing ressource consumption and maximizing production. This task will be solved and evaluated according to the chosen criteria.

• In order to confront these research contributions with reality, the computed optimal cultivation strategy will be executed on a test bed of the ALICE project (the robotic hydroponic system or the Farmbot), and evaluated according to actual execution.

• The research project continues by multiplying these planning/RL tasks, improving the associated cultivation stategies, and evaluating them in practice.

Multi-Disciplinary Analysis and Optimization for Precision Agriculture in Life Support Systems

Description:

Now that humanity is able to go to other planets, the next challenge is to send human there, and to be able to settle there permanently. Since supplying the future settlers from Earth would be far too expensive, if not impossible, one of the major problems in achieving space exploration is the lack of resources and favorable local conditions. Moreover, according to the latest work of the Intergovernmental Panel on Climate Change (IPCC), sustaining life on our own planet also seems to be a challenge. Contexts that support life will be more difficult to access on Earth, mainly because of climate change itself, and maybe in the shorter term as a consequence of the policies to fight it, and the depletion of resources. Finally, on Earth or in space, it is necessary to find solutions to ensure the sustainability of life despite the lack of resources and unsuitable environments.

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ALICE Project:

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1. the design of plant cultivation systems using Multi-Disciplinary Analysis and Optimization (MDAO) frameworks taking into account various models and criteria,
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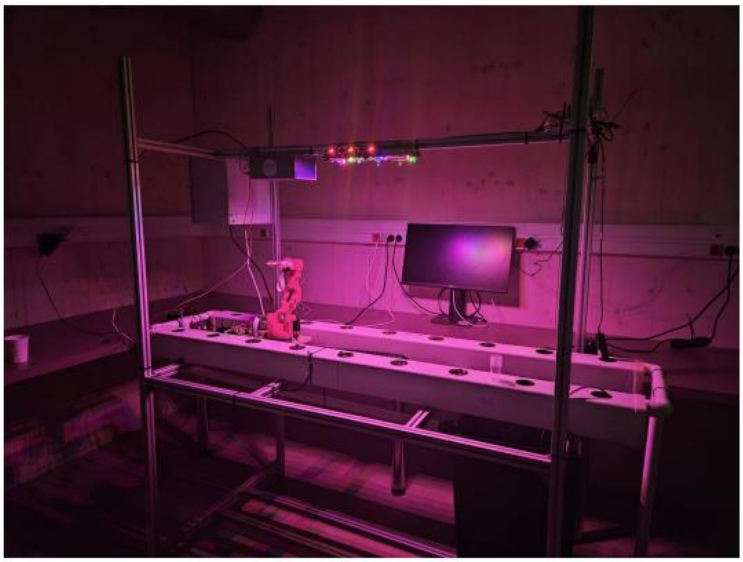

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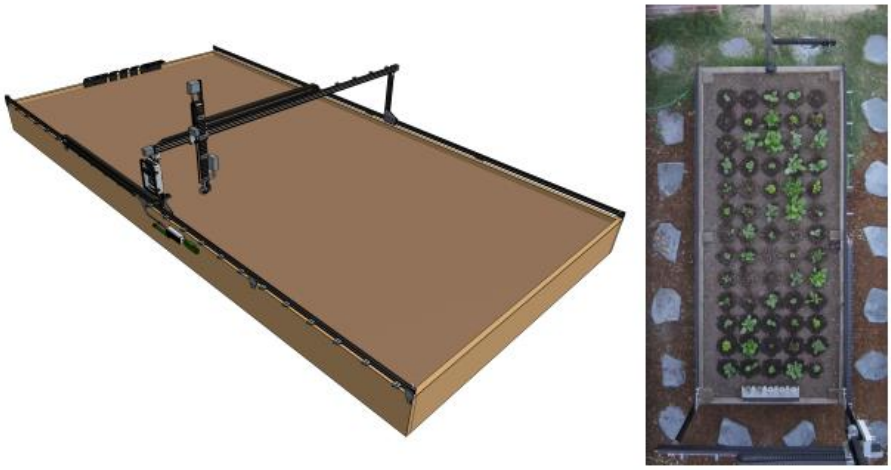

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The ALICE project also sets up test beds to collect plant cultivation system data useful for the 4 main issues, and to ensure that the tools developed work in practice. One of them is a robotic hydroponic system (see Figure 1) developped and improved by previous students. This robot controls the intensity and the frequency of the light, as suggested by [12, 11], the flow of the water and the nutrients level, measures the temperature, the pH of the water, and with its robotic arm fixed on a rail, it is able to take pictures of each plant and to move them.

Another test bed of the ALICE project is the Farmbot Genesis XL2 (see Figure 2), an open source Cartesian coordinate robot farming machine that has been set up next to the ISAE restaurant. This robot can plant seeds, water plants, remove weeds, take pictures, and measure the soil moisture. The hydroponic system as well as the Farmbot may be used for this research project addressing the first main issue, namely the optimization of the design of plant cultivation systems using MDAO frameworks.

Objectives:

The objective of the presented research project is to use Multi-Disciplinary Analysis and Optimization (e.g. OpenMDAO [4]) to model plant cultivation systems in order to analyse and optimize some of its parameters on the basis of the ALiSSE (Advanced Life Support System Evaluator) criteria [2].

• The first step in any research project is to begin a literature review of the subject. For this project, it will concern plant cultivation systems, the various disciplines and models that make them up, and more generally precision agriculture and multidisciplinary analysis and optimization.

• In parallel, it will be necessary to learn how to use an MDAO framework such as OpenMDAO [4]. A test bed of the ALICE project (the robotic hydroponic system or the Farmbot) will be also studied and tested, listing accessible data and possible actions of the system on the environment, to ensure accurate modelling. The measurement tools needed to estimate some of the ALiSSE metrics [2] may be added on the system.

• Once the state of the art has been sufficiently analyzed, a first model of plant cultivation system will be proposed, composed of sub-models associated with the literature (e.g. plant gas exchange and biomass models [9, 11]). This multi-disciplinary model will then be described, analyzed and optimized using an MDAO tool, according to selected criteria.

• In order to confront these research contributions with reality, a test bed of the ALICE project (the robotic hydroponic system or the Farmbot) will then be modeled with the same tool. The analysis and optimization phases will then be used to improve the propotype.

• Finally, the improvements will be evaluated using direct measurements during data collection campaigns with the test beds.

Computer Vision and Machine Learning for Precision Agriculture in Life Support Systems

Description:

Now that humanity is able to go to other planets, the next challenge is to send human there, and to be able to settle there permanently. Since supplying the future settlers from Earth would be far too expensive, if not impossible, one of the major problems in achieving space exploration is the lack of resources and favorable local conditions. Moreover, according to the latest work of the Intergovernmental Panel on Climate Change (IPCC), sustaining life on our own planet also seems to be a challenge. Contexts that support life will be more difficult to access on Earth, mainly because of climate change itself, and maybe in the shorter term as a consequence of the policies to fight it, and the depletion of resources. Finally, on Earth or in space, it is necessary to find solutions to ensure the sustainability of life despite the lack of resources and unsuitable environments.

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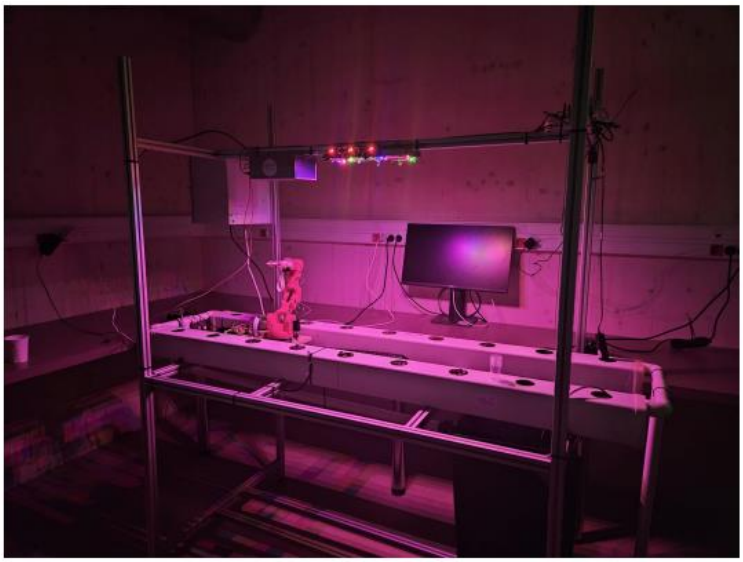

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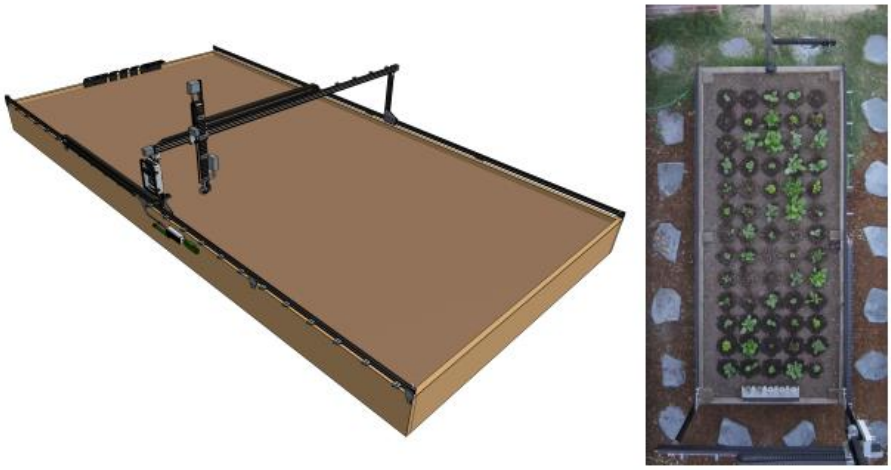

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Objectives:

The objective of the presented research project is to use Machine Learning (Scikit-Learn [9]) and Deep Learning (Pytorch [8]) to extract information from sensor measurements in plant cultivation systems. Typically, object detection and image segmentation algorithms can be trained and used on the camera sensors of these systems.

• The first step in any research project is to begin a literature review of the subject. For this project, it will concern plant cultivation systems, precision agriculture, Machine/Deep Learning and Computer Vision.
• In parallel, it will be necessary to learn how to use Machine/Deep Learning frameworks such as Scikit-Learn [9] and Pytorch [8]. A test bed of the ALICE project (the robotic hydroponic system or the Farmbot) will be also studied and tested, listing accessible data and possible predictions that can be performed with the system.
• Once the state of the art has been sufficiently analyzed, a first prediction task will be proposed, i.e. a dataset (e.g. the plant phenotyping dataset [4]) along with estimators to be trained on it, as well as performance metrics to evaluate and compare them.
• In order to confront these research contributions with reality, a test bed of the ALICE project (the robotic hydroponic system or the Farmbot) will then be used to collect data to be analysed and perform predictions to be evaluated.
• The research project continues by multiplying these prediction tasks and improving the associated estimation of the state of the growing plants and their environment, enabling them to be monitored more closely and comprehensively.

Visual Navigation Using Multiple Cameras in Challenging Environments

Description:

Robotic positioning heavily relies on cameras and satellite-based navigation systems, or GNSS. The former permits local, or relative, positioning and mapping, while the latter gives access to global position estimates. Recent work has tried to combine these complementary characteristics. Although both approaches can offer good accuracy in adequate conditions, they each face specific challenges in certain environments. GNSS struggles with satellite blockage and signal reflections, notably in urban or dense forest environments. An approach to mitigate this effect is the use of a sky-facing camera, which helps identify which satellite's signals are likely to be affected by obstacles. On the other hand, traditional visual odometry with stereo cameras performs poorly on images of low feature density, such as the sky or uniformly colored walls. Vision-based positioning is also affected by the presence of moving objects, which need to be identified and excluded, or at least treated separately for each object. Figure 2 illustrates the process of finding and matching geometric features in two successive images.

Within the PNX lab at Navir^{2}es, an algorithm has been developed that segments sky-facing images semantically, i.e. it assigns classes such as "Sky" or "Building" to each patch. An example of such labeling is given in Figure 3. Initially conceived for satellite classification and environmental context detection, recent work has expanded the application of the sky-facing camera towards visual odometry. Facing upwards, this camera is little affected by pedestrians or other vehicles moving around it. Key results of this new approach are that image areas classified as "Building" provide reliable visual features, while others such as "Sky" or "Tree" are better ignored. Figures 4 to 7 show some examples where visual odometry may struggle. As building-rich areas are precisely where GNSS tends to fail, a combined vision/GNSS estimator has been studied by the lab and compared to the state-of-the-art [3]. Here, a forward-facing stereo camera combined with a covariance estimator assuming Gaussian errors has shown good results in both in- and outdoor environments. A forward-facing camera provides the highest quality features near the vehicles "eye level" and is most suitable for obstacle detection. These are the most challenging for the sky-facing camera, being near the edge of its field of view and therefore subject to the largest distortions. Combining both should further improve the estimator's robustness and adapability.

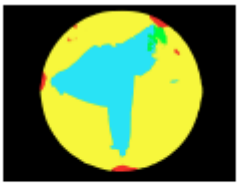


Figure 3: Semantic segmentation of a sky-facing fisheye camera image, using [2]

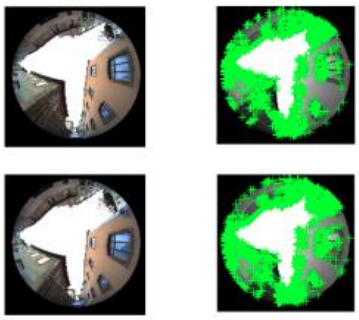


Figure 1: Successive images taken in an « urban canyon » (left) and identified features using ORB [1] (right)

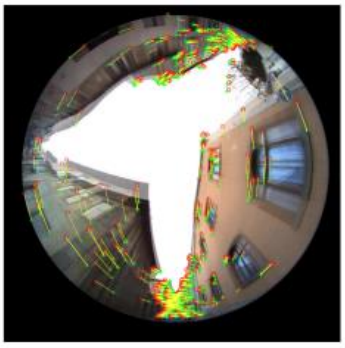


Figure 2: Similar ORB features detected in both images

Figure 4: Good Image

Figure 5: Overexposed

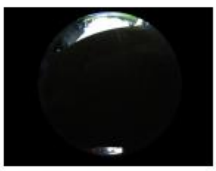


Figure 6: Underexposed

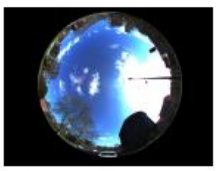


Figure 7: Too much sky

the highest quality features near the vehicles "eye level" and is most suitable for obstacle detection. These are the most challenging for the sky-facing camera, being near the edge of its field of view and therefore subject to the largest distortions. Combining both should further improve the estimator's robustness and adapability.

Objectives:

In addition to accuracy, a key criterion for good estimators is consistency. An estimator is called consistent if its accuracy as estimated by itself (typically in form of a covariance matrix) matches the actual error. Figure 8 shows the estimated uncertainty ellipse of an existing visual odometry package [4]; its actual error should lie within this.

However, camera-based navigation experiences strongly nonGaussian measurement errors and outliers, with several methods available to mitigate, but not remove, their effects. This research project will examine the error distribution at multiple levels within the visual odometry pipeline, using real data in various distinct environments. This will help the estimator make an informed decision whether to rely more on the forward- or upward facing cameras. It can also aid in choosing or tuning outlier rejection schemes.
The statistical results will permit the student to propose a novel estimator that integrates all three cameras, even while handling images without or only minimally overlapping field of view. Visual odometry with non-overlapping-FoV cameras is an ongoing research topic [5]. As a perspective, absolute GNSS position estimates may be available depending on the environment. A consistent and robust visual odometry pipeline is an essential building block towards multi-sensor fusion.

The work will encompass the following stages:
1. Introduction to visual odometry, feature detection and tracking, based on the results of a prior RP which 2 used a monocular sky-facing camera (+GNSS).
2. Determine properties which may influence the visual odometry's performance, such as image metadata, environmental context and semantic information.
3. Statistically characterize the distribution of the forward- and upward-facing VO performance, concerning both the position estimate errors as well as the feature detection / matching stage.
4. Explore variants of the existing estimator and study impacts on its performance, e.g. modify image pre-processing, feature detection / tracking, outlier detection, estimator tuning.
5. (Propose a concept to combine forward- and upward-facing cameras in a single estimator based on the prior analysis [if time permits])
6. (Implement and evaluate this novel estimator [if time permits]) For all of these stages, a study of the state-of-the-art will be performed. Initially, the work will be focused on statistical evaluation, which will lay the foundation for the eventual implementation of a novel estimator. New data may be acquired using the PNX lab's robotic experiment platform.

Cardiorespiratory Electromagnetic Measurement (CEM)

Description:

In cooperation with aviation medical doctors, we will conduct electromagnetic field measurements in an anechoic chamber. These measurements target natural emissions from the human body, but usually it is the cephalospinal system that is observed. Here, cardiorespiratory emissions will be observed in order to detect changes related to rhythm variations. The patient cohort consists of the doctors themselves and the research director physicist, and the student's role will be to collect data, help interpret it, and lay the foundations for a future publication.

Bringing humans back in the center of systems development

Description:

In recent years, a transition from the automation-centric Industry 4.0 to a more human-centered Industry 5.0 emerged. Going beyond the efficiency and productivity achieved with Industry 4.0, respect for human values and contribution to society's vital needs came in the spotlight. Human-Cyber-Physical Systems (HCPSs) and their development are expected to provide features such as collaborative intelligence, adaptability, and resilience. Such features may be obtained by leveraging the consideration of the human (user/operator) early on in the design process and the use of capabilities such as integration, intelligence, and collaboration.

This project wants to contribute to the question on how to adapt current processes and tools to address the design, human in the loop integration, and multidisciplinary assessment of increasingly complex systems of systems with human and automation in the loop that characterise today's industrial context. Such a novel approach should facilitate and support the design of HCPSs with the objective of promoting a better integration of Systems of Systems (SoS), automation and human parts of such HCPSs from the earliest design phases.

This project proposes to build upon and contribute to a currently ongoing PhD project through:

- refining the analysis of the state-of-the-art - many things are ongoing in this exciting field, and it would be good to have a complete comprehensive overview on what is happening
- propose solutions as to how to better incorporate human aspects in the design process
- work on the realisation of such improved processes

The exact topic on which this project will work on will depend on where we are with the topics at the moment of the start of the research project your personal interest
It is therefore important to discuss in detail.

Modeling of air transport systems

Description:

In discussions on environment and sustainable development, there is a critical eye on air transport. Some discussions suggest better optimization of aircraft during the design phase. However, the aircraft is not “alone”. Even with very significative optimization during its design phase, and validated against this, optimality once in operation cannot be guaranteed. Indeed, aircraft in operation are subject to many constraints, such as the routes proposed by Air Traffic Control, weather influence, impact of failures and maintenance, etc.

A research project currently underway aims to mobilize new disciplines to better evolve the air transport system and covers the following aspects:

1. new scientific bases for air traffic management,
2. new models or simulations for key components of the technical air transport system,
3. understanding the dynamics and resistance to the evolution of the socio-technical system,
4. proposing approaches to remove obstacles,
5. combining systems engineering methods and non-technological disciplines (economics, sociology, innovation, design, etc.).

As a starting point in this research project, and focusing on the second point, we want to document in detail the state of the art in terms of modeling the different components of the air transport system. Indeed, one of the most important scientific obstacles concerns the difficulty in obtaining an adequate model (or set of models) that faithfully describes the air transport system as a whole and in ensuring/maintaining consistency between the system and the model. As part of the proposed research project, the student(s) search the literature to identify candidate models, seek to reproduce them and make a start of a global model.

Knowledge Graphs and how to build them

Description:

In knowledge representation and reasoning, a knowledge graph is a knowledge base that uses a graph-structured data model or topology to represent and operate on data. Knowledge graphs are often used to store interlinked descriptions of entities – objects, events, situations or abstract concepts – while also encoding the free-form semantics or relationships underlying these entities. Since the development of the Semantic Web, knowledge graphs have often been associated with linked open data projects, focusing on the connections between concepts and entities. They are also historically associated with and used by search engines such as Google, Bing, Yext and Yahoo; knowledgeengines and question-answering services such as WolframAlpha, Apple's Siri, and Amazon Alexa; and social networks such as LinkedIn and Facebook.

Recent developments in data science and machine learning, particularly in graph neural networks and representation learning and also in machine learning, have broadened the scope of knowledge graphs beyond their traditional use in search engines and recommender systems. They are increasingly used in scientific research, with notable applications in fields such as genomics, proteomics,
and systems biology.

This project proposes to continue work on the main question: How to derive knowledge graphs from existing data sources?
Some work was done in the past on using LLM's to build up knowledge graphs, but also work was done on setting up ontologies (concept-wise close to knowledge graphs) building on case-bases [Muñoz-Hernandez et al., 2021].
The idea in this project is to continue this research and see whether

- other possibilities may be interesting
- how to bring the options together for maybe a unified approach
- see how to bring closer such knowledge graphs to other paradigms used in design, such as MBSE, game-theory-based decision, etc.

Brain-in-the-Loop Reinforcement Learning: Using EEG Error Potentials to Improve Human–AI Collaboration in Overcooked

Description:

When collaborating with humans, AI teammates often make actions that *feel wrong* or *non-cooperative* (repeating action, prioritize one elements already choose by human).
Interestingly, the human brain automatically reacts to such errors by generating Error-Related Potentials (ErrPs), detectable in the EEG within ~300 ms after the event.
This project explores how these spontaneous brain signals can be used as real-time feedback to train AI agents to behave more collaboratively.
The objective is to develop and evaluate a closed-loop system where EEG-based ErrP detections trigger penalties in the reward function of an RL agent during cooperative gameplay in an already developped similar overcooked game (see Figure 1).

Figure 1: Overcooked environment.

The main goals are:

- Integrated EEG pipeline and prefiltered signal using Timeflux
- Sending EEG data to LSL
- Modifying the reward function to integrate this events in the Reinforcement Leaning paradigm being used
- Recording data for further analysis.

Understanding and Improvement of Modeling Approaches for Spatial Lattice Structures

Description:

Lattice structures are used in many fields. For example, in the space industry, it is essential to understand how waves propagate within these structures, particularly in satellites. To ensure their energy autonomy, satellites are equipped with solar panels mounted on slender structures. Due to their design and the low-damping environment in which they operate (no air friction), these structures are particularly sensitive to vibrations, especially during deployment [6].

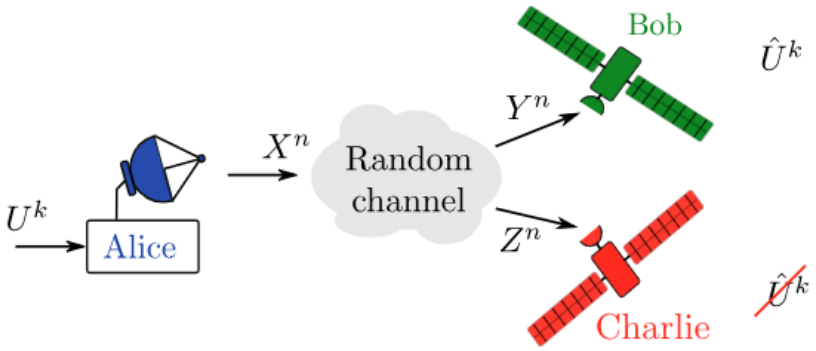
Figure 1: Lattice structures in space infrastructure.

The aim of this project is to deepen our understanding of the dynamic behaviour of lattice structures with a view to reducing vibrations. Several advanced approaches are currently used to model wave propagation, including wave-based or exact methods [5]. Initially, a numerical modelling phase will be used to characterise the vibrational response of different lattice structure topologies and identify the parameters that influence their dynamic behaviour. This can be achieved using homogeneization techniques [3, 2, 1] or using ray tracing methods from optics [4]. Secondly, an experimental phase will be conducted on structures manufactured using 3D printing. Particular attention will be paid to the quality of manufacture and the geometric reproducibility of the samples.
A series of dynamic validation tests on a vibration table will then be carried out at the Clement Ader Institute in order to compare the numerical predictions with the experimental measurements. Work and tasks
The project will be carried out in several stages:
• Numerical modelling of lattice structures (finite elements, analytics) 1
• Topological optimisation for the design of lattice structures with low vibration response
• Additive manufacturing and geometric/dynamic characterisation of lattice structures
• Dynamic testing and model-experiment correlation.

A Software Defined Radio (SDR) secure satellite communication scheme

Description:

Since its introduction in one of Shannon's most celebrated papers [1] and its elaboration by Wyner [2] and Csisz´ar & K¨orner [3], physical layer security has proved to be a promising means of securing communications and generating random secret keys by exploiting the inherent non-reproducible randomness in either the communication links (noisy channels, fading channels, quantum optical channels,...) or some physical processes involved in the communication (SRAM units, Ring Oscillators, ...).



One of the most common settings in physical layer security is the wiretap channel, in which a legitimate transmitter (Alice) wishes to communicate a message to a legitimate receiver (Bob) whilst keeping it secret from an eavesdropper (Charlie), as depicted in Figure 1. For such a setting, security is achieved through the so-called wiretap coding, which consists of distilling an advantage for Bob over Charlie, by exploiting the asymmetry of their respective communication channels and signal qualities. Whilst long regarded as a purely theoretical form of security, as compared to cryptography, wiretap coding has substantially matured over the last decades, and constructions of practical wiretap codes [4, 5] were implemented
through numerical simulations.

In a previous research project of the team, we aimed at going beyond poofs of concept and computer-based simulations by building practical wiretap codes, based on Polar codes [6] and assessing their performances on realistic satellite channel models. Emulating channels and communication chains which have the same characteristics as realistic satellite communication channels was done by resorting to a family of Software Defined Radio (SDR) components
named USRPs [6], leading to the PHYSEC bench of the T´el´ecommunications lab of ISAE-SUPAERO.
The objective of the present research project is to upgrade the PHYSEC bench, initially designed with static eavesdroppers, to withstand mobile eavesdroppers as well. To model this, the eavesdropper (Charlie) is on board a car that moves around the legitimate receiver (Bob), attempting to intercept the communication. Since the wiretap code construction requires the timely acquisition of the Signal-to-Noise Ratios (SNR) of both Bob and Charlie, the offline SNR estimation routine of the static setting needs to be performed online. Hence, the PHYSEC bench needs to be upgraded to allow real-time SNR acquisition and code adaptation.

Project program
The research program of this project will first consist in the following.
• State of the art and implementation of real-time SNR estimation algorithms ([7] and references therein)
• Real-time adaptation of the wiretap code construction and packet signaling
• Programming specific trajectories of the robotic car which carries the USRP (Raspberry Pi programming)
• Assessing the performance of the whole wiretap setting from a reliability (at Bob) and security (at Charlie) point of view.

Technology Roadmapping

Description:

Technology roadmapping is widely used to identify critical technologies and inform strategic investment decisions. However, most existing approaches remain qualitative, failing to capture the strategic interactions among competing actors and the uncertainty inherent in technological progress. In 2023, a thesis explored the application of game theory to quantitatively model technological development. Within this work, a military simulation was designed to test a framework that models technology investment decisions while incorporating the stochastic nature of scientific outcomes. Each player manages a portfolio of technologies that evolve through different levels of investment, influencing their respective military capabilities. These capabilities are then evaluated through simulated battlefield scenarios.

The objective of the current project is to extend and assess this framework in alternative contexts, such as the automotive industry.

Performance robusness analysis for time-periodic models of space flexible structures

Description:

In a previous study [1], the three axis model of spacecraft fitted with flexible solar pannels and a rotating RF (Radio-Frequency) antenna was derived. This model is fully parametrized according to the uncertain dynamic parameters (mass, centering, inertia, flexible mode frequencies) and varying parameters (solar array angular configuration, RF antenna rotating rate). A robust three axis attitude controller was designed to reject orbital disturbances. Nevertheless, the robustness analysis of the pointing performance in spite of parametric uncertainties, orbital disturbances and internal disturbances, coming from the Solar Array Driving Mechanism (SADM) and the time-periodic disturbance coming from to the rotating RF antenna, for such an LTP (Linear Time Perdiodic) system is still missing. The lifting procedure, proposed in [2], to assess the robust stability of LTP systems didn't yield satisfactory results on this space application because:
• it is not today adapted to perform robust performance budgets,
• even for robust stability analysis, the lifted model obtained is not representative probably because the system period is very large in front of the system dynamics (aliasing effects).

Thus the objective of this research project are:

• to evaluate the lifting procedure and it representativeness on such an LTP model characterized by a period very large in front of the time constant of the systems or very large in front of the periods of its flexible modes,
• to extend the lifting porcedure, proposed in [2] and restricted to the robust stability analysis, to cope with robust performance analysis,
• to validate the robustness of the design proposed on the study case (stability and pointing performance) considering the time-periodic feature of the system.

Work to be performed The technical work to be performed will consist in:

• Understand the dynamic modelling of the flexible space vehicuke fitted with a large rotating antenna,
• Study the robustness analysis of LTP systems,
• Adapt the lifting procedure to handle robust performance,
• Application to the study case,
• Write a scientific paper to be submitted in a conference or journal.

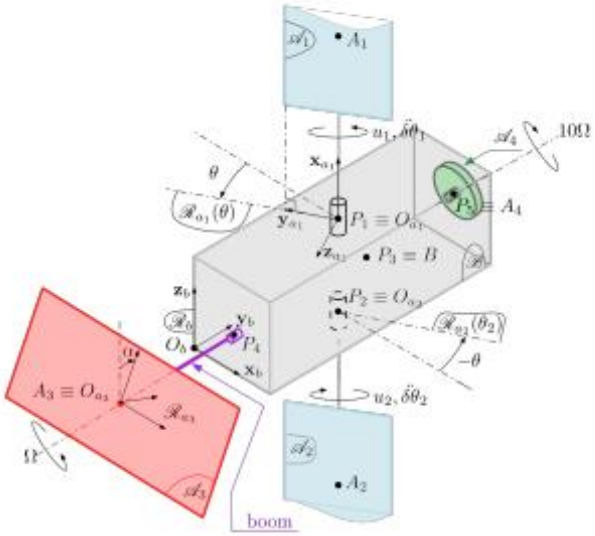


Figure 1: Example of large flexible spacecraft with a rotating RF antenna.

Testing and Design of a Hybrid Rocket Thrust Chamber

Description:

AEther is one of the projects being pursued by Supaero Space Section. It consists in developing a hybrid rocket to participate at EuRoC in 2027. The student team is currently in the process of designing and testing the hybrid rocket propulsion system.
The AEther propulsion system uses high-concentration hydrogen peroxide as oxidizer, which is decomposed through a permanganate catalyst bed to then ignite and combust the solid ABS plastic grain. A partnership with ONERA allows the students to perform tests of the system. More details in the paper: *Design and testing of the combustion chamber of a H2O2/ABS student-developed hybrid rocket engine (IAC 2023)*

Objectives
Over the following year, the club will need to perform tests on the already built combustion chamber and feed system. Test results and learned lessons will then be used to design the flight-version of the propulsion system. The current RP will coordinate research activities with a second RP "Testing and Design of a Hybrid Rocket Feed System", this project will put special focus on the catalyst bed and on the combustion chamber. The research project will therefore tackle the following points:

- Literature review on hybrid propulsion chamber and catalyst bed design and testing.
- Post-process catalyst bed and hot fire test results from the November 2025 campaign.
    - Update GriffonSimulator (student-developed code) to be able to reproduce tests.
    - Measure regression rate of the tested grain.
    - Calibrate Marxman coefficients using GriffonSimulator.
    - Measure pressure drops through the catalyst bed.
- Interpret results and coordinate with ONERA to perform new tests in order to understand inernal ballistics.
- Design new version of thrust chamber to achieve desired performance requirements.
- (if applicable) publish results at an international conference

All work shall be documented to build and keep know-how within the rocket club.

Droplet evaporation models for real gas and transcritical conditions

Description:

The study of droplets evaporation is of interest for many applications going from mechanical engineering, chemical processes to natural sciences. This motivates many studies and research that are devoted to their characterization. But despite these large efforts some questions remain opened particularly related to specific conditions for which evaporation phenomena are not clear: high pressure and high temperature conditions.
Droplets evaporation at high pressure can occur typically in liquid rocket engines. To simulate numerically combustion chambers in such conditions, we rely on CFD models using typically Lagrangian approaches to describe sprays. These incorporates models providing the evaporation rate of the droplets and their drag coefficient. However, the models used to describe the droplets evolutions are typically based on models valid from low pressure conditions. Recently some models including real gas effects and eventually non equilibrium approximation have been proposed.
The objective of the present research project is to develop a 1D numerical code for a single droplet evaporation able to reproduce low- and high-pressure conditions starting from available models present in literature. It is the continuation of an ongoing MAE RP (2024-2026).

Development

- *Bibliography:* overview of available evaporation models in the literature dealing with high pressure conditions and real gas modeling
- *Development:* implement the models in python
- *Analysis:* compare the models and their prediction in different conditions

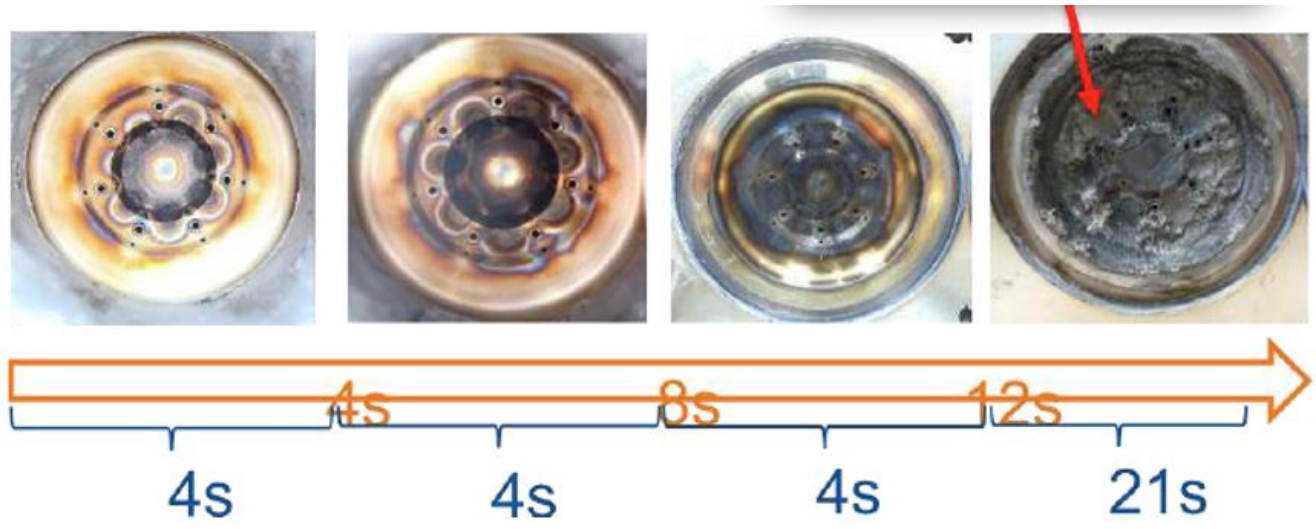
Swirl injector design and test for the MINERVA engine

Description:

This research project is proposed in the framework of PERSEUS, a CNES-led initiative to engage students in the space sector. ISAE-SUPAERO is participating in the development of ASTREOS-1, a bi- liquid demonstrator rocket powered by the LOX/Ethanol MINERVA engine.
The current design of MINERVA uses an injector head with seven impinging injectors. The engine is tested by Ariane Group at Vernon.
The current design of the injector head has several issues among which 1) to high heat fluxes toward the injector head (see figure) 2) to high pressure losses in the injector.

Objectives

The objectives of the research project will be to propose a novel design for the injector head in order to overcome the above issues. The requirements are the expected performances of the chamber. A swirl injector has been identified by previous work as being the best candidate. The objective of this research project will be to optimize the injector design on the basis of its performance, produce it with 3D printing and test it (with water) at ISAE – Supaero.



Self-explaining rover with Embodied Conversational AI

Description:

Modern robots are increasingly expected to operate alongside humans and to explain their goals, decisions, and limitations in natural language. However, most conversational systems in robotics remain cloud-dependent and limited to predefined dialogue scripts, preventing meaningful transparency and autonomy in communication. At the same time, advances in large language models (LLMs) and on-device AI inference enable new forms of "self-explaining" robots that can generate contextualized and adaptive discourse without relying on remote servers. This project explores how an embedded LLM-based dialogue system can serve as the cognitive and communicative core of a robot capable of explaining its own purpose, architecture, and operation principles. Such a capability is crucial for user understanding, acceptance, and safety — especially in educational, research, and collaborative environments. The challenge lies in designing a lightweight, real-time, and robust pipeline that can process speech input, generate coherent and contextually appropriate responses, and synthesize speech output — all locally, within the limited resources of an embedded computing platform (e.g., Raspberry Pi 5 or NVIDIA Jetson).

Objectives:

The work will focus on the design, implementation, and evaluation of a prototype able to engage in autonomous explanatory dialogue.

The main objectives are :
• Literature Review : Study existing frameworks for spoken human–robot interaction, embedded dialogue systems, and explainable AI in robotics. A review of existing methods for each step of the process is required.
• Architecture Design : Define a modular speech pipeline integrating speech-to-text (STT), LLM-based dialogue management, and text-to-speech (TTS).
• Local LLM Integration : Search, deploy locally and customize an open-source LLM (e.g., Mistral, Phi, Qwen... via, for example, Ollama) for local inference and personality definition.
• Evaluation : Assess dialogue naturalness, latency, and user perception through real-time tests with human participants.
• Dialogue Control : If possible, implement mechanisms for conversational flow management, including interruption detection and context memory.

FIGURE 1 – The Lab robot we want to equip with an embedded conversational module.

PACIFIC - Passive Acoustic Control for Improved Fuselage Interaction with Propellers

Description:

The noise of propellers interacting with the fuselage/wing, from drones to light aviation, is an obstacle to the deployment of this type of aircraft. This is important as history showed us that not considering acoustic interaction effects can lead to unbearable noise in the cabin for example [1] and require a posteriori architecture changes that are extremely costly. Rapid analytical or semi-analytical methods permitting to estimate during the design process of the flying object its acoustic footprint on the ground are necessary.
In the low Reynolds number regime, studies have been conducted on rotor-strut interaction noise at ISAE-SUPAERO [1,2,3]. The presence of a strut nearby produces additional tonal noise at harmonics of the blade passing frequency. This noise depends on the geometry of the strut, its position relative to the rotor disc plane, and the distance from this plane. This extra noise source component can come from several noise source mechanisms, one of them being the unsteady loading on the strut. This noise mechanism is the dominant one in one case studied experimentally, numerically, and analytically at the laboratory [2], and whose far field acoustic spectrum is given in Figure 1.

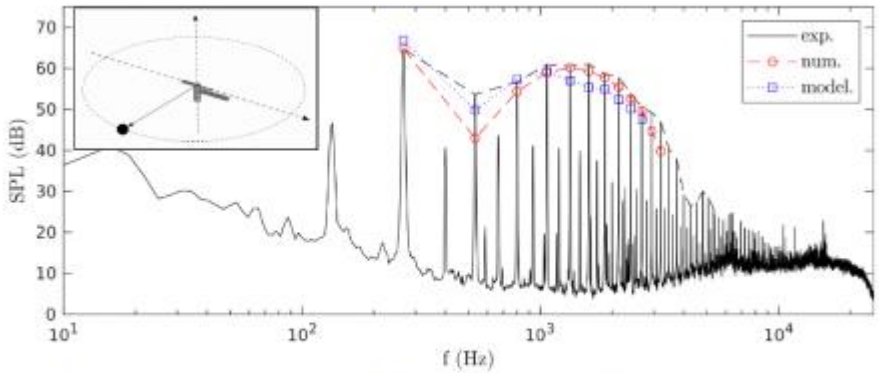


Figure 1: Experimental, numerical and analytical modelling of the interaction noise of a two-bladed rotor with a cylindrical strut [2]

It would thus seem interesting to mitigate this noise source by working on the strut. Preliminary tests have been performed with the use of a 3-D printed porous material (Figure 2, left) and small noise mitigation have been performed on the harmonics of the BPF. Moreover, for the students to have an easy access to experimental testing, a small test bench has been built (Figure 2, right) and will be used in order to test rapidly the mitigation technologies the student will build. Other geometries like airfoils could also be studied to go towards distributed electric propulsion architectures

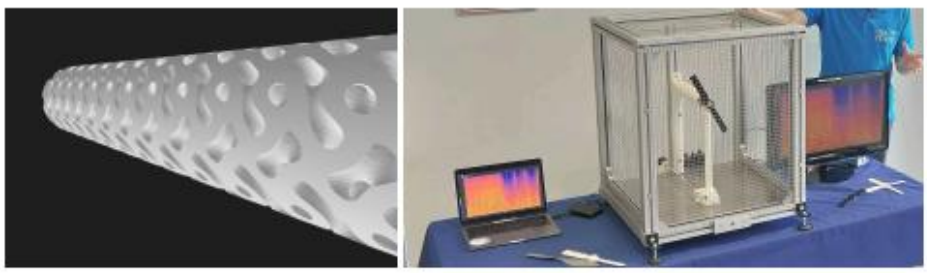


Figure 2: Left: Example of a porous material tested to try to mitigate the noise of a propeller interacting with a strut. Right: Test Bench that will be used during the project to test passive technologies

Program of internship

The aim of this internship is to do a bibliographic study to know what passive acoustic control technology would be the most beneficial to mitigate this noise source. A modelling part will be done to tune the material towards the acoustic source we are targeting. Then, manufacturing of this material (preferably using stereolithography 3-D printer but other technics could be deployed) will be conducted and exeperimental tests on the small test bench presented before will be carried out. The best candidates will be tested later in the anechoic room of ISAE-SUPAERO to have a precise quantification of the acoustic gains reached.

Inclusion of safety considerations in the design of hybrid-electric distributed propulsion aircraft architectures

Description:

Electric and hybrid aircraft have been identified as a key lever for the reduction of aircraft emissions and costs. Although the technology is still in its infancy raising questions about its certifiability it offers gains ranging from reduced to zero emissions during flight. It also offers the prospect of new capabilities for capturing multidisciplinary synergies and relieving design constraints on the aircraft, adding new degrees of freedom. This thus creates the need for new sizing methodologies capable of capturing those synergies and capable of assessing the impacts, at aircraft level, of hybrid- and all-electric powertrains. However, because of the disruptive nature of these technologies, considerable work will have to be done to prove that they are safe and airworthy. The lack of safety analysis closely embedded in the MDAO problem was identified as one of the shortcomings of existing conceptual methodologies for the sizing of unconventional configuration [1,2]. This aspect must however be considered early in the design since the oversizing of secondary branch to account for failures can generate significant added mass which the aircraft has to embark [3,4]. In addition to that, the lack of historic data and experience on these new configurations makes the task of ensuring that these architectures are safe paramount for an early EIS [4].

The goal of this project is to make a first step towards integrating safety assessment, both from the angle of the probability of failures and from the angle of their severity; in a preliminary aircraft design sizing tool. The tool in question, called FAST-OAD-CS23-HE, is a tool developed at ISAE-SUPAERO and which tackles the question of the potential complexity and infinity of powertrain architectures using a graph based approach for the description of the propulsive architecture [5]. This approach means the powertrain is a user input of the sizing process under the form of a simple file listing components and their connection making the interfacing with MBSA tool like Altarica very easy.

The final deliverable will include:
- The proposition of an aircraft architecture which leverages DEP and hybrid electric propulsion that will serve as a baseline for the integration of safety in the sizing process
- The identification of aircraft flight conditions which will lead to sizing constraints on the powertrain
- An automated evaluation of the performances of the selected architecture in those conditions with a selected number of failures.
- A literature review on the failure rates of the componnets in the powertrain which will lead to an automated assessment of the probability of those failures (using Altarica for instance)
- A resizing of the initial configuration considering those failures.

On the use of Learning Methods with Model Predictive Control

Description:

Over the last decades, Model Predictive Control (MPC) [3] has drawn considerable attention, both in academia and industry, due to its ability to handle constrained systems. Indeed, MPC exploits the knowledge of a dynamical model to cast an optimisation problem in which its future behaviour is expressed as de- cision variables. By doing so, it can explicitly account for constraints on states, inputs, or functions of these variables, for general, nonlinear, multivariate systems – which is a hard, or even impossible, task to achieve with classical control methods [9]. The state of the art is very rich, and several theoretical (e.g., stability, convergence, recursive feasibility) [5] and practical [8] results have been reported.

However, one of the difficulties in deploying an MPC controller relates to its numerical complexity. Indeed, since MPC solves the underlying optimisation problem at every sampling time, the computational time can be sharply affected by its complexity, hindering real-time applications.

Recently, with the growing popularity of artificial intelligence, several interesting intersections have been proposed between machine learning methods and MPC. For instance, learnt models have been proposed for enhanced prediction [11, 6], neural networks have been used to approximate the solutions of an existing MPC controller (and thus completely discarding the online solution of the optimisation problem) [7, 2], and even directly designing an MPC controller through reinforcement learning [10, 1, 12, 4]. Although showing clear advantages in terms of alleviating numerical burden, the preservation of theoretical properties is not guaranteed.

The objectives of this project are (i) to propose a concise and comprehensive state-of-the-art, pointing out the methods currently employed, their advantages and limitations, (ii) to code a complete framework allowing the suitable methods to be readily applied and compared, and (iii) to propose numerical simulations in given test cases (robotics, aeronautical applications).

Robust control of a gimballed spacecraft

Description:

Recent collaborations between NASA and the European Space Agency (ESA) highlighted the need in Space industry to have preliminary design tools able to guarantee spacecraft control performance robustly in the very early design phases [1]. For this reason uncertainties have to be taken into account to validate control architectures. ISAE-SUPAERO recently developed a tool, the Satellite Dynamics Toolbox (SDT), which is able to build a generic flexible spacecraft in a modular way by tacking into account all uncertainties in the attitude control synthesis. With this tool is nowadays possible to cop with the modeling, synthesis and linear analysis tasks. The study case to take into account in this research project is a gimballed platform used to scan Earth for which a model has been already implemented in the SDT in a previous research study

Figure 1: Exemple of gimballed spacecraft

Work to be performed A preliminary bibliographic study is required to be familiar with the multi-body modeling of flexible Space structures in the Two-Input Two Output Port (TITOP) framework [2] and its implementation in the last version of the Satellite Dynamics Toolbox (SDT) [3].

The technical work to be performed will consist in:
• enhancing the spacecraft robust control based on gimbal angles in order to increase the spacecraft agility to scan a given Earth area;
• propose a guidance law to drive the gimbal angles
• validate control laws with respect to the system uncertainties

Airlines and fleet planning adaptations for low-CO2 emissions aircraft performances

Description:

The road to carbon-neutral aviation involves the introduction of new sources of energy to replace fossil fuel. In addition to use of sustainable aviation fuels, it leads to numerous projects of electric aircraft, hybrid-electric aircraft, hydrogen aircraft, with various technologies and architectures. Those projects come/will come with the performances and operational capabilities, possibly with reduced capabilities compared to existing fossil-fuel aircraft. This could be associated to the development of new market segments such as thin haul commuting. What about their overall airline compatibility?

This project aims are exploring the impacts of those sources of energy and associated aircraft designs, on elements such fleet planning (operating weights and payload capability, revenue and cost, …), airline's perspective on aircraft selection (mission capability, network, etc), and possibly lessor's perspective on aircraft selection. The objective is to investigate the adaptations that would be needed for an airline/operator to introduce into service those aircraft architectures while being profitable, accounting for carbon reduction schemes (e.g. CORSIA).
It will include the following research activities based on exploration of existing literature and student's original contributions:

- Mapping existing technologies, their maturity, their performances
- Defining the possible Concepts of Operations (ConOps) for the various aircraft architectures
- Investigating and modeling the impacts on airlines/operators
- Exploring how airlines/operators/(lessors?) have to adapt their organization, their network, etc, and what could be a profitable network/routes organization. Use cases focusing on some regions will have to be selected.

Keywords for suggested bibliography:

- Electric, hybrid-electric, hydrogen aircraft design and performances
- Aircraft selection, fleet planning
- Regional aircraft market, thin-haul commuting
- Literature review and mapping of low-CO2 emissions aircraft architectures and performances
- Concept of Operations of low-CO2 emissions aircraft architectures
- Exploration of impact on airlines/operators e.g. aircraft selection, fleet planning
- Exploration of airlines/operators and routes network adaptations and proposal of roadmaps/measures to ease the adoption of those aircraft.

Digital & Conscious Aircraft, from Concept of Operations to Safety of Operation

Description:

Next generation of commercial transport aircraft or military aircraft will be digital-native, to optimize and enhance their operations, performances, support, maintenance, etc. From design to operation, digitalization will be a core-driver for those aircraft. This will include concepts such as – but not limited to – aircraft connectivity, digital twins, digital airline concepts, maintenance of tomorrow, artificial intelligence (as per design, for certification, for support for operation, etc). Research activities expand those considerations to the concept of *Conscious aircraft* as proposed by Cranfield University.

This project aims are exploring and defining the aircraft and its operation (e.g. maintenance, support) in a widely digital environment and digital-oriented design approach, and to investigate the related safety / airworthiness impacts. It will include the following research activities based on exploration of existing literature and student's original contributions:

- Defining the Concept of Operations (ConOps) of digital aircraft and digital aircraft operations (focusing on maintenance and support)
- Proposing a generic concept for digital aircraft its operations including the underlying technologies & benefits
- Investigating and modeling the safety and airworthiness-related effects of the introduction of those technologies
- Developing and modeling roadmaps to ensure safety of operation of the ConOps, and its certifiability and operability.

Mapping using Certification Readiness Level Scale (CRL) can be used. NASA Advocate software can be used to model safety cases.

Waveforms for dual-function radar-communication systems

Description:

In this project, we consider the design of a waveform for covert dual-function radar-communication (DFRC) systems. DFRC systems have been actively studied in recent years, enabling the use of a single waveform to simultaneously sense the environment (radar function) and transmit information (communication function). In specific applications, it is desirable to ensure covert transmission, namely, ensuring that an unintended user cannot detect the presence of the waveform. A question arises then: is it possible to design an efficient DFRC waveform?

Objectives:

To address this question, the lab has recently proposed and investigated the use of the so-called DSSS-FTN waveform to enable covert DFRC transmission [1, 2, 3]. The objective of this project is to examine further the performance of this waveform, particularly in the context of radar applications. In [3], a first study was provided that seems to indicate that the FTN aspect creates only a marginal additional interference in the so-called range-Doppler map obtained by a conventional matched filter. Nonetheless, many questions remain unanswered at this stage.

HORIZON - Enhancing Fluency and Performance in Human-Robot Teams

Description:

The **CASAC chair**, between ISAE-SUPAERO and Dassault Aviation (DA), aims to study means for performance improvement in human-machine teams. It expects to propose methods and tools built upon the Neuroergonomics and Artificial Intelligence fields to favor human-machine collaboration. The **HORIZON** project, supported by the **CASAC chair**, aims to improve fluency and performance in human-autonomous robot teams.

More specifically, autonomous systems can be seen as advanced intelligent artifacts from which one may expect a sort of self-directedness (i.e. freedom from outside control) (Bradshaw et al., 2013), as the term autonomy would result from delegation of a decision to an authorized entity (e.g. artificial agent into a machine) to take actions within specific boundaries (David and Nielsen, 2016). Autonomous robots are an example of those kind of systems: mobile robots that can be deployed in dirty, dull, or dangerous environments to avoid people to be exposed (Kawatsuma et al., 2012); drones or Unmanned Aerial Vehicles (UAVs) that can be used for persistent surveillance of critical infrastructures or sites (Aiello et al., 2020). In those application, autonomous robots can be see as a support system.

Although for the general public an autonomous system is expected to operate without human intervention, in reality all machines are supervised by humans to some degree. Therefore, the overall performance of the system would depend on a good coordination and collaboration between humans and machines (Ferrari, 2019; David and Nielsen, 2016) in a human-centered design perspective. Thus, assuming that the division of tasks between humans and artificial agents is not fixed, the objective is to reach a Mixed-Initiative Interaction (MII) level, where autonomous systems collaborate with humans on a peer-to-peer basis (Goodrichet al., 2008), implementing a kind of dynamic, adaptive, or adjustable autonomy (Sheridan, 2011).

MII defines a flexible interaction framework that allows each agent not only to take charge of the tasks in which they are specialized (Allen et al., 1999), but to dynamically assume the role deemed most relevant given the context. **The problem is whether, why, when, and how artificial agents could seize the initiative to perform tasks that, a priori, are expected to be performed by a human agent**, as the human operator, which is responsible for the system decision, and preferred for complex tactical, legal or ethical decisions. This problem is known in the literature as the transfer-of-control problem (Scerri et al., 2002), which aims to determine whether and when such a transfer-of-control (in both directions) should occur in adjustable autonomy.

However a human operator in charge and interacting with several autonomous robots, deployed in a complex environment, can be confronted with task overload and other difficulties. Recent literature has shown examples where artificial (software) agents assist human operators while they operate complex systems in a man-machine teaming perspective (Ferrari, 2019): intelligent ground stations for (multi-)robot deployment (Kaufmann et al., 2021), aircraft cockpits (Zhang et al., 2021; Brand and Schulte, 2021), or power or nuclear plants control (Ahn et al., 2022; Marot et al., 2020).

In this context, our goal is to enhance embedded decision-making to favor a peer-to-peer collaboration. We believe that by improving systems abilities to model human's strategies and by adapting machines' decision-making to humans during interaction would push such systems towards a fluent peer-to-peer collaboration. In particular, we are interested on methods that could be applied to model and to translate the human operator behavior and strategies in function of her/his profile and mission context.

Brief experimental environment description:

The Firefighter Robot Game (FRG) (Drougard et al., 2017; Charles et al., 2018) presents a scenario where a human teleoperates a robot to extinguish fires in a bounded area (see Figure 1). The simulated forest has trees that can catch fire, and the human-robot team must extinguish as many fires as possible within 10 minutes. The robot has limited battery power, an embedded water tank for extinguishing fires, and a thermometer enabling the human operator to monitor its temperature. The robot must recharge its battery at an energy supply zone and refill its water tank at a water pool which the level must also be monitored by the human operator. When necessary, the human operator must fill the pool using control commands on a moving valve. The pool's walls are susceptible to leaks and frequently necessitates a manual intervention from the human operator for repairing it using a tool.

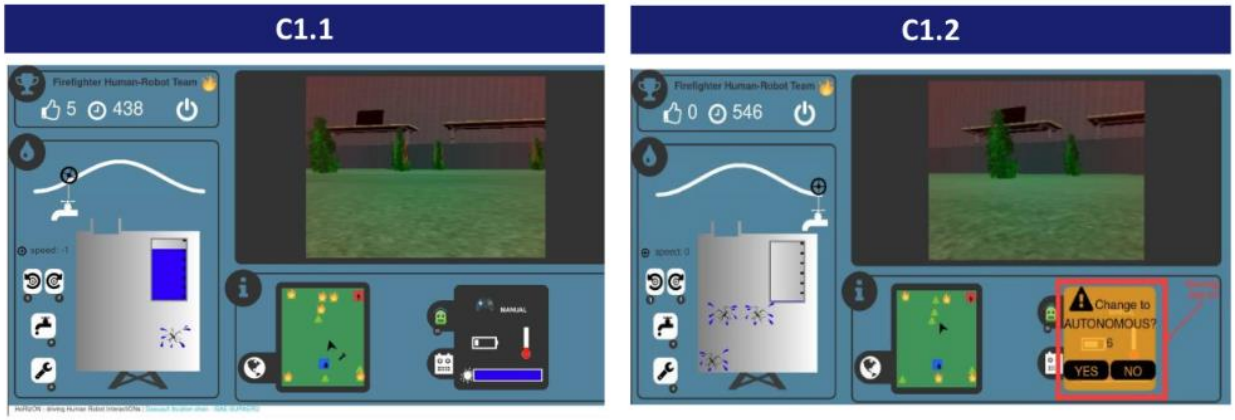


Figure 1: (a) shows screenshots of the Graphical User Interface (GUI) regarding the experimental condition

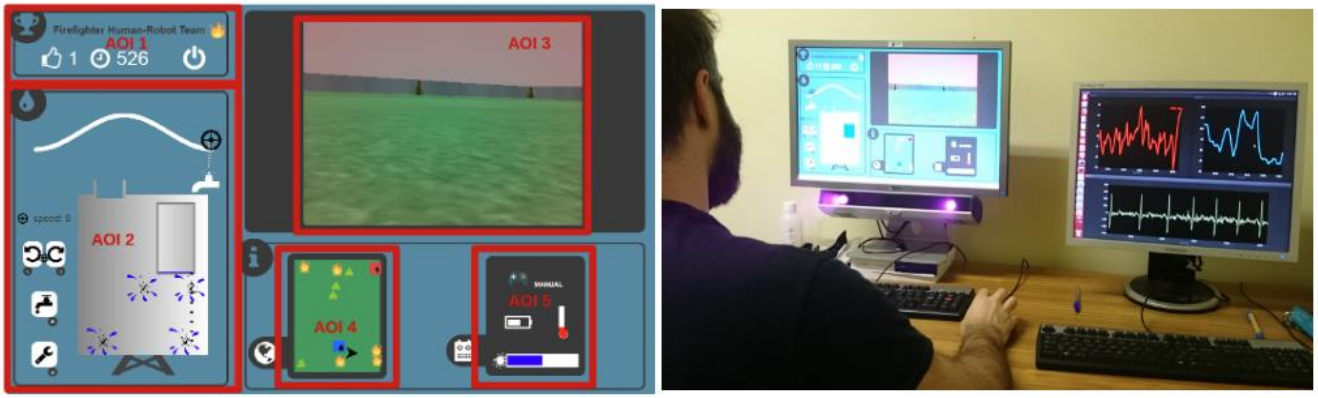


Figure 1 : (b) shows Areas of Interest defined for Eye-Tracking-data acquisition, and ECG-data acquisition during the experiment.

The human operator can manually operate the robot or can chose to put the robot in automatic navigation mode. In automatic mode, the robot prioritizes battery recharging and embedded water tank refilling (it navigates to the energy supplier or water pool when resources are low). When battery and tank levels are sufficient, the robot finds the shortest path to the nearest burning tree and extinguishes the fire. In manual mode, the human operator remotely controls all robot actions, including navigation, recharging, temperature monitoring, and water dispensing. This mission scenario was designed to generate deleterious cognitive states in human operators, mainly due to multitasking, uncertainty, and time pressure. Such situations are known to generate stress and cognitive workload, thus impacting human agent performance (Dehais et al., 2020). Deleterious mental states affecting performance can be estimated using physiological computing (Roy et al., 2020; Fairclough, 2009). For instance, metrics such as the Heart Rate (HR) and the Heart Rate Variability (HRV) are known to be impacted by workload (Heard et al., 2018).

In a previous work (Angelotti et al. 2024), we proposed an interaction model learning methodology and an approach for adaptive robust interaction policy selection, aiming to improve the performance of such a human-robot team by choosing between manual or autonomous robot navigation mode in function of the estimated (mental) state of the human operator. The results showed the performance of the human-robot team was improved when the adaptive policy was applied, but, in terms of fluency of interaction, the approach deserves more attention and could be enhanced.

Profile-based strategy learning

Human's strategies can be guided by their psychological profiles (Akbari et al., 2021). In particular, some works in entertainment games (Vahlo et al., 2018; Bean and Groth-Marnat, 2016) and in robotics (Nikolaidis et al., 2017) have shown that both level design and system's actions can be adapted to each gamer profile in order to provide an enjoyable experience. In a **previous MAE study**, we confronted gaming profiles, derived from the Bartle's Taxonomy (Bartle, 1996), with the FRG. We invited participants to play the game twice during the 10 minutes mission under two experimental conditions: one where they were free to control the operation mode of the robot and the other where the machine asked periodically to take the control on the navigation task. Our preliminary results with sixteen participants suggest differences in behavior and strategies according to different user profiles. For instance, in Figure 2 we detail the percentage of mission time the participants led the robot in manual (resp. autonomous) mode in function of their (gaming) profile. However, at the present moment, we did not yet investigated the impact of profiles on physiological features neither if there are common mission contexts in which operators are more likely to accept the iniative of the machine to put the robot on manual (resp.autonomous) mode.

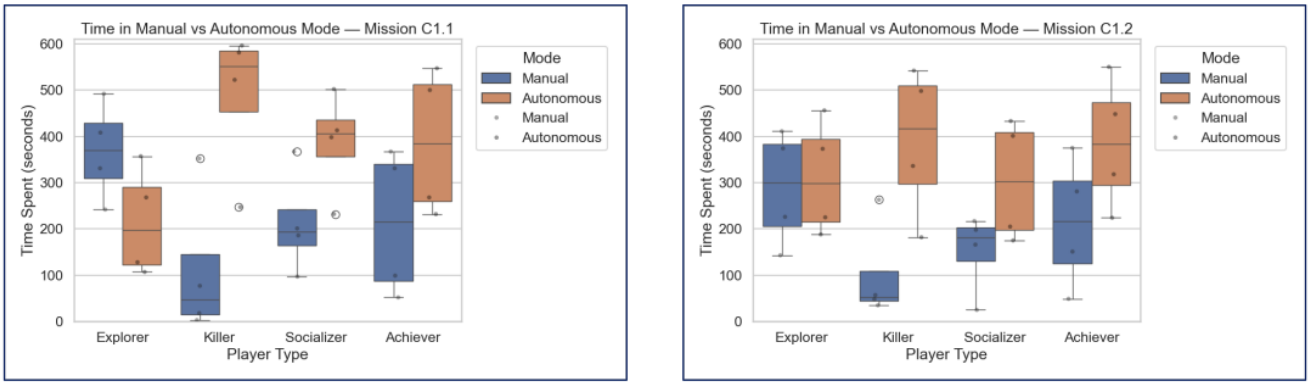


Figure 2 : Preliminary analysis of the data collected (until now) shows differences between the profiles.

Project's objective

These preliminary results encourage us to believe that people with different psychological profiles tend to prefer different experiences with intelligent agents, expecting different intervention levels, responsibility and control depending on their own mental state or level of task engagement in a certain activity. However, there are several open questions:

- How to identify the main mission contexts where participants are more likely to change the robot operation mode?
- Is this behavior also dependent of the profile? If yes, how to determine the effective number of different profiles?
- How to set up profiles strategies ? Could such a profile-based classification be useful for interaction modeling?
- Could one learn an adaptive strategy that accounts with human profil and suggest adaptations (initiatives) at the right moment ? This would improve fluency and team-performance?

This research projet aims to bring some answers for the above research questions.

MINERVA - Mixed-initiative INtEraction: pRofile-based adaptiVe decision-mAking

Description:

The **CASAC chair**, between ISAE-SUPAERO and Dassault Aviation (DA), aims to study means for performance improvement in human-machine teams. It expects to propose methods and tools built upon the Neuroergonomics and Artificial Intelligence fields to favor Human-Machine Collaboration in aeronautical study-cases. The **MINERVA** project, supported by the **CASAC chair**, aims to improve fluency and performance in the operation of a civil cockpit.
This project aims to firstly construct a database of the human-AA team interaction data for a emergency landing scenario, and secondly to develop a decision-making model that considers the different personality traits of humans to change the Articifial Agent's (AA) behaviour. We are seeking to understand the decisions made during a hard-task moment to model the human agent preferences and then, to enable an AA to propose activities, assume roles and even take authority at some points, being then an important part of the team. We expect to improve the fluency and to enhance the overall performance. The final system should be able to **adapt** to the pilot's expectations, according to his **profile**, proposing alarms, sharing information and **showing commitment** to the task in particular when it estimates that the human is overloaded.

Brief description of the project

Efficient collaboration is important to face real-world scenarios with several uncertainties (Xiong et al., 2022). While machines excel at gathering information and remain unaffected by emotional states, they struggle to handle highly uncertain cases (Bier et al., 1999). On the other hand, humans leverage their experience to generalise and improvise, but their decisions can be influenced by poor situational awareness, fatigue, mental workload (Roy et al., 2020), lack of confidence, emotional commitment (Souza et al., 2016; Xiong et al., 2022), and other factors. In this context, the **MINERVA** project aims to develop a profile-based decision-making model capable of inferring human teammate expectations for a given context. The system will then be able to suggest changes, choose relevant information and, if convenient, assume the responsibility on some tasks during the interaction. We aim to reproduce a specific and controlled situation where the interaction between human and AA is as close as the human-to-human interaction.

Human's strategies can be guided by their psychological profiles (Akbari et al., 2021). In particular, some works in entertainment games (Vahlo et al., 2018; Bean and Groth-Marnat, 2016) and in robotics (Nikolaidis et al., 2017) have shown that both level design and system's actions can be adapted to each gamer profile in order to provide an enjoyable experience. In previous studies, correlations between psychological profiles and decision-making were pointed out. Interestingly, it is known that serious games can be applied to training people for corporate and even military persons (Ram et al., 2007). However, most of these studies ignores individual information and expectations of the different users (Barata et al., 2016). Several gamer typology models were presented in the last fell years. One of them is the Bartle's Taxonomy (Bartle et al., 2016), a quantitative model of four players (Killers, Achievers, Socializers and Explorers) according to the player's preferences identified in synthetic worlds.

Our collaborative environment as create to test preferences of the pilots in an emergency forced landing situation using the **X-Plane Flight Simulator.** We chose this scenario because pilots reported that in a hard situation they need help to properly perform a safe landing. In detail, our decision-making model will help a pilot in a flight simulator to land an aircraft in a hard situation (fire during flight) by proposing aids in the four main flight phases:

- *aviate*: by maintaining the flight (Roll, Pitch, Altitude, Vertical Speed);
- *navigate:* by finding and setting the heading of flight;
- *communicate:* by sending and receiving ATC information;
- *manage:* by performing or monitoring the memory itens and checklist procedure

We divided this project in three main phases. The first phase will involve data acquisition of participants during a first experimental campaign regarding the monitoring of the resources management and the choices made by the participants. A second phase will address offline processing of acquired data to characterise the behavioural and physiological features of interest as well clustering the choices to analyse profile-related decisions during "normal" and "emergency" phases. In the third and last phase, the proposed system will be evaluated, a new emergency scenario. The decision-making model system will provide support to the pilot through AA actions.

Actual Project's Architecture
The architecture is being built using the Robot Operation System (ROS), an open-source robotics middleware suite, with lots of frameworks for robot software development. ROS is language and platform indepentent, can be implemented using Python, C++ or both and can be used to any robot system (ground, aerial, fixed). Furthermore, ROS can synchronize systems launched even on different computers, allowing consistent data collection. The current system is made up of 2 main modules: one for voice recognition for initialization and the second consists of a state machine that activates and deactivates aids following the pilot's c
Figure 2: Architecture of the MINERVA Project and provided aids

The projects objectives are:

- **Implementation** the fluency related-metrics to be used to define the quality of the collaboration between the AA and the Human;
- **Creation** of the automatized experimental protocol for both campaings;
- **Experimentation** in the pilots following the protocol;
- **Analysis** of the data using behavior and fluency metrics collected related to the pilot's profile;
- **Development** of the profile-based decision-making method;
- Final **analysis** of the implemented method in fluency, performance and acceptance by the pilots.

HEROIC - evaluating assistance functions in Single-Operator Multi-UCAV operations

Description:

The **CASAC chair**, between ISAE-SUPAERO and Dassault Aviation (DA), aims to study means for performance improvement in human-machine teams. It expects to propose methods and tools built upon the Neuroergonomics and Artificial Intelligence fields to favor human-machine collaboration in aeronautical study-cases, such as the operation of drones from a military cockpit.
Supported by the **CASAC chair**, the **HEROIC** project aims to study, prototype and evaluate support functions that could be deployed in a military cockpit to help the human pilot in multi-tasking scenarios in which operators may be confronted to difficulties impacting their (mental) states and performance.
In previous common work with DA, the scenario of study (including the operator's role, mission phases and interface for drones operation) has been defined and is actually under development. The next step on this project, will be to invite participants to *play* this scenario, in order to collect data that in turn will be analyzed (using statistics and machine learning) by the students involved in the project.
Project Objectives:
The long term objective of this research project is to reinforce the intervention of assistance functions in the context of *Single-Operator Multi-UCAV operation* (SOMU). To achieve such an ambitious goal we propose a two steps methodology, comprising two experimental campaigns to be held in ISAE-SUPAERO campus in cooperation with Dassault Aviation.
The first experimental campaign, aims to **study and prototype assistance functions** to help the operator in high workload situations (time-constrained decisions under uncertainty). The first experimental campaign will provide mission context-data and human-operator data regarding behavioral and physiological measures. To that, participants will be confronted to a air-ground attack simulated mission, in which the human operator will be in charge : of the assignment of UCAV roles, of the identifications of treats, and of the allocation of equipment. Figure 1 illustrates the user interface that will be used during experiments. During simulated missions, different assistance functions will be proposed to the operator in different mission phases. The launch or not of those support functions characterize different experimental conditions.

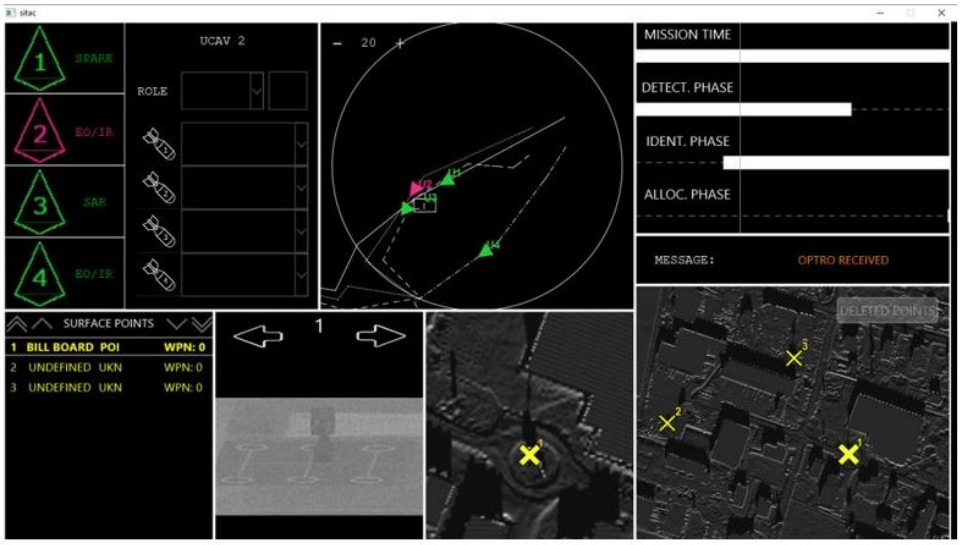


Figure 1 : User interface developed by Dassault Aviation.

CHIP-GT : Exploiting Hierachical Planning Methods for Heterogeneous Agents Teams Task Exécution

Description:

In several scenarios, as natural resource preservation, surveillance, mapping or search and rescue, it is relevant to deploy heterogeneous teams of autonomous agents to cover large environments. These teams can be composed by human and artificial agents with different characteristics and capabilities. For instance, in natural resource preservation cases, it could be useful to coordinate two or more teams, each of them composed by rangers and drones, to survey areas and to detect and keep away poachers. The Figure 1 illustrates such an example.

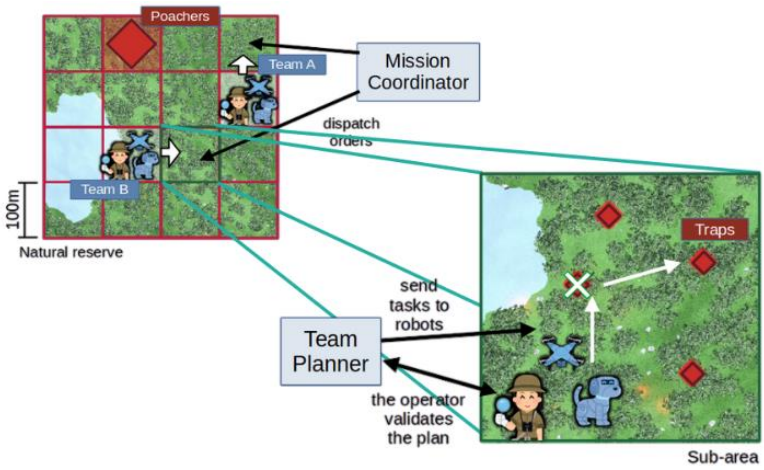


Figure 1: Illustration of two heterogeneous teams that need to coordinate their actions in a natural preservation scenario.

The project **CHIP-GT** aims to study means for heterogeneous teams coordination applying the stochastic game framework to set high level tasks to each team. This high level task, considered as the current objective of the team, need to be translated to a plan which is characterized by a sequence of actions. In other words, the objective task may be decomposed from its high level (abstract) description (what to do) into primitive actions (how to do).

The difficulty on producing such a plan is that the result of some primitive actions can have non-deterministic (or probabilistic) effects, or agents can be confronted to uncertainties related to meteorological conditions or terrain traversability conditions. For instance, let's consider a human-drone team which is asked to *visit* some area of interest. This *visit* objective, can be decomposed in several ways: the drone can fly over the area to detect the presence of traps or poachers, while the human (or a ground robot) can inspect a *possibly detected trap*. In order to execute such an inspection, the ground agent needs to move in the terrain where the trap was localized, however, during move action execution, *the trap could not be reacheable* by this agent. The words *"possibly detected"* or "*could not be reacheable"* characterize two types of non-deterministic effects of the *fly over* or *move* actions.

In order to be **robust to such non-deterministic effects**, it could be relevant **: (i) to produce plans** for this heterogeneous team **that integrate solutions for all the different effects**; or (ii) **to produce nominal plans and re-planning** (*on line*) as soon as a non-nominal event appears. Looking into the automated planning theory (Ghallab et al, 2016) three classes of planning methods could provide insights to solve such a planning problem : Hierarchical Task Networks (Hogg et al, 2009, Georgievski et al, 2014), Contingent Planning (Albore et al, 2009), or Hierarchical Markov Decision Processes (Feyzabadi, et al. 2017). Regarding the planning and acting architectures the *plan-replan* (Fox et al, 2006, Cashmore et al, 2015), or the *planning in parallel to action execution* (Chanel et al., 2019) are two promising approaches to implement such a planning system.

Project's Objective

The goal of this research project is five-fold:

- to identify which planning method would be the more appropriate to address such a decision-making problem
- to model the decision-making problem and to use a state-of-the-art planner to solve it
- to deploy the chosen method in a (simulated) robotic mission
- to identify pros and cons of the implemented approach
- to propose new planning methods, possibly hybrid methods, to improve the planning framework.

Efficient simulation tool for mechanical multi-body systems

Description:

Company: ISAE-SUPAERO
Type: Research project MAE 2025-2027

Description

ISAE-SUPAERO/DCAS develops methods and tools to model the non-linear dynamic behavior of multi-body systems under Matlab/Simulink environment. Theses tools always provide the Equation of Motions (EoM) under the general form:

$$\begin{aligned} \dot{\mathbf{x}} &= \mathbf{f}(\mathbf{x}, \mathbf{u}) \\ \mathbf{y} &= \mathbf{g}(\mathbf{x}, \mathbf{u}) \end{aligned}$$

which can also be expressed as state-depends Linear Fractionar Transformation (LFT):

$$G(\mathrm{s}, \mathbf{x}) = \mathcal{F}_u(\mathbf{M}(\mathrm{s}), \mathbf{\Delta}(\mathbf{x}))$$

as depicted in Figure 1

Nevertheless, when these EoM are directly implemented in Matlab/Simulink, the time-domain simulation run-time is still too long to perform intensive Monte-Carlo as required to validate the design. That can be easily illustrated by comparison with the simulation performed on Simscape/Multibody (https://www.youtube.com/watch?v=e1MVM3VZW7s) of a represenative study-case as depicted in Figure 2 . Thus the objective of this research project are:

- to improve the numerical integration of such State-dependent LFT models in Matalb Simulink using eventually S-function compliant with the accelertor mode proposed in Simulink,

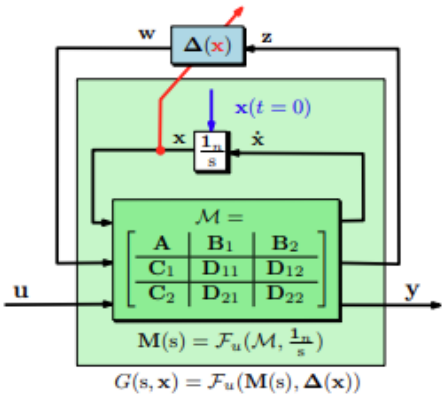


Figure 1: State-Dependant LFT representation of a non-linear system.

- to compare the simulation run-time with alternative numerical solvers, eventually outside the Matlab Simulink environment, on the particular study-case (Figure 2),
- for the best numerical solver retained, to develop a generic interface with the modeling tool.

Work to be performed

The technical work to be performed will consist in:

- Understand the dynamic modelling of multi-body systems,
- develop and implement numerical integration methods,
- compare / evaluate with simulation accelerator available in Matlab/Simulink

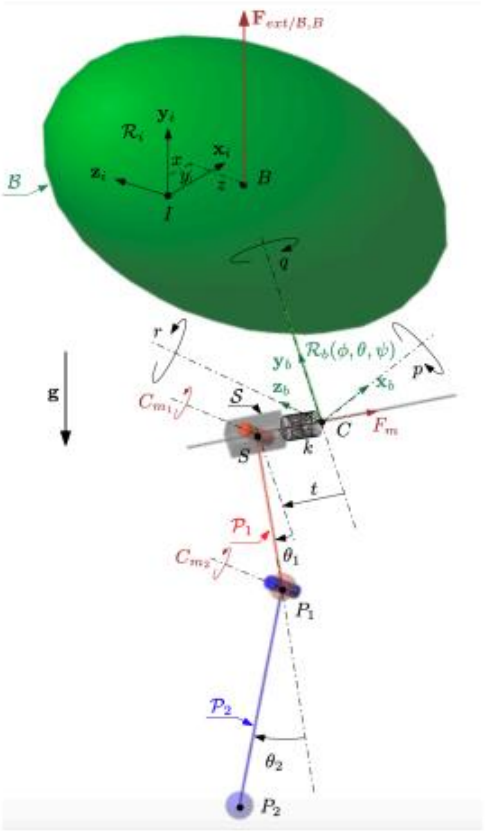


Figure 2: Example of a multi-body system.

- Write a scientific paper to be submitted in a conference or journal.

encyclopedia," 2025, [Online; accessed 7-November-2025]. [Online]. Available: https://en.wikipedia.org/w/index.php?title=Numerical_methods_for_ordinary_differential_equations&oldid=1272123190

Experimental Setup for Open and Closed-Loop Sloshing Studies for Spacecraft Applications

Description:

Liquid sloshing in spacecraft represents a critical challenge for modern aerospace applications. During orbital manoeuvres, attitude reorientation, or on-orbit refuelling operations, large-amplitude liquid motion and fluid reorientation can generate significant disturbance forces and torques that affect spacecraft dynamics and control performance. These effects become particularly pronounced in satellites carrying substantial propellant masses, where the coupling between liquid sloshing and spacecraft attitude can compromise mission success, structural integrity, and pointing accuracy.

While high-fidelity numerical simulations and reduced-order models provide valuable insights, experimental validation remains essential for understanding the complex physics of sloshing phenomena and for developing robust control strategies. Ground-based experimental facilities offer a cost-effective approach to investigate sloshing behaviour, validate numerical tools, and test control laws under controlled and repeatable conditions before flight implementation.

This project focuses on the design and assembly of an experimental setup to study liquid sloshing dynamics under both open-loop (prescribed motion) and closed-loop (feedback-controlled) conditions. The facility will enable systematic investigation of sloshing forces, validation of mechanical analogue models, and assessment of control strategies for spacecraft attitude control in the presence of fuel sloshing. The experimental platform will serve as a testbed for future research activities and will contribute to bridging the gap between simulation and flight applications.

Work to be performed Design and assembly:
• Support in the mechanical design and assembly of the experimental platform
• Integration of sensors (force transducers, IMUs) and actuators
• Development of the electronic hardware interface using Arduino-based systems

Software development:
• Implementation of data acquisition systems in Python
• Development of real-time control algorithms for closed-loop experiments
• Creation of post-processing tools for experimental data analysis Experimental campaign:
• Assembly and calibration of the experimental setup • Execution of open-loop tests with prescribed maneuvers
• Implementation and testing of closed-loop control strategies
• Comparison of experimental results with numerical predictions and analytical models

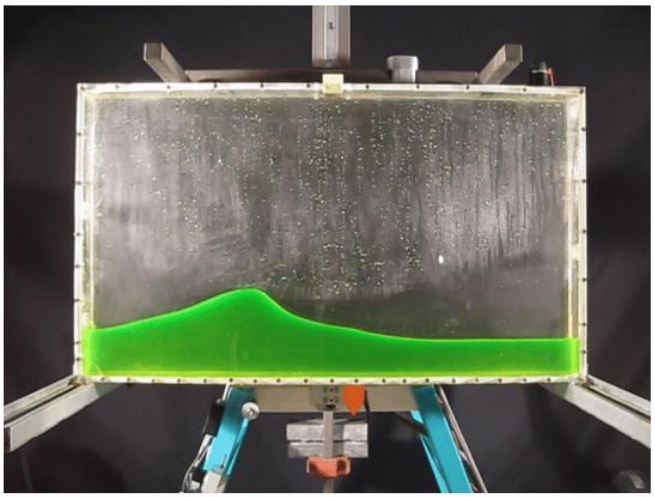


Figure 1: Conceptual representation of an experimental sloshing facility.

GNSS-based Precise Positioning for LEO Collision Avoidance

Collision avoidance in LEO is an increasingly critical challenge due to growing object population and more frequent close approaches. Accurate knowledge of the spacecraft (S/C) state and its uncertainty at the Time of Closest Approach (TCA) is required to reliably assess collision probability and to plan avoidance maneuvers. Traditionally, precise orbit knowledge and catalog object states are supplied by ground operators, but autonomous on-board decision making requires robust and precise on-board positioning, especially when ground contact is limited or delayed.

GNSS (Global Navigation Satellite System) receivers on board LEO satellites are attractive: GNSS chips are inexpensive and many constellations (GPS, GLONASS, Galileo, BeiDou, etc.) already provide signals in orbit. Depending on the technique and the quality of the signal and receiver, onorbit GNSS positioning can reach centimeter levels under favorable conditions. However, GNSS signals in orbit face perturbations. Which can have an impact on the accuracy of the estimation of position of the LEO satellite during the TCA.

Keywords: Collision avoidance, LEO satellites, GNSS, positioning,

Project goal:

Investigate the feasibility, implementation, and performance of on-board GNSS-based precise positioning for collision avoidance maneuvers of a LEO satellite.
The project is divided into two main parts:
1. Astrodynamics part: to understand LEO orbital mechanics, perturbations, and the highdynamics environment affecting satellite motion and measurement conditions. This phase will allow the student to master orbital propagation using GECKO and to characterize the physical and dynamical parameters influencing GNSS reception in orbit.
2. GNSS and estimation part: to analyze and model the reception of GNSS signals in LEO, identify and characterize the dominant sources of error, evaluate the feasibility and accuracy limits of precise positioning, and implement estimation filters to assess navigation performance and its impact on collision avoidance decisions.

Objectives:
- To build the test bench for simulate the LEO satellite tracking scenario with the different GNSS constellations
- To obtain the astrodynamics parameters of the mentioned scenario to simulate the GNSS observables.
- To identify and quantify the error sources that dominate the position uncertainty at the Time of Closest Approach (TCA).
- To determine realistic error bounds (m / dm / cm) for on-board GNSS positioning using various methods in LEO.
- To compare different GNSS constellations in terms of signal availability, geometry, and resulting positioning quality for a given LEO orbit.

AI agents and Overcooked: an automated planning approach

Description:

Recent advances in artificial intelligence (AI) have produced agents that outperform humans in competitive domains such as Chess, Go, Dota 2, and StarCraft II. However, developing agents that can collaborate effectively with humans remains a major scientific challenge. Most training methods still rely on self-play, resulting in reinforcement learning (RL) policies that are highly efficient but often rigid and difficult to interpret when paired with real humans.

At ISAE-SUPAERO, the HAICO project (Human–AI Collaboration) explores how AI agents can adapt to human behavior, interpret implicit cues (e.g., gaze, intention), and communicate their own goals to achieve more fluent teamwork. Our current experimental platform is a cooperative cooking game inspired by Overcooked, implemented in Unity, where humans and RL agents must coordinate to prepare and deliver dishes.

At DCAS, we are currently leading a data-based approach, relying on reinforcementlearning-based agent inspired from Overcooked-AI benchmark environment for fully cooperative human-AI task performance.

We would like to compare this approach with a model-based agent, relying a more traditional automated planning approaches such as classical planning (and execution) [1], hierarchical planning [2], and/or goal oriented planning [3]. the idea behind this approach would be to enable the agent to reason explicitly about sub-goals, task allocation, and/or joint intentions. This step would provide a more interpretable and adaptable framework for mixed human–AI collaboration.

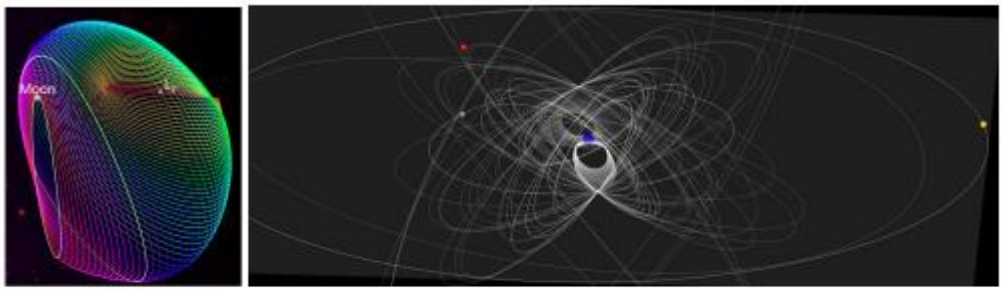
left: Alpha Go https://deepmind.google/research/alphago/
right: Overcooked

Objectives:
1. State of the art about AI agents in video games/serious games.
2. State of the art on plan/policy execution in classical planning, and more specifically on Goal Oriented Planning
3. Based on existing libraries, implement a GOAP approach (or a more efficient one!) for the artificial agents in the HAICO Unity simulator.
4. Compare performance between the GOAP (or a more efficient one!) and RL approach
5. (bonus) generalize approach to a multi artificial agent scenario

Non-keplerian orbit design mapping

On one hand, SEMPY (Sun-Earth-Moon system in Python) [?] is a astrodynamics software tool developed at ISAE-SUPAERO for research and mission analysis focused on the Circular Restricted Three-Body Problem (CRTBP). Building upon SEMAT (an older MATLAB-based CRTBP tool from ISAE-SUPAERO), SEMPY was implemented following software engineering best practices, including code versioning, continuous integration and Python development standards. using The package is organized into sub-packages, modules, classes, and methods, enabling the computation and initialization of eight types of CRTBP orbits. SEMPY successfully computes and interpolates Halo orbits around various Lagrange points across multiple CRTBP systems, laying the groundwork for future development and research applications. On the other hand, astrodynamic trajectory optimization focuses on finding the most efficient path for a spacecraft between two points in space, typically minimizing fuel use, time, or energy [?, ?].

Goal of this RP would be to draw/synthesize a map of different astrodynamic trajectory optimization methods and tools, especially in non-keplerian dynamic. This RP will involve code development, re-use of existing libraries to provide to the SacLab a practical, pedagogical and concrete selection tool for classic astrodynamic trajectory optimization methods and tools.



left: The L 1 and L 2 halo orbit families and the NRHOs [?].
right: https://www.esa.int/Enabling_Support/Space_Engineering_Technology/Sign_up_for_mystery_America_s_Cup_of_rocket_science

Objectives:
1. State of the art on trajectory optimization for non-keplerian orbits
2. Propose a synthesis of methods as a decision tree
3. deploy/implement this decision tree based on Sempy with associated optimization calls
4. (extra) visualize, evaluate performance, compare different approaches
5. (extra) publication of the work

1.Monocular Localization and Pose Estimation for Drone Racing

Description:

The objective of this internship is to design and implement a real-time localization system for a quadrotor using a monocular camera within a known racing environment. The environment map and landmarks (e.g., gates, poles, or obstacles) are known a priori. The student will improve landmark detection, estimate the drone's pose, and progressively integrate inertial measurements to enhance accuracy.

Main Tasks:
1. Implement and optimize a landmark detection algorithm from monocular camera images using the known environment map.

2. Develop a real-time localization pipeline using geometric correspondences and pose estimation techniques (PnP, reprojection error minimization, etc.).

3. Integrate IMU data (accelerometer and gyro) into an Extended Kalman Filter (EKF) and later refine the estimator with a quadrotor dynamic model and motor RPM feedback.

2. End-to-End Vision-Based Control for Drone Racing using Reinforcement Learning

Description:

This internship focuses on learning an end-to-end control policy for drone racing using only monocular camera images as input. The system should output control commands (roll, pitch, yaw rate, and throttle) to follow a predefined racing trajectory through known gates. The student will investigate model-based reinforcement learning approaches, particularly the Dreamer-V3 architecture.

Main Tasks:
1. Build a simulation environment with monocular visual input and known gate positions for training.

2. Implement a Dreamer-V3-style model-based reinforcement learning pipeline to learn end-to-end control.

3. Evaluate and compare the learned controller with classical or supervised approaches for trajectory tracking and racing performance.

3. Reinforcement Learning for Improving Classical Trajectory Tracking Controllers

Description:
This internship investigates the synergy between reinforcement learning (RL) and classical control. The objective is to use RL to enhance traditional trajectory tracking algorithms (e.g., MPCC or INDI) by learning adaptive correction terms, leading to high-performance yet interpretable control laws.

Main Tasks:
1. Implement a baseline classical trajectory tracking controller and define a comparison metric with RL-based control.

2. Train an RL agent to learn correction or adaptation terms that improve classical controller performance.

3. Analyze and interpret the resulting hybrid controller to assess performance gain and maintain interpretability.

4. Incremental Nonlinear Dynamic Inversion (INDI) Control for Hybrid UAVs

Description:

The goal of this internship is to extend an existing attitude controller towards a complete guidance loop for hybrid aerial vehicles (quad-planes, tilt-rotors). The focus is on developing the outer-loop INDI guidance that computes control increments to achieve trajectory tracking and smooth transitions between hover and forward flight.

Main Tasks:
1. Review and model the dynamics of hybrid UAV configurations and define suitable control inputs for INDI.

2. Design and implement the outer-loop INDI guidance law that generates reference increments for the inner attitude loop.

3. Validate the proposed controller in simulation for trajectory tracking in hover, transition, and forward flight modes., and eventually do real flights.

5. Differential Flatness-Based Feedforward Control for model-free control Tracking

Description:

This internship aims to improve model-free control strategies (INDI, MFC) by introducing a feedforward term derived from the vehicle's differential flatness. Starting from quadrotor dynamics, the student will derive and implement flatness-based feedforward control laws, and then extend the approach to fixed-wing flight.

Main Tasks:
1. Derive and implement differential flatness equations for quadrotor and fixed-wing models.

2. Integrate flatness-based feedforward terms into the existing INDI tracking controller.

3. Evaluate performance improvements in simulation for various trajectory tracking scenarios.

Integration and Assessment of Aircraft Performance and Fuel Consumption Models for Sustainable Aviation

Description:

The aviation sector contributes to both CO_2 and non-CO_2 climate impacts, including contrail formation. Reducing these impacts requires evaluating operational strategies such as contrail-avoidance flight paths and sustainable aviation fuel (SAF) usage. The PhD project "OPTIMAL" investigates optimization methods for minimizing aviation climate impact by combining trajectory adjustments and SAF strategies.

A critical component of this work is the accurate estimation of aircraft performance and fuel consumption, which underpins both trajectory optimization and climate impact assessment. This Master's project focuses on developing a solid foundation for the performance modeling aspect, ensuring that fuel and emission calculations are accurate, and what are the limitations and fundamental hypothesis of each model.

Objective:

The primary objective of this Master's project is to integrate aircraft performance and fuel consumption models into the OPTIMAL research framework, providing reliable inputs for trajectory and fleet-level optimization studies.

Research Tasks:

1. Review of Aircraft Performance Models o Study and comparison of performance models (preferred open-source) such as OpenAP, BADA and other relevant frameworks.
o Identify strengths, limitations, and suitable applications for different flight types.

2. Aircraft Characteristics and Routes Impact Analysis
o Analyze how aircraft characteristics (type, maximum takeoff weight, payload) and routes affect fuel consumption and emissions.
o Quantify variations across representative aircraft and routes used in the European air space.

3. SAF Blending Effects
o Understand how blending SAF with conventional jet fuel affects fuel consumption and emission metrics.
o Investigate the representation of SAF in existing performance models.

4. Model Standardization and post-processing
o Develop a standardized model wrapper that enables to select one of the envisaged performance model.
o Test the model wrapper integration into trajectory optimization and climate impact assessment workflows.
o Develop post-processing tools and visualization that are useful for performance analysis.

Expected Outcomes:

- Comprehensive review of aircraft performance models and their applicability.
- Quantitative analysis of performance variations across aircraft types, weights, and SAF blends.
- Recommendations on suitable models for trajectory optimization studies.
- A modular implementation of performance and fuel consumption models ready to feed the broader OPTIMAL framework

Experimental Validation of Robust Guidance and Landing Algorithms for Small Body Exploration

Description:

The exploration of small Solar System bodies, particularly near-Earth asteroids (NEAs), has become a major focus of current and future space missions. These objects hold key information about the early stages of planetary formation and serve as potential resources for in-situ utilization.
At the Space Advanced Concepts Laboratory (SaCLaB) of ISAE-SUPAERO, the research team has developed significant expertise in mission analysis and trajectory design for asteroid exploration missions, including sample collection and high-resolution cartography to better understand their composition and internal structure.
Previous work has focused on:

- The design of scientific orbits around irregular small bodies.
- The development of robust landing trajectories and guidance strategies under dynamical, technical and environmental uncertainties.
- The integration of stochastic analysis methods for trajectory robustness assessment.

The next step is to validate these algorithms experimentally, bridging the gap between theoretical modelling and real-world implementation.

Objectives:

The goal of this project is to contribute to the experimental validation of SaCLaB's algorithms for asteroid proximity operations and landing, using scaled testbeds or hardware-in-the-loop simulations.
The student will:

1. Conduct a literature review on existing experimental platforms and validation methods for asteroid landing guidance (e.g., free-fall testbeds, air-bearing tables, optical tracking, and vision-based navigation).
2. Identify representative test scenarios to emulate the dynamical conditions near small bodies.
3. Participate in the specification, design, development or adaptation of a test platform (simulation or physical) to test key guidance and control algorithms.
4. Analyze the performance and robustness of the tested algorithms, comparing them with numerical simulations.
5. Propose improvements or extensions to the validation framework.

Proximity Guidance and Control of a spacecraft around an asteroid

Description:

Rendezvous and proximity operations of spacecraft such as assembly of large flexible structures (e.g. solar panels and telescope mirrors), demand precise, adaptable autonomous spacecraft, and require the capability of planning and executing highly constrained trajectories. On the modelling and control side, the literature lacks adequate analysis for complex missions, especially when the flexibility of structures is crucial for safety. Regarding the guidance, complex high-level mission planning scenarios are generally solved using methods suffering from poor scaling capabilities and their integration into agile autonomous systems with low computational capabilities today remains out of reach. Another way of looking at high-level mission planning is from the perspective of logic operators. Derived from the Linear Temporal Logic (LTL) theory. Logical operators such as And, Or, Eventually, Always, Until provide a formal language to express complex temporal constraints and objectives in optimization models. Signal Temporal Logic (STL) was later introduced in the state of the art as a derivative of the LTL to guide simulation-based verification of complex nonlinear and hybrid systems against temporal properties. Recently, arbitrarily complex graphs of STL constraints were shown to be discretized and linearized to fit the convex framework [CML+23], thus enabling complex high-level mission scenarios to be executed in an agile and autonomous manner.

Objectives:

This project aims at modelling and optimizing the approach phase for an agile flexible spacecraft around an asteroid. The primary objectives of this activity are to model the 6 degrees of freedom dynamics of the spacecraft. The second objective is to adapt convex STL constraints to create robust optimal guidance laws for complex rendezvous maneuvers based on the availability of a tool developed for a recent research activity [CML+24].

Covariance steering applied to UAV guidance and control in constrained environments

Description:

The missions of unmanned aerial vehicles (UAVs) are becoming increasingly complex as their numbers increase and they are used in environments which can be very constrained or even hostile. This raises the requirements on guidance, navigation, and control (GNC) algorithms to be able to not only follow a safe trajectory, but also to guarantee that it is indeed a safe trajectory.

In recent years, control methods have emerged that control simultaneously the mean state and its dispersion, under input and state constraints, so-called covariance steering. Until recently, these control methods could only be used for offline guidance due to the computational burden. Recent reformulations of the covariance steering method have led to solutions that are sufficiently fast for real-time implementation, either in simulation (e.g. PyBullet) or embedded in a flight controller. Leveraging model predictive control (MPC) techniques in combination with covariance steering would allow for guidance with guarantees on the inputs and states for nonlinear UAV dynamics.
This research project aims to implement an online version of a covariance steering using MPC on a quadrotor model. In a first step, the control algorithm will be implemented on a simulation platform (PyBullet). Depending on the results of the implementation and the overall progress, we also aim to implement the controller onboard a real quadrotor platform available at ENAC.

The research project is divided into several steps:
- Bibliographical study of the covariance steering problem and its application to multirotor GNC
- Development of a covariance steering control method using MPC
- Implementation of the control method on a multirotor simulation platform (PyBullet)
  - Testing of the approach on a complex scenario
- **Optional:** Implementation of the control method on a real quadrotor platform
  - Comparison of the simulated and real flights
- Writing a technical report describing the method and the experimental results

Depending on the findings and the interests of the student, these steps can be subject to modification or extension.

Fibre rupture under compression in composites : study of kink-band

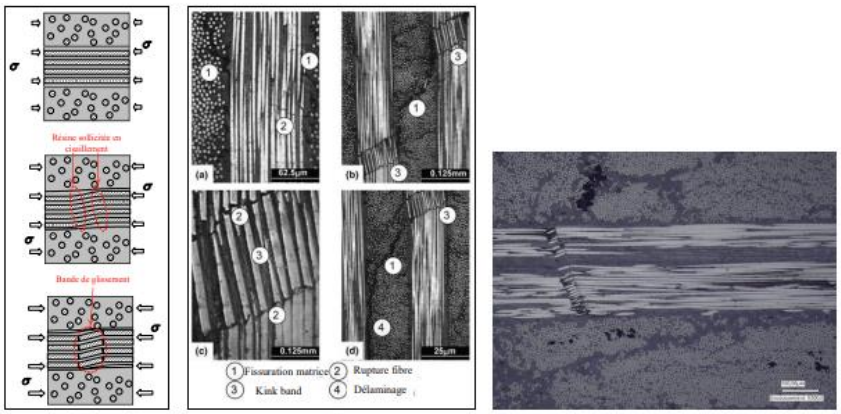
Description:

This project takes place in the framework of research works on composites led at ICA (Institut Clément Ader) since a few years, and more specifically in the context of a PhD study currently in progress.

Fiber rupture under compression in composite structures is a complex phenomenon that has been extensively studied in the literature [Ada05, Eye15, Jum10, Lo92, Sun17, Wis97] because it has a significant impact on design. The laminate fails in the form of a shear band, also known as a kink band (Figure 1) [Ada05, Lo92, Pin06]. Despite numerous studies on this type of failure under compression, several phenomena are still poorly understood and not sufficiently taken into account in the associated models. This is particularly true given that experimental observation of these phenomena is complex due to the scale at which the mechanisms occur and the fact that they most often appear at the core of the material.

The objective of this study will be to go beyond existing models in the literature that currently allow this type of phenomenon to be simulated [Xie17, Sun17], by participating in the development of a micromechanical finite element model that enables reliable modeling of the compression failure of a unidirectional composite at the fiber scale, and associated tests for understanding and validating these models.

One student will be assigned to the numerical part, carried out using Abaqus. The second will be assigned to carrying out the tests and analyses (microscopy, DIC, etc.). They will be required to share their results to ensure the smooth progress of the project, under the supervision of the professor and the doctoral student.



-a- -b- -c-

Figure 1 : Failure under longitudinal compression: diagram (a) and micrographic section (b) [Pin06] of a kink band; micrographic section from ICA lab.

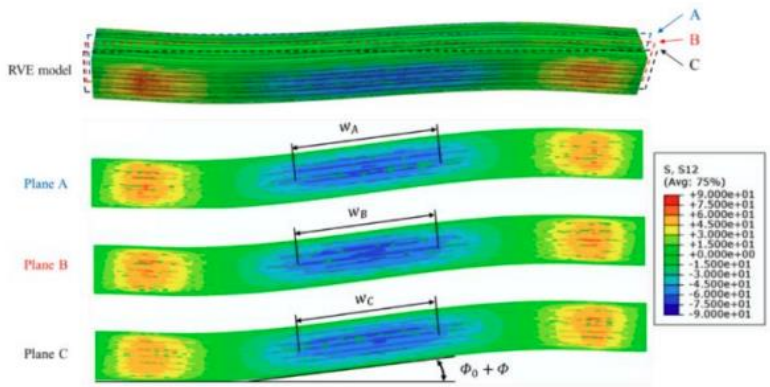


Figure 2 : 3D FE model of a kink band [Che24]

Radiations Effects on Image Sensors

Description:

Image sensors are widely used in engineering cameras and embedded on satellites, probes, and rovers. In astronomy as well as in Earth observation missions, image sensors are one of the most critical building blocks as they convert the wavelength of interest into measurable signals. However the space environment is harsch on the hardware as radiations interfere with the material by changing its atomic structure or conveying a surplus of energy into it.

Objectives:

1. This project will first focus on developing a Python (or MATLAB) user interface to centralize and standardize sensor characterization tests at ISAE. The student will learn about key sensor metrics (such as quantum efficiency, dark current, gain, etc.) and how to implement adaptable code procedures for different types of cameras.
2. The student will then use this interface to test sensors both before and after irradiation, and will compare the experimental results with simulations generated using ESO's Pyxel software.

LILIENTHAL WP1-2026-2027: Focus on Structural Wing Design & Weight Optimization

Description:

The new Lilienthal meta project aims at gathering all ISAE-SUPAERO projects related to glider/motorglider design. Following an initial initiative, the EUROGLIDER project – an electric two-seate motorglider of the CS22 category -, ran from 2014 to 2023 and was based on a partnership between the ISAE institutions and an external association closely linked to the gliding community. A full size test bed - testing the energy & engine chain – was flown in 2019 but ultimately the project stalled because of a lack of industrial funding. Therefore a new project, called Lilienthal, has been launched in 2024, specifically targeted to the pedagogical needs of the ISAE institutions which are wrapped in the so-called Design-Build-Fly paradigm:

The selected “starting point” is now an aircraft of the microlight category, called Gaz’Aile2 (http://gazaile2.free.fr/). In parallel to the prime target of manufacturing that reference aircraft (several years effort), the design part of the project will be to study several changes to the initial aircraft. This project LILIENTHAL WP1-2026-2027 will be specifically dedicated to (a) the structural design methodology for a new wing, developed for a motorglider version of the GazAile, (b) to put in place an optimization process of the composite wing, (c) and potentially to consolidate the aircraft design platform FAST-CS23 or FAST-OAD-CS22/VLA (2021).

Objectives:

o Literature review of wing sizing methods of light aircraft/glider;
o Selection of medium fidelity wing sizing methodology to be made compatible with the FAST-OAD aircraft design code;
o Validation of the developed methodology to verify the sizing strategy;
o To enrich, with this sizing methodology, the initial FAST-OAD-CS23 /CS22/VLA version, on the basis of current FAST-OAD aircraft design codes, written in Python (https://github.com/fast-aircraft-design/FAST-OAD & https://github.com/supaeroaircraft-design/FAST-GA). The new platform will be used to define potential optimum configurations;
o To summarize the methodology and findings into a competitive research paper (hints on novelty: open source glider design platform);
o Typical target of publication: EASN conference, OSTIV.

LILIENTHAL WP2-2026-2027: Focus on Aerodynamic Wing Design & OAD Optimization

Description:

The new Lilienthal meta project aims at gathering all ISAE-SUPAERO projects related to glider/motorglider design. Following an initial initiative, the EUROGLIDER project – an electric two-seate motorglider of the CS22 category -, ran from 2014 to 2023 and was based on a partnership between the ISAE institutions and an external association closely linked to the gliding community. A full size test bed - testing the energy & engine chain – was flown in 2019 but ultimately the project stalled because of a lack of industrial funding. Therefore a new project, called Lilienthal, has been launched in 2024, specifically targeted to the pedagogical needs of the ISAE institutions which are wrapped in the so-called Design-Build-Fly paradigm:

The selected “starting point” is now an aircraft of the microlight category, called Gaz’Aile2 (http://gazaile2.free.fr/). In parallel to the prime target of manufacturing that reference aircraft (several years effort), the design part of the project will be to study several changes to the initial aircraft. This project LILIENTHAL WP2-2026-2027 will be specifically dedicated to (a) the aerodynamic design methodology for a new wing, developed for a motorglider version of the GazAile, (b) to put in place an optimization process of the wing within the aircraft design platform FAST-CS23 or FAST-OAD-CS22/VLA (2021).

Objectives:

o Literature review of wing aerodynamic design methods for light aircraft/glider;
o Aerodynamic analysis of the Gaz’Aile 2 aircraft;
o Selection of medium fidelity aerodynamic methodology to be made compatible with the FAST-OAD aircraft design code;
o To enrich, with this sizing methodology, the initial FAST-OAD-CS23 /CS22/VLA version, on the basis of current FAST-OAD aircraft design codes, written in Python (https://github.com/fast-aircraft-design/FAST-OAD & https://github.com/supaeroaircraft-design/FAST-GA). The new platform will be used to define potential optimum configurations;
o To summarize the methodology and findings into a competitive research paper (hints on novelty: open source glider design platform);
o Typical target of publication: EASN conference, OSTIV.

LILIENTHAL WP3-2026-2027: Focus on Flight Dynamics & Control Surfaces

Description:

The new Lilienthal meta project aims at gathering all ISAE-SUPAERO projects related to glider/motorglider design. Following an initial initiative, the EUROGLIDER project – an electric two-seate motorglider of the CS22 category -, ran from 2014 to 2023 and was based on a partnership between the ISAE institutions and an external association closely linked to the gliding community. A full size test bed - testing the energy & engine chain – was flown in 2019 but ultimately the project stalled because of a lack of industrial funding. Therefore a new project, called Lilienthal, has been launched in 2024, specifically targeted to the pedagogical needs of the ISAE institutions which are wrapped in the so-called Design-Build-Fly paradigm:

The selected “starting point” is now an aircraft of the microlight category, called Gaz’Aile2 (http://gazaile2.free.fr/). In parallel to the prime target of manufacturing that reference aircraft (several years effort), the design part of the project will be to study several changes to the initial aircraft. This project LILIENTHAL WP3-2026-2027 will be specifically dedicated to (a) the design methodology for control surfaces of a new wing, developed for a motorglider version of the GazAile, (b) to put in place a flight simulator platform tuned on the Gaz’Aile2 and developments.

Objectives:

o Literature review of flight dynamics of light aircraft/glider, with a specific focus on flying quality and control surfaces sizing;
o Review of relevant simulation approaches and proposal of implementation schemes in one of the ISAE flight simulator;
o Validation of the developed methodology on the Gaz’Aile2; o Evaluation of flying qualities of the Gaz’Aile - motorglider;
o Proposal – early design – of a dedicated flight simulator;
o To summarize the methodology and findings into a competitive research paper (hints on novelty: open source glider design platform);
o Typical target of publication: EASN conference, OSTIV.

LILIENTHAL WP4-2026-2027: Focus on Electric & Hybrid Propulsion

Description:

The new Lilienthal meta project aims at gathering all ISAE-SUPAERO projects related to glider/motorglider design. Following an initial initiative, the EUROGLIDER project – an electric two-seate motorglider of the CS22 category -, ran from 2014 to 2023 and was based on a partnership between the ISAE institutions and an external association closely linked to the gliding community. A full size test bed - testing the energy & engine chain – was flown in 2019 but ultimately the project stalled because of a lack of industrial funding. Therefore a new project, called Lilienthal, has been launched in 2024, specifically targeted to the pedagogical needs of the ISAE institutions which are wrapped in the so-called Design-Build-Fly paradigm:

The selected “starting point” is now an aircraft of the microlight category, called Gaz’Aile2 (http://gazaile2.free.fr/). In parallel to the prime target of manufacturing that reference aircraft (several years effort), the design part of the project will be to study several changes to the initial aircraft. This project LILIENTHAL WP4-2026-2027 will be specifically dedicated to (a) the study and evaluation of a pure electric propulsion version of the Gaz’Aile 2 aircraft, (b) the study and evaluation of an hybrid electric-thermal propulsion version of the Gaz’Aile 2 aircraft.

Objectives:

o Literature review of electric and hybrid propulsion sytems and OAD methods, specifically for light aircraft/gliders;
o Study and evaluation of a pure electric propulsion version of the Gaz’Aile 2 aircraft, with FAST-OAD-CS23 aircraft design codes(https://github.com/supaero-aircraft-design/FASTGA);
o Study and evaluation of an hybrid propulsion version of the Gaz’Aile 2 aircraft;
o To summarize the methodology and findings into a competitive research paper (hints on novelty: open source electric microlight aircraft design platform);
o Typical target of publication: EASN conference, OSTIV

LILIENTHAL WP5-2026-2027: Focus on Landing Gear System

Description:

The new Lilienthal meta project aims at gathering all ISAE-SUPAERO projects related to glider/motorglider design. Following an initial initiative, the EUROGLIDER project – an electric two-seate motorglider of the CS22 category -, ran from 2014 to 2023 and was based on a partnership between the ISAE institutions and an external association closely linked to the gliding community. A full size test bed - testing the energy & engine chain – was flown in 2019 but ultimately the project stalled because of a lack of industrial funding. Therefore a new project, called Lilienthal, has been launched in 2024, specifically targeted to the pedagogical needs of the ISAE institutions which are wrapped in the so-called Design-Build-Fly paradigm:

The selected “starting point” is now an aircraft of the microlight category, called Gaz’Aile2 (http://gazaile2.free.fr/). In parallel to the prime target of manufacturing that reference aircraft (several years effort), the design part of the project will be to study several changes to the initial aircraft. This project LILIENTHAL WP5-2026-2027 will be specifically dedicated to (a) the study and evaluation of the landing gear system of light aircraft – seen from an OAD point of view - and more specifically of the Gaz’Aile 2 aircraft, (b) the study and evaluation of a new retractable landing gear for the Gaz’Aile 2 aircraft under strict constraints of weight and volume.

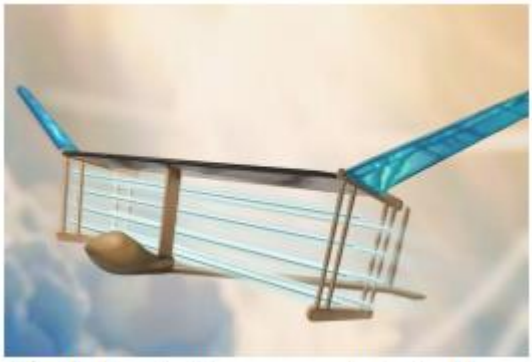
Objectives:

o Literature review of landing gear system at OAD level, specifically from weight, volume and aerodynamics points of view;
o Study and evaluation of the impact of the fixed landing gear on performance of the Gaz’Aile 2 aircraft, with FAST-OAD-CS23 aircraft design code (https://github.com/supaero-aircraft-design/FAST-GA);
o Design and evaluation of a retractable landing gear for the Gaz’Aile 2 aircraft, while respecting severe limitations of weight.
o To summarize the methodology and findings into a competitive research paper (hints on novelty: search for innovation on LG system);
o Typical output: proposal of a new LG design to be integrated into the Lilienthal V0 or V1.

Ionic Wind Propelled airplane – Multidisciplinary design analysis

Description:

Ionic wind propulsion is a relatively under-researched technology, that has the potential electrically powered flight. Contrary to other propulsion techniques, it does not require any moving parts, reducing maintenance costs for operators. Ionic wind propulsion utilises electric fields to create either oxygen or nitrogen ions (depending on the polarity of the field) and accelerates these ions to create thrust. Unlike established propulsion technologies, it does not require any moving parts, reducing maintenance costs for operators. First presented as a technology in the 1960s, not a lot of research has been conducted, with mainly hobbyists developing designs. Researchers at MIT presented a 2.5kg model plane using ionic wind propulsion in 2018.



This project aims to identify design challenges associated with using ionic wind propulsion systems in Light aircraft and CS-25 aircraft. In particular, changes to existing aircraft designs to enable ionic wind propulsion should be identified. Particular attention needs to be paid to the energy required to facilitate ionic wind propulsion, aerodynamic effects and weight and safety implications. Recent research efforts at ISAE should be taken into account.

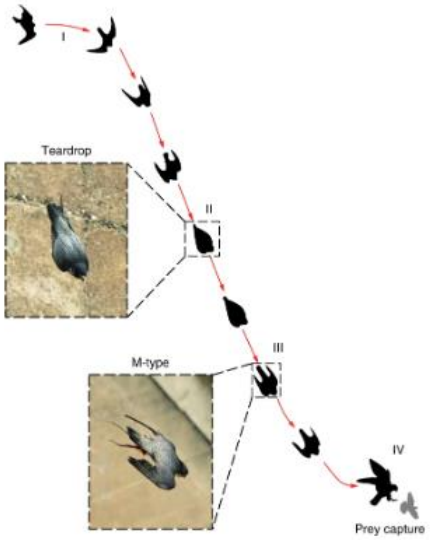
Objectives:

o The realization of a literature review of the state of knowledge surrounding the ionic wind propulsion and non-propulsion technology.
o To identify key differences between ionic wind propulsion and conventional propulsion technologies.
o To propose OAD of a light aircraft and CS-25 aircraft using ionic wind propulsion
o To utilize simulation tools based on a literature review
o To evaluate aerodynamic and propulsion benefits while considering energy, weight, and safety penalties
o To summarize the methodology and findings into a competitive research paper (hints on novelty)

Bio-inspired morphing for efficient and robust gliding

Description:

In nature many species can still operate in highly perturbed environment due to their ability to morph their wings into more efficient aerodynamic surface which extends their flight envelope, whilst the majority of man-made transport system will very rapidly encounter their limits. Such a morphing strategy is displayed by the peregrine falcon during the stoop flight while hunting from Figure1 (RHS) the falcon can adapt its morphology from the teardrop shape where the wings are completely tucked to an M-type shape (or C-type) to adjust its trajectory when subjected to gust or other environmental perturbation or follow the moving prey. On the other some squirrels can glide as well, even to a lesser extent however with a more compact morphology.



Objectives:

Further understanding of the wing morphing strategies employed by birds and the underlying flow behaviour could help in the implementation of bio-inspired technologies for high stability and manoeuvrability and for the development of loads and gusts alleviation techniques. Here we aim to further develop these tools which would allow us to approach more realistic conditions encountered in nature. This could be achieved by deformable models which results in very strong fluid and structure interaction leading to further complexity for numerical simulations.
Following an extensive literature review on the morphing strategies adopted by birds or squirrel the major tasks will be split into the numerical simulation of rigid and deformable wings and the second part involves complementary wind tunnel experiment to validate the numerical simulations, which can be then further exploited to further morphing scenarios.

<u>Low order modelling</u>
Familiarisation with low order modelling of variable sweep.
Analysis and validation with experimental results on rigid wing.
Analysis and validation with experimental results on deformable wing.
Star CCM+ simulations repeated with dynamic pitching (to be decided).

<u>The wind tunnel experiment</u>
Aerodynamic force measurement on rigid wing model with and without oscillatory freestream flow – force balance
Aerodynamic force measurement on deformable wing model – force balance
Model deformation measurement – Using local laser displacement sensors or global optical technique such as DIC
Characterisation of the flow over the deformable wing with and without oscillatory freestream
Repeat measurements coupled with dynamic pitching (to be decided).

HERA-WP1-2026-2027: High Aspect Ratio Wing for Future Regional Aircraft

Description:

The new HERA meta project aims at gathering all ISAE-SUPAERO projects related to regional type aircraft design. From some years, ISAE-Supaero has worked with ATR on hybrid regional aircraft and a specific aircraft design platform FAST-OAD-CS25/RTA has emerged from that work. It is very likely that this type of work will be extended through futures collaborations with ATR and other EU partners (new Clean Aviation project HERA).

Source: Aviationsourcenews.com

The purpose of this project is to explore the potential of high-aspect-ratio wings to reduce the environmental footprint of regional aircraft through an innovative Overall Aircraft Design (OAD) approach. Due to their inherent structural complexity, new methods need to be developed to account for the strong coupling between aerodynamics and structures in the wing sizing process. Owing to its flexibility, low computational cost, and validated results against high-fidelity data, OpenAeroStruct has been selected as the reference aerostructural optimization framework. Originally developed for conventional configurations, work is currently underway to extend its capabilities to strut-braced wing configurations and integrate it with FAST-OAD-CS25/RTA for an innovative and integrated OAD approach for regional HAR wings concepts.

Objectives:

o To complete an updated literature review on specific OAD strategy and results for future aircraft concepts: this is a key step as a very substantial effort is currently made all across Europe to demonstrate the feasibility of a new generation of Regional Aircraft.
o To review the specific aspects of high-aspect-ratio wing concepts, with a focus on strutbraced and joined-wing configurations.
o To explore the implementation of joint wing model into OpenAeroSturct.
o To attempt an OAD optimization for low environmental joint-wings/high aspect ratio wing regional aircraft, using the RTA-FAST-OAD code, currently modified for interfacing with OAS code.
o To summarize the methodology and findings into a competitive research paper (hints on novelty: use of high aspect ratio wing for regional aircraft)
o Typical target of publication: EASN conference

HERA-WP2-2026-2027: Turboprop modelling for Future Regional Aircraft

Description:

In the frame of the decarbonization, ATR (Airbus group) and ISAE-SUPAERO jointly work on developing the next generation of aircraft notably with the Clean Aviation program. In this scope a multi-disciplinary tool specially fit for regional aircrafts has been developed (RTA-FASTOAD) permitting to size a regional aircraft, starting from specific TLAR and requirements. To enhance the fidelity of the tool, research teams are needed specially to improve the modelling of the turbo propulsor engine.

Source:
https://www.prattwhitney.com/fr/newsroom/news/2022/07/19/pratt-whitney-canadas-pw127xt-engine-series-continues-to-bring-value

https://www.atr-aircraft.com/

The goal of this research project is to change the current engine modelling on the multidisciplinary tool (RTA-FAST-OAD), to improve the fidelity of the model and, in fine, find the optimized turboprop engine adapted to a hybrid propulsive chain. Based on the RTA open source code, the target is to integrate a whole sizeable turbo propulsor engine from the air inlet to the outlet nozzle.

Objectives:

o To complete an updated literature review on specific OAD results & strategy: this is a key step as a very substantial effort is currently made all across Europe to demonstrate the feasibility of a new generation of Regional Aircraft;
o To complete a literature review on turbo propulsor modelling, especially in the field of MDAO (Multidisciplinary Design Analysis and Optimization).
o To implement such model in the dedicated tool for regional modelling (RTA-FAST-OAD code) (Python code modelling), including all the different components, such as air inlet, compressor, combustion chamber, etc;
o To attempt an OAD optimization for low environmental regional aircraft, using the RTAFAST-OAD code;
o To summarize the methodology and findings into a competitive research paper (hints on novelty: Complete modelling of a turboprop engine for regional aircraft)

Application and Evaluation of a Control Law for a Space Manipulator System on SpaceROS

Description:

This two-year Master's project focuses on developing and evaluating a control law for a space manipulator system using SpaceROS, a ROS 2–based framework for space applications. The first year covers literature review and environment setup (Docker + SpaceROS), while the second year focuses on implementing and testing a state-of-the-art control strategy.

Objectives:

- Study space manipulator dynamics and control challenges.
- Familiarize with SpaceROS and implement it in Docker.
- Review and select a state-of-the-art control law.
- Implement, test, and evaluate the chosen control strategy in simulation.

Year 1 – Foundations & Setup:

1. Literature review on space manipulator control and dynamics.
2. Study of SpaceROS architecture and capabilities.
3. Implement SpaceROS in Docker and test sample simulations.
4. Comparative study of control methods and selection of one for implementation.

Year 2 – Implementation & Evaluation:

1. Model and simulate the space manipulator in SpaceROS.
2. Implement the selected control law as a ROS 2 node.
3. Test and evaluate performance under various conditions.
4. Optimize, document, and present results in the final thesis.

Expected Outcomes:

- Working SpaceROS Docker environment.
- Implementation of an advanced control law (adaptive, impedance, or MPC).
- Quantitative evaluation of control performance.
- Final Master's thesis and potential conference paper.

Prototyping and comparing of two approaches for integrating LLM-based assistance in MBSE

Description:

Model-based systems engineering (MBSE) relies on the extensive use of models, which can be large and extremely complex. This complexity is intrinsic, as the model needs to capture different views of the system of interest, each having its own syntax and semantics. The need for assistance for model creation and comprehension from tools has been recognized for a long time and solutions have been explored in the past [9, 11, 7]. Recently, our team has been working on a novel approach to provide MBSE assistance [5], by interfacing LLMs directly with the Capella MBSE tool through the Model Context Protocol[3, 8].

MBSE tools like Capella provide a modeling environment where all information, including functional, structural, and behavioral elements, are maintained in a unified model repository. On the other hand, graph databases have emerged as a promising technology for representing complex, highly connected data, aligning naturally with the relationship-centric nature of MBSE models. Their ability to efficiently model, traverse, and query richly interconnected elements positions graph databases as an attractive backend for next-generation MBSE environments [10]. Previous work has explored how graph databases may be used to represent models in standard modeling languages such as UML or Ecore [6, 4]. This opens another avenue for LLM-based assistance: using an off-the-shelf MCP tool for graph-database access such as [2, 1] to give access to the MBSE model.

The objectives of this project are as follows:
• Contribute to the Capella MCP project in order to bring it to a stable and usable version that completely covers at least one layer of the Arcadia method (Operational Analysis).

• Create a graph database schema for the Arcadia concepts included in the studied layer, and validate the schema by modeling a proof-of-concept system (e.g., the Inflight entertainment example provided with Capella). At this stage, the following alternatives shall be explored:
– schema-less graphs vs. structured graphs with a pre-defined schema (e.g., Neo4j vs. Kuzu)
– persistent vs. in-memory setup for the DB (e.g., Neo4j vs. Kuzu)
– manually created schema vs. automatically generated schema (from the Ecore meta-model of Capella).

• Define the method and criteria for an empirical study comparing the quality of assistance for MBSE modeling tasks, obtained from an LLM that uses the Capella MCP vs. the generic graph database LLM.

• Conduct the empirical study on a medium-size system, for example the AIDA (Aircraft Inspection by Drone Assistant) system1.

HERA-WP3-2026-2027: Multi-criteria decision process and modelling for Future Regional Aircraft's hybrid propulsive electric chain components

Description :

In the frame of the decarbonization, ATR (Airbus group) and ISAE-SUPAERO jointly work on developing the next generation of aircraft notably with the Clean Aviation program. In this scope a multi-disciplinary tool specially fit for regional aircrafts has been developed (RTA-FASTOAD) permitting to size a regional aircraft, starting from specific TLAR and requirements. Hybrid electric propulsive chains investigated, imply numerous electric components and hence impose a multi criteria decision making process.

https://www.directindustry.fr/prod/saft-19840.html

https://www.atr-aircraft.com/

The goal of this research project is to build a decision-making process to trade electric components of the hybrid propulsive chain (electric motors, batteries…) and determine the ones fitting for the next generation of regional aircraft. This research should discriminate the different type of components using a relevant method. In a second time, the selected components should be modelled and implemented in a multi-disciplinary tool: RTA-FAST-OAD code.

Objectives:

o To complete an updated literature review on the multi criteria decision making methods.
o To complete an updated literature review on specific OAD results & strategy: this is a key step as a very substantial effort is currently made all across Europe to demonstrate the feasibility of a new generation of Regional Aircraft;
o To complete a deep literature review on electric components for a hybrid propulsive chain (batteries, electric motors etc.) especially in the field of aircraft hybrid propulsion, and perform all along the research project, a technological watch.
o To model the selected components (Python code modelling).
o To implement such models in the dedicated tool for regional modelling (RTA-FAST-OAD code) (Python code modelling).
o To summarize the methodology and findings into a competitive research paper (hints on novelty: Complete modelling of a turboprop engine for regional aircraft)

HERA-WP4-2026-2027: Nacelle models for Trade-Off Studies

Description:

In the frame of the decarbonization, ATR (Airbus group) and ISAE-SUPAERO jointly work on developing the next generation of aircraft notably with the Clean Aviation program. In this scope a multi-disciplinary tool specially fit for regional aircrafts has been developed (RTA-FASTOAD) permitting to size a regional aircraft, starting from specific TLAR and requirements. Hybrid electric propulsive chains investigated, imply numerous trade-offs and in particular impose the assessment of aeroacoustic footprint of the installed propulsion system versus the cost of installation.

The noise generated by propellers interacting with the fuselage or wings remain a major obstacle in designing aircrafts or drones. History has shown that neglecting acoustic interaction at the predesign stage can result in unacceptable noise levels, sometimes necessitating costly architectural modifications (e.g. SAAB 2000 aircraft). The goal of this research project is to build a realistic model – structural and aerodynamical – of the system at the interface between the propeller-engine and the wing, the nacelle, within the context of aeroacoustics, seen at OAD point of view. This research should discriminate the different type of components using a relevant method. In a second time, the selected components should be modelled and implemented in a multi-disciplinary tool: RTA-FAST-OAD code.

Objectives:

o To complete an updated literature review on the system “nacelle”, with a special focus on volume, weight, structures, aerodynamics and thermal management. A specific attention to OAD results & strategy, in relation to Nacelle Systems should be added
o To model the selected components (Python code modelling).
o To implement such models in the dedicated tool for regional modelling (RTA-FAST-OAD code) (Python code modelling).
o To summarize the methodology and findings into a competitive research paper (hints on novelty: Complete modelling of a turboprop engine for regional aircraft)
o Typical target of publication: EASN conference

Test Sequence Generation from SysML Models

Description:

The widespread of Model Based System Engineering approaches has encouraged several communities to develop their own modelling language. For instance, the Object Management Group (OMG) and the International Council for Systems Engineering (INCOSE) have jointly developed and standardized the Systems Modeling Language (SysML).

The benefits and potential of using SysML have been acknowledged in several application domains, in particular avionics. SysML is now supported by proprietary and open-source and free tools, such as TTool. The latter helps automating an important variety of activities throughout the design trajectory of complex systems. One of these activities is test sequence generation, an activity that is cost-prone and time consuming, and therefore worth being automated to reduce time to market of complex systems.

Objective:

The purpose of the research project is to define, formalize and implement in TTool a test sequence generation algorithm.

Implicit dynamic representation for partially deaf persons

Description:

Research conducted in the field of biodynamics. The internship includes a theoretical component and an experimental component.

The theoretical part lays the foundations for an article linking singularity theory, holographic cognitive representation, and the criteria for a sensory alphabet, based on implicit representation. Starting from the structural gaussian representation by eigenmodes and reference solutions, the aim is to describe a process for coding dynamic cognitive information that could potentially address the four disabilities. If sufficient progress is made during the internship, it could lead to a publication in a biophysics journal, to which the interns could be associated.

The practical part is included in a multisensory program involving hearing-impaired pilots. In this context, interns will be asked to propose graphic protocols for glasses equipped with LEDs, based on concrete situations on the airport circuit.

[IONLAB] Model Predictive Control for Tail-Sitting Dual-Engine Flying-Wing Drones

Description:

Compared to their fixed-wing counterpart, rotary-wing drones perform vertical takeoff at a considerable energy expense that precludes long-range operations. Convertible drone development has recently grown to fill that operational gap and provide platforms that can take off vertically and fly to distant locations. ISAE-SUPAERO was an early adopter of the convertible architecture through the MAVION project, which provides a flying-wing capable of sustaining trimmed flight from 0 to 15m/s. A mathematical model, namely the ϕ-theory[1], was also developed to model convertible aerodynamics and propulsion (and their interactions). Φ-theory holds a granularity level simple enough for real-time Model Predictive Control implementation and at an adequate complexity to reduce robustness margins requirements.

While researchers at the Massachusetts Institute of Technology (MIT) proved that ϕ-theory is adequate for agile tail-sitter flight, this research project aims to extend their results to a Model Predictive Control-based framework. This yields: (i) Control Law Design in MATLAB, (ii) hardware-in-the-loop validation through DSPACE, and (iii) flight testing in a motion capture facility.

A video partially demonstrating the project is available on:
https://www.youtube.com/watch?v=ohkVRMSH2BI

Figure 1: (i) **MAVION** during outdoors flight; (ii) **MAVION** next to a soda can for size comparison; (iii) **MAVION** during indoors flight.

[IONLAB] The IONLAB Drone Competition Team: Control and Avionics

Description:

The IONLAB/PNXLAB Drone Competition Team is a pedagogical mechanism that encourages hands-on learning by proposing to students the design of experimental flying model-scale demonstrators for driving research, innovation, and competitions. While joining the group, the students choose their specialties (e.g., Embedded Systems, Control Systems, Computer Vision), are assigned a portion of the design, and execute the technical roles (e.g., programming, soldering, 3D printing). This pedagogical tool differs from student clubs since Prof. Lustosa (IONLAB) and Prof. Vivet (PNXLAB) closely orchestrate the projects through weekly meetings. Besides, Prof. Lustosa offers special technical lectures (e.g., embedded systems, Pixhawk autopilot, robotics, project management, and collaboration tools). Finally, periodic technical review sessions with additional specialized professors and engineers provide the students with feedback and other knowledge. The students further apply their learned skills by participating in international drone competitions. In 2022, the IONLAB Competition Team achieved Top 5 out of 53 teams from 22 countries in a competition in Croatia during the 2021 International Conference on Unmanned Aircraft Systems.

To build up combat readiness while the 2025 Competition rules are cooking, the IONLAB proposes internal challenges. This Research Project encompasses answering the previous challenge from the IMAV 2023 Competition, where an autonomous line/circuit tracking mission was proposed. Please visit the following link for more information: https://2023.imavs.org/.

Skills: manufacturing, embedded systems, robotics, programming, teamwork.

* IONLAB Program Immersion and Flight Testing participation This Project is a component of the ISAE-SUPAERO's IONLAB Program initiative. Accordingly, the student will collaborate with other ION projects and assist in field tests. A critical example is flight testing. The student shall have a fixed role during his stay at the group and specialize in it. Dependability and multi-tasking between flight testing activities and the assigned research project are expected.

(a) The IMAV 2023 Competition Counterpart. (b) The IMAV 2023 Scientific Counterpart.

[IONLAB] Very Flexible Aircraft Iron Bird Design, Implementation and Manufacturing

Description:

To satisfy the strict power requirements of solar-energy-powered high-altitude pseudo-satellite aircraft, there's an increasing trend to optimize aerodynamic performance by increasing aspect ratio and to reduce weight by minimizing structure. Both solutions lead to increasingly flexible aircraft. Such potentially fragile systems call for protective control laws for managing load distribution during gusts and ensuring dynamic structural stability. The HALION Project intends to study such control laws through a flying demonstrator at ISAE-SUPAERO (based on the University of Michigan's X-HALE aircraft) equipped with the innovative HALION real-time structural estimator system. Our novel technique[1] uses a combination of inertial sensing and computer vision, and it is already theoretically verified.

More specifically, this research position contributes to the development of the avionics of a non-flyable 1-1 scale version (i.e., a 6m-span model) of the aircraft for validation and test purposes. The appointed Research Project student will assess the required communication bandwidth, computational resources, and real-time requirements of the autopilot software. The student will also develop the Companion Computer (currently an NVidia Jetson Nano) Middleware, including inter-thread communication between Ground Control Comms, Pilot Radio Command Comms, Data Logger, Control Laws, Estimation Algorithm, and Flight Mode State Machine. Development and resizing of hardware (e.g., power module, microcontroller, cameras) might be necessary.

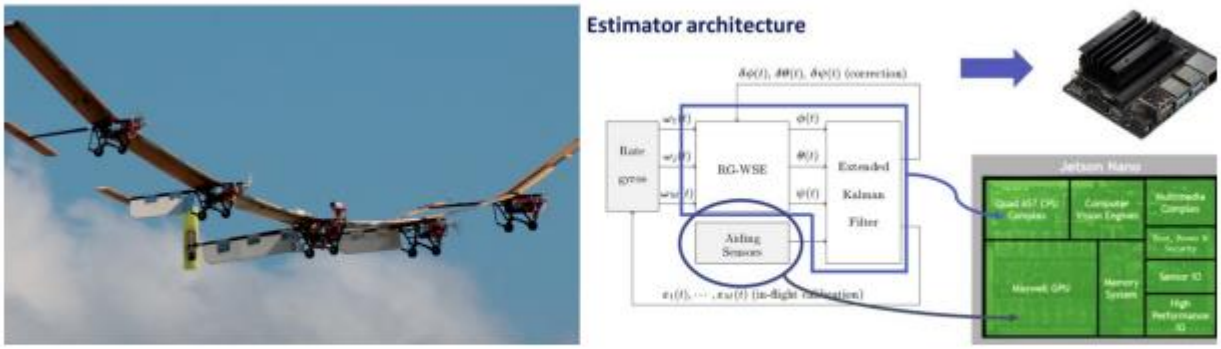


Figure 1: *(Left)* X-HALE demonstrator; *(Right)* Estimator Architecture and Allocated Hardware.

Joint development of a system and its digital twin using SysML v2

Description:

Digital Twins (DTs) are widely used in industries to address concerns of design and control of complex systems, during their entire life cycle (from feasability up to V&V and operational and maintenance phases). For these reasons, digital twins contribute to decision-making processes, as detailed by CEA-List in the white paper on holistic digital twins [2].

Every year, the Association Fran ̧caise d'Ing ´enierie Syst `eme (AFIS) proposes exciting technological challenges to engineering students through the RobAFIS competition. The RobAFIS 2025 edition celebrates the 20th anniversary of the competition and proposes to students to develop and prototype RugbAFIS, a robot capable of playing rugby, the emblematic sport of the city of Toulouse. Details of the RugbAFIS system are given in its specification [4].

The objective of this project is to use SysML version 2.0 [6] (SysML v2) to model a dual system composed of the physical RugbAFIS system and its digital twin, allowing virtual testing, behavioral simulation and continuous synchronization between physical and digital entities. To do so, main Model-Based Systems Engineering (MBSE) processes, like Stakeholder needs and requirements definition, functional, logical and physical architectures, integration and interfaces management, and V&V, shall be performed. The model could be built using [3] and [5], two open source SysML v2 tools.

The 5-dimensional (5D) Digital Twin concept can be used, as it allows successful modeling of dual systems [1, 7]. The 5-D approach consists in modeling the dual system based on 5 pillars: the Physical Entity (the real system), the Virtual Entity (the digital representation of the real system), the Services (functions and applications provided by the whole system), the Data (generated, collected, processed and stored by the system) and the Connections (that ensure the communication between the real system and the virtual entity).

BFS « Back From Space »

Description:

The BFS project aims to develop a re-entry kit capable of safely recovering space payloads back to ground. After a preliminary study to recover a 1U module from a 3U spacecraft investigated at ISAE-MAE1 from 2020-2022, the upgraded version of BFS12U in a 16U deployer in 2022-2025 . The scenario for this study is to recover up to 24-30U payloads inside an ISS locker (MDL = STS Middle Deck Locker) from an autonomous reentry kit attached to the ISS Locker and performing as an autonomous reentry capsule and allowing flight of the 100W max experiment during >1month a Nanosat aiming t to achieve In Orbit Servicing / Manufacturing recovery of sample or space manufactured stuff space down to the ground.

The 1rst phase of this project has been kick-off in 2022Q3 and is currently funded by French “plan de relance” for development of Nanosat Innovative Technology for Flexible Thermal Protection F-TPS able to survive atmospheric reentry. The 2nd Phase aims to start early 2024 to investigate feasibility of a mission scenario to provide P/L (payload) customer with the cheapest cost ratio (KE/Kg) to fly back its payload back on earth and investigate the business opportunities and related customers. The main driver of the study is to achieve trade-of in a newspace approach : Accessible to SMEs , in a low cost approach , able to high production rate , taking advantage of reusability costs , Main goal is to achieve the entire mission with a P/L(payload) customer requirement objective of 20- 25KE/kg considering standard current cost (10kE/kg).

Problem Statement

This research project has highly innovative aspects in order to achieve its objectives in the NEWSPACE market (low cost reentry kit able to mass production compatible to several units per month).

(1) To investigate best mission scenario to offer a cheaper cost for the Payload (KE/Kg) : Cubesat ? Nanosat ? In-Orbit Servicing ? Space Tug ? On-Purpose nanosat launcher vehicule ? Others ? Landing Budget accuracy ? best landing system scenario ? guided capsule with AOCS ? RCS ? or un guided capsule with parasail autonomous glided flight ? Best Landing shock capability ? Inflatable / deployable system ? parachute – Airbag landing ? Reentry trajectory on Ground / on Sea ? investigate Recovery & Test Range constraints. Investigate customers network interested by the promotion of this emerging business. (in orbit manufacturing , science or technological experiments ...)

(2) To investigate Autonomous BFS electronic Unit : an environmental monitoring unit (P°;T°;Gx,y,z; Wx,y,z, GPS Location (Lat, Long , Altitude) able to transmit via SATCOM(IRIDIUM, Globalstar?, Inmarsat? other innovative networks)

(3) To investigate Deployment mechanism design and related deployment mechanisms (list of concepts and Trade-off: inflatable – deployable) deceleration and landing system (parachute? Crash system ?) damping system (crushable materials ?) Structural frame compatible to launch constraints and reentry aerodynamic pressure and landing crash sequence.

(4) To investigate the entire system approach with interfaces with P/L(payload) , P/F(platfrom) , P/M (Propulsion Module) and mission ground control, ground Tracking system , On-board tracking system (ADS-B? , RF beacon ?); ground recovery team,

(5) To investigate aerothermal and thermos-mechanical constraints from mission analysis and trajectory a. Inflatable system envelope.

Software-Defined Radio (SDR) Implementation of a Covert Waveform

Description:

The Russia-Ukraine conflict has become the most electronically contested battlefield in history. U.S. Space Force officials describe it as featuring "more EW than we have ever seen before" [1], with Ukrainian EW units jamming 65% of Russian drone missions and reducing their success rate from 70% to 45% [2]. In one week alone, Ukrainian forces neutralized almost 8,000 Russian drones through electronic warfare [3]. This environment has exposed critical vulnerabilities: Russian EW has hamstrung Western Excalibur precision artillery [4], GPS-dependent systems face constant jamming, and entire front segments exist where operators cannot fly drones due to jamming [5]. Conventional radio transmissions are easily detected, geolocated, and targeted for destruction within minutes.

Low probability of detection (LPD) systems are now essential because they enable forces to maintain command and control, coordinate operations, and share intelligence without revealing their positions to enemy direction-finding systems. In modern warfare, the electromagnetic spectrum is as contested as physical terrain—forces without covert communications become operationally blind and vulnerable to precision targeting. Adversaries like China are developing extensive EW suites specifically to disrupt C4ISR capabilities [1], making LPD communications a fundamental requirement for survival and mission success in peer conflicts.

The lab has recently proposed an LPD waveform referred to as DSSS-FTN [6,7]; beyond traditional direct sequence spread spectrum (DSSS) as used in satellite navigation systems and 3G cellular communications, its Faster-Than-Nyquist (FTN) property, combined with "long" spreading sequences, enables a statistical signature that can be hardly distinguished from the background noise. DSSS-FTN has passed several field tests (terrestrial, satellite) in the last month, using post-processing-based receivers.

Objectives:
Our purpose is to integrate the DSSS-FTN waveform in real-time on a software-defined radio (SDR) platform, showcasing its ability to balance the performance-complexity tradeoff. The proof of concept will be developed using MATLAB and USRP B200 SDR transceivers.

Design and Optimization of Transfers to the Sun–Earth Lagrange Points L4 and L5

Description:

The Lagrange points L4 and L5 of the Sun–Earth system are strategic locations for future solar observation and space weather forecasting missions. Positioned 60° ahead (L4) and 60° behind (L5) Earth along its orbit, these points offer complementary viewing geometries of the solar surface, enabling continuous monitoring of active regions before or after they rotate into Earth's line of sight. Scientific interest in these regions has increased significantly in recent years, as illustrated by upcoming missions such as ESA's Vigil mission to L5.

In this context, a previous internship conducted at the NASA Goddard Space Flight Center (GSFC) focused on studying dynamical transfers toward L4 using the Circular Restricted Three-Body Problem (CRTBP).

The work included:
• the computation of periodic orbits around L1 and L4,
• the use of invariant manifolds associated with unstable orbits near L1,
• the design of a low-cost transfer from L1 to L4,
• validation within a high-fidelity model (GMAT) including real perturbations. However, many extensions remain to be explored: studying the dynamical behavior around L5, comparing the L4 and L5 environments, investigating additional families of periodic orbits, developing more advanced transfer optimization methods, and integrating increasingly realistic dynamical models. This project is therefore a direct continuation of the previous work and aims to further develop and broaden the trajectory design capabilities for transfers to L4 and L5.

Project Objectives:

The goal of this project is to extend the work initiated at GSFC by exploring new orbital configurations and improving transfer design methods toward the triangular Lagrange points L4 and L5.
The main objectives are:
• Study and generate new families of periodic orbits around L4 and L5
• Explore multiple departure and transfer scenarios
• Test and compare several optimization methods
• Validate the resulting trajectories in a high-fidelity dynamical environment

[IONLAB] Very Flexible Aircraft Avionics Hardware-In-The-Loop Validation

Description:

To satisfy the strict power requirements of solar-energy-powered high-altitude pseudo-satellite aircraft, there's an increasing trend to optimize aerodynamic performance by increasing aspect ratio and to reduce weight by minimizing structure. Both solutions lead to increasingly flexible aircraft. Such potentially fragile systems call for protective control laws for managing load distribution during gusts and ensuring dynamic structural stability. The HALION Project intends to study such control laws through a flying demonstrator at ISAE-SUPAERO (based on the University of Michigan's X-HALE aircraft) equipped with the innovative HALION real-time structural estimator system. Our novel technique[1] uses a combination of inertial sensing and computer vision, and it is already theoretically verified.

More specifically, this research position contributes to validating the demonstrator's Stability Augmentation System (SAS) avionics through a Hardware-In-The-Loop (HITL) setup. This requires the actual avionics (a Pixhawk Autopilot and an NVidia Jetson Nano Companion Computer) to control a simulated aircraft in real time. The appointed Research Project student will interface the existing avionics to a simulated environment in a dSPACE real-time computing module. Additionally, in 2024, the IONLAB will begin manufacturing a non-flyable 1-1 scale version (i.e., a 6m-span model) of the aircraft for avionics installation, validation and test purposes. Beyond avionics HITL interfacing, we expect the student to also participate in the manufacturing of the model.

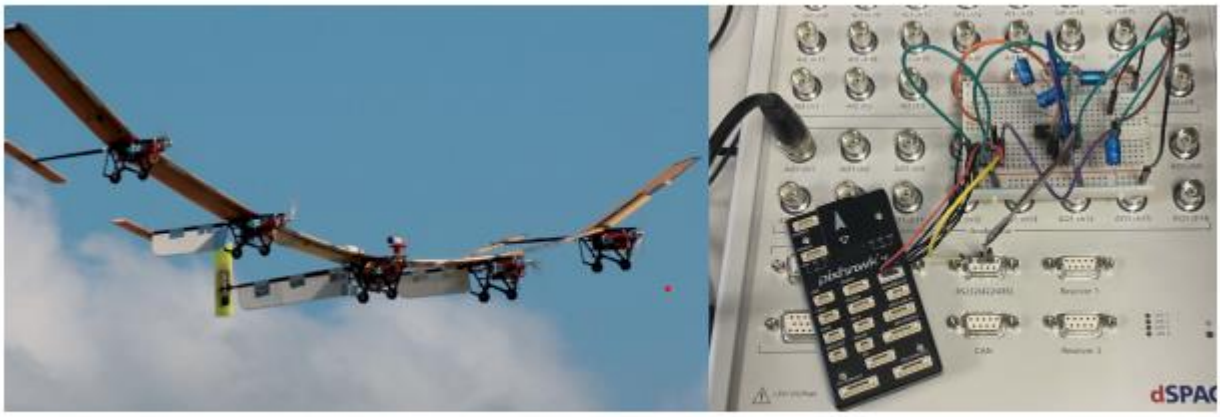


Figure 1: *(Left)* X-HALE demonstrator; *(Right)* HITL Autopilot Setup.

Robust estimation filters to faulty GNSS measurements

Description:

Global Navigation Satellite System (GNSS) techniques play a decisive role in outdoor navigation. However, it faces several critical shortcomings to meet the requirements of applications which evolve in complex environments. Indeed, the presence of multipath or non-line-of-sight (NLOS) measurements can produce severe outliers, which strongly affect the accuracy of standard solutions. Various methods have been proposed to try to tackle this problem [1]-[4], but robust statistics-based estimation approaches seem to be a reasonable trade-off between complexity, computational load and efficiency.
Robust statistics were first developed for regression problems with outliers [5]-[7]. Since then, robust estimators have been widely applied to various domains, including signal processing [8], [9], and GNSS [10]. The application of M-estimators has been proved to be much useful to mitigate the impact of signal reflections, working directly on the pseudoranges, inside the extended Kalman filter (EKF) framework [11]-[13]. However, the main drawback is that M-estimators rely on parameters, which encode a trade-off between efficiency and robustness, and are usually fixed. Recently, a robust methodology based on machine learning, within the framework M-estimation, was developed [14] (LEAR-EKF: Learning-Enhanced Adaptive Robust EKF). The key idea of the concept is to automatically tune the M-estimator's hyper-parameter allowing the model to adapt the robustness according to the environment in which a robot operates. As changing navigation conditions are hard to model in a dynamic context, a data-driven method was proposed to infer the parameter. It was shown that the learning problem on a single parameter enables to efficiently learn with a lightweight neural network.

Objectives:

The project's main goal is to investigate the use of robust filtering methodologies within a GNSS navigation framework, provide at least one MATLAB implementation of a robust filtering algorithm and evaluate its performance. The limitations studied robust algorithms will also be highlighted.
The project is divided into two main parts:

1. GNSS and estimation part: the student will become familiar with GNSS and estimation filters and will analyse the phenomena that affect GNSS measurements. As part of this task, the definition and characterization of outliers in GNSS measurements will also be addressed.
2. Robust filtering: this part will allow the student to understand the principles of robust filtering, with an emphasis on robust statistics and, if relevant, comparisons to machine learning techniques. The student will explore how these approaches can be applied to estimators such as Least Squares or Kalman-type filters within a GNSS framework.

Furthermore, the student will be required to conduct and critically analyze a literature review on robust methodologies. If time permits, measurement campaigns will be designed and carried out to assess the performance of the studied algorithms when confronted with real-world data.

A Robust, Flight-Controller-Agnostic MAVLink Abstraction Layer for Unifying Asynchronous Micro-services

Description:

The operational capability of modern Unmanned Aerial Vehicles (UAVs) is built upon a critical system dependency: Global Navigation Satellite Systems (GNSS). This has created a foundational single point of failure, as the use of electronic warfare to jam or spoof weak GNSS signals is no longer a theoretical threat, but a standard operational reality. As Figure 1 illustrates, the prevalence of ”GPS-denied environments” is a widespread problem capable of neutralizing entire autonomous fleets.

The first move in a modern conflict is often to blind an opponent’s positioning systems. This reality creates an urgent and defining engineering challenge. The core problem is no longer if GNSS will be denied, but how to ensure robust navigation when it is. The operational viability of autonomous aerospace systems is now inextricably linked to solving this.

The development of robust, self-contained, and reliable positioning systems is the central enabling technology for the next generation of autonomous systems. This thesis directly confronts this challenge by focusing on the critical software integration barrier that prevents such robust positioning systems from being universally adopted.

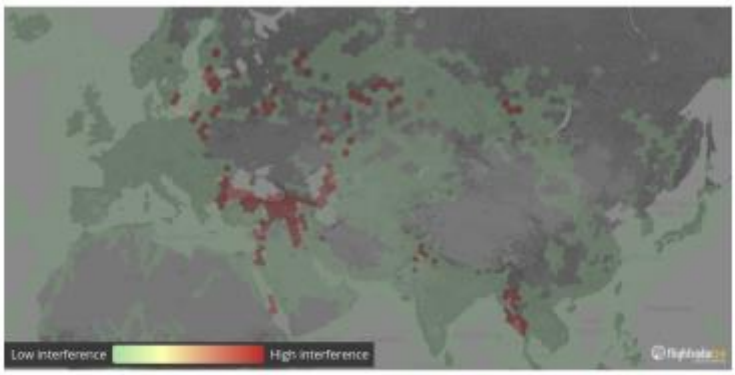


Figure 1: GPS Interference Heat Map from Flightradar24

Zero Industries is a European deep-tech startup, incubated at ISAE-SUPAERO and founded by aerospace engineers. Our mission is to build the essential, sovereign building blocks for autonomy, starting with robust navigation in GPS-denied environments.

We are developing a defence-grade Visual Positioning System (VPS), a modular AI intelligence layer that enables precise, real-time navigation. Our core technology uses advanced computer vision and sensor fusion algorithms to determine a vehicle’s position by matching what it sees against a geospatial intelligence engine.

As a 2025-launched company with European backing, our initial prototype has already demonstrated sub-20-meter navigation accuracy in real-world flight tests. This thesis project is focused on the critical next step: designing, building, and testing the high-performance core of our next-generation system.

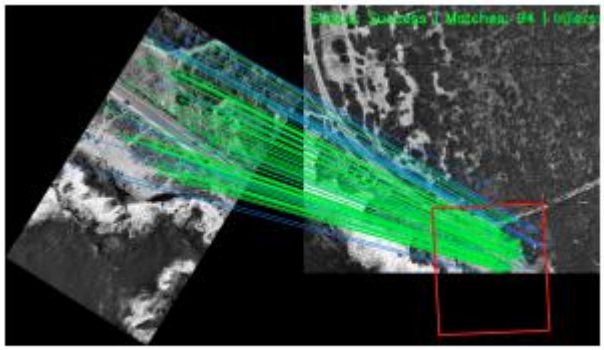


Figure 2: Visual Positioning System

Figure 3: Visual Odometry (VO)

This research project:

The Micro Air Vehicle Link (MAVLink) protocol is the de-facto standard for communication between a drone's Flight Controller (FC) and its peripherals, including companion computers and Ground Control Stations. It enables the bi-directional flow of data necessary for advanced autonomy, from reading the drone's state (e.g., attitude, position) to sending high-level commands (e.g., "inject a new waypoint," "change speed"). However, the MAVLink ecosystem is fragmented. The two dominant, open-source autopilot projects, Ardupilot and PX4, form the backbone of the industry but have evolved MAVLink into incompatible "dialects". This creates a significant challenge for developers, as the stacks have subtle (or not so subtle) differences in implementation. For example, they may use different messages for the same data or different enumerations for critical values. A developer wishing to create a drone-agnostic module is therefore forced to write highly complicated software to support both or abandon the goal of agnosticism. This challenge is compounded by MAVLink's reliance on complex, asynchronous micro-services.

Sending a command is not a "fire-and-forget" operation, but a multi-step, stateful handshake that must be robustly managed. The companion computer must send a command, await, and then correctly parse the acknowledgment to see if it was accepted, rejected, or if the FC is busy. Implementing this logic in a non-blocking way that handles timeouts and retries, without interfering with other real-time tasks, is a non-trivial software engineering challenge.

The aim of this thesis is to research and develop a robust MAVLink Abstraction Layer (MAL) that solves this fragmentation by providing a single, clean, high-level API (e.g., mal_get_attitude()). Internally, the MAL will automatically detect the connected flight controller dialect and employ a strategy design pattern to route API calls to the correct implementation. It will also encapsulate all asynchronous complexity within a suite of event-driven, non-blocking finite state machines, presenting a simple, unified interface. This project will answer the following research question:

What is the optimal software architecture for a unified MAVLink Abstraction Layer that unifies the Ardupilot and PX4 "dialects", while providing robust, non-blocking management of asynchronous micro-services in a real-time-safe manner?

Objectives:

The central challenge is to design a software layer that successfully abstracts the protocol-level "dialect" differences between Ardupilot and PX4, while robustly managing asynchronous, stateful command sequences in a non-blocking manner suitable for a real-time system. To achieve this goal, the student will:

• Analyse the literature to draw a consistent state-of-the-art on software abstraction layers in robotics (e.g., UAL), the MAVLink protocol's asynchronous micro-services (e.g., Command Protocol, Mission Protocol, and Parameter Protocol), and the documented implementation differences between the Ardupilot and PX4 "dialects".

• Propose and implement a baseline solution (e.g., a monolithic client with conditional logic and blocking function calls) to serve as a benchmark for code complexity, robustness, and real-time performance.

• Design and implement the complete MAVLink Abstraction Layer (MAL), employing a Strategy Design Pattern to

automatically detect the FC type via its HEARTBEAT message, and a suite of non-blocking, event-driven Finite State Machines (FSMs) to manage stateful, asynchronous MAVLink micro-services.

• Integrate and test the MAL against both Ardupilot and PX4 flight controllers, moving from software simulations to the participation in live flight tests to validate performance in realworld conditions.

• Evaluate the MAL based on quantitative metrics for: (1) functional correctness across both FC dialects, (2) robustness to packet loss, and (3) code complexity reduction achieved by the high-level API compared to a non-abstracted implementation.

Multi-Modal Measurement Fusion for Robust UAV State Estimation

Description:

The operational capability of modern Unmanned Aerial Vehicles (UAVs) is built upon a critical system dependency: Global Navigation Satellite Systems (GNSS). This has created a foundational single point of failure, as the use of electronic warfare to jam or spoof weak GNSS signals is no longer a theoretical threat, but a standard operational reality. As Figure 1 illustrates, the prevalence of ”GPS-denied environments” is a widespread problem capable of neutralising entire autonomous fleets.

The first move in a modern conflict is often to blind an opponent’s positioning systems. This reality creates an urgent and defining engineering challenge. The core problem is no longer if GNSS will be denied, but how to ensure robust navigation when it is. The operational viability of autonomous aerospace systems is now inextricably linked to solving this.

The development of robust, self-contained, and reliable positioning systems is the central enabling technology for the next generation of autonomous systems. This thesis confronts this challenge by focusing on a key component of a real-time, computer vision-based navigation system: the design and validation of fusion algorithms for multi-modal measurements.

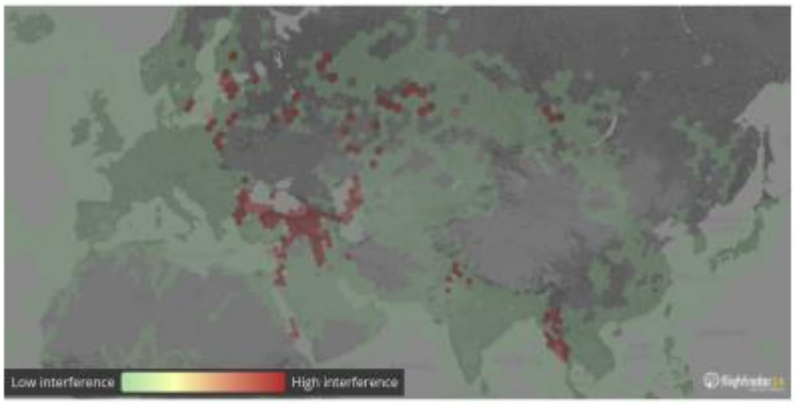


Figure 1: GPS Interference Heat Map from Flightradar24

Zero Industries is a European deep-tech startup, incubated at ISAE-SUPAERO and founded by aerospace engineers. Our mission is to build the essential, sovereign building blocks for autonomy, starting with robust navigation in GPS-denied environments.

We are developing a defence-grade Visual Positioning System (VPS); a modular AI intelligence layer that enables precise, real-time navigation. Our core technology uses advanced computer vision and sensor fusion algorithms to determine a vehicle’s position by matching what it sees against a geospatial intelligence engine.

As a 2025-launched company with European backing, our initial prototype has already demonstrated sub-20-meter navigation accuracy in real-world flight tests. This thesis project is focused on the critical next step: designing, building, and testing the high-performance core of our next-generation system.

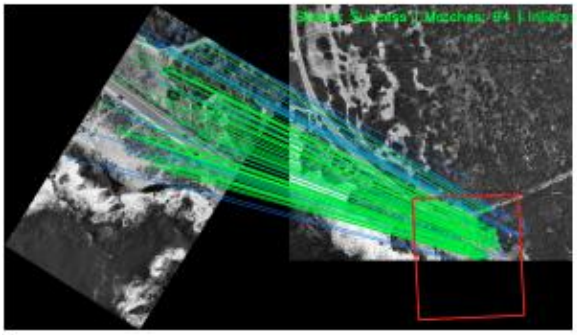


Figure 2: Visual Positioning System

Figure 3: Visual Odometry (VO)

This Research Project:

The Extended Kalman Filter (EKF) is the standard for drone navigation, but it relies on a critical assumption: all sensor measurements are random variables following a Gaussian distribution.

In the context of visual navigation in GPS-denied areas, it may happen that the computer vision modules underperform due to the lack of clear, rich visual features (for example, when the drone flies over a lake). This can lead to a poor position estimation, with an estimation uncertainty growing uncontrollably. At Zero, a powerful computer vision model was trained, which activates when the EKF's uncertainty becomes unreasonably large. This system does not provide a simple measurement; it generates a probability heat map of the drone's likely position within a given (often very large) area.

The generated heat map is inherently non-Gaussian and multi-modal. Not only does it contain several high-probability peaks, it can also contain multiple false-positives due to similar visual features that deceive the computer vision model. These properties present a challenge or measurement processing using the EKF formalism. As an example, simply trusting the highest probability peak as the input measurement would violate the EKF model assumptions, and would result in an irrecoverable state due to the presence of false positives. However, the information provided by this heat map cannot be discarded, as it contains invaluable information.

The aim of this thesis is to research, develop, and critically compare different algorithms to process this non-Gaussian, multi-modal likelihood heat map in a robust way. This project will answer the following research question:

How can likelihoods from multi-modal probabilistic measurements be processed in a navigation filter update, while balancing accuracy, robustness to false-positives, and computational speed?

Objectives:

The central challenge is to find the optimal trade-off between estimation accuracy, robustness to false positives, and the computational efficiency required for onboard operation.
To achieve this goal, the student will:

• Analyse the literature to draw a consistent state-of-the-art on non-Gaussian state estimation, robust data fusion, and multi-modal likelihood processing.

• Propose and implement a baseline solution (e.g., a simple "peak-picking" method) to serve as a benchmark for performance.

• Develop and implement multiple algorithms to compare against the baseline solution.

• Participate in the definition and execution of test flights to acquire new, relevant test data.

• Validate the proposed algorithms and evaluate them based on quantitative metrics for accuracy, robustness, and computational load.

Identification of Inertia Matrix of a small aircraft

Description:

Identification of Aerodynamic coefficients of aircraft is usually conducted from flight tests. The inertia matrix of the aircraft is generally assumed to be measured from ground tests and measurements or computed from a precise numerical model. This research project will focus on new experimental methods for the identification of the inertia matrix from flight tests.

ISAE SUPAERO is equipped with a fully instrumented light twin-engine aircraft dedicated to flight experimentations. A large database of flight records is already available, and dedicated tests can be performed when necessary. Although identification of some aerodynamic coefficients has already been done, identification of inertia matrix remains to be performed as the size and weight of the aircraft do not allow for usual ground identification methods.

This project started in 2023 and some results have been obtained (identification algorithm, flights tests). The next phase will specifically address three topics:
- Development of a simulation environment dedicated to the P68 of ISAE-SUPAERO
- Development of a toolboxe dedicated to extraction of specific flight test patterns on the large flight test database
- Use of prior knowledge in the identification algorithm (Bayesian estimation)

Some specific flight tests will be conducted in order to enrich the flight test database.

[IONLAB] Rocket Landing on Model Scale through Geometric Control

Description:

This research task proposal is part of the FUSION Project, which belongs to the IONLAB Program initiative to push the envelope of Control Systems by tackling challenging Aero/Astro vehicles. In particular, the FUSION Project aims to study partially controllable systems (either by design or due to failure yielding degraded mode operation). A great example of such a problem is the automatic landing of non-throttleable rockets. While highly underactuated and not controllable, previous research[1] in our group showed that landing is still possible in degraded mode at the expense of not choosing a precise touchdown location. Since partial controllability (in the linearized sense) and the presence of strong non-linearities preclude linear control theory, this project pursues Geometric Control as an alternative. (See the Model Predictive Control alternative on the LMS database for an optimization-based approach on the same problem.)

This research project will provide the students with an entry experience in geometric control, topology, and differential geometry. The student will exploit Lie Brackets to control the rocket in otherwise previously unattained directions in the linearized configuration space. Guidance in Scientific Experimental Design will be available. Additionally, the student will assist in building the rocket prototype and implementing the resulting geometric controller in an embedded system

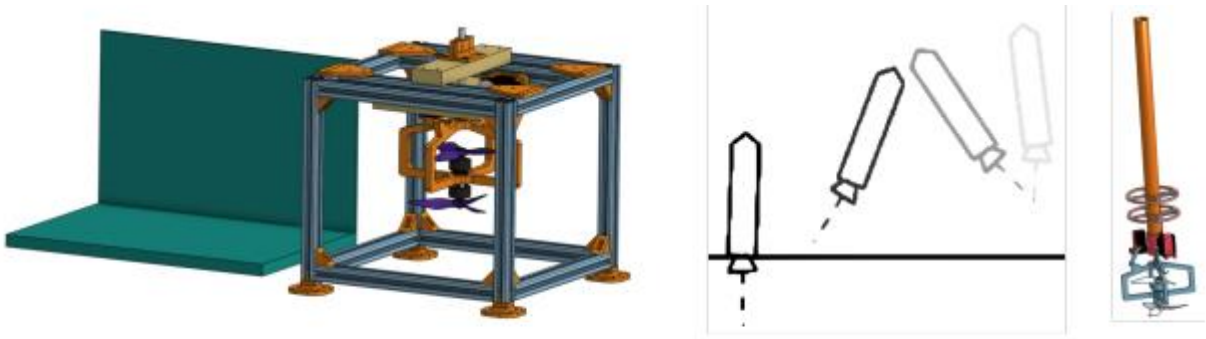


Figure 1: *(Left)* **FUSION** Thrust Vector Control Mount CAD drawing, *(Center)* Landing simulation example in 2D, *(Right)* Preliminary **FUSION** platform CAD drawing.

Preliminary Design of an MPC control strategy for collaborative guidance

Description:

The MPC (Model Predictive Control) approach is an advanced control method used to regulate a process while satisfying a set of known constraints, thereby optimizing the system at the current moment while predicting its behavior over a future horizon **[1]**. Although the state of the art presents multiple applications of controllers in the broad field of control systems, MPC is increasingly being studied as a control strategy to manage a fleet of vehicles. Its main advantage lies in the fact that the constraints specified in the specifications are explicitly taken into account to solve the internal optimization problem.

Several interesting application cases using such an approach can be noted:

- Underwater drones following a trajectory while maintaining a predetermined formation **[2]**.
- A formation of quadrotors avoiding obstacles and seeking to reach a destination while respecting a given travel time and the dynamic constraints of the vehicles **[3][4]**.

The work of Zhou et al. **[5]** and Bertrand et al. **[6]** are particularly relevant to the needs identified in our study:

- Use of autonomous UAVs
- Formation maintenance
- Inter-agent collision avoidance
- Trajectory tracking

The goal of this project is first to build a solid state of the art on cooperative or collaborative guidance strategies, with a particular focus on Model Predictive Control (MPC). This includes surveying the main theoretical approaches, evaluating their strengths and limitations, and reviewing their applicability to multi-agent or multi-aircraft coordination scenarios.

In parallel, a detailed review of the relevant sensing and communication technologies—such as ADS-B and other cooperative surveillance sensors—will be conducted. Their characteristics (accuracy, update rate, latency, integrity, limitations, and operational constraints) will be analyzed with respect to their impact on guidance performance and multi-vehicle coordination.

Based on this knowledge base, the next step is to design and develop an initial prototype application integrating collaborative guidance algorithms with realistic sensor models. This preliminary implementation will serve as a proof of concept, enabling simulation-based evaluation of cooperative behaviors, performance assessment of the guidance strategies, and identification of key technical challenges for future development.

Full Kinematic and Dynamic Modeling, Control Design, and Simulation of the PhantomX AX Hexapod Robot

Description:

This project focuses on the development and implementation of a complete kinematic and dynamic model of the PhantomX AX Hexapod robot, together with the design of model-based control strategies suitable for robust and adaptive locomotion. The first phase consists of establishing the full geometric model of the robot, including forward and inverse kinematics for each leg's coxa–femur–tibia chain and the overall body pose representation. Mechanical parameters, joint constraints, and servo characteristics from the PhantomX AX platform (driven by Dynamixel AX-12 actuators) will be integrated to ensure consistency with the physical system.

The second phase will address dynamic modeling using methods such as Euler–Lagrange or Newton–Euler formulations. The dynamic model will capture joint torques, ground reaction forces, foot–terrain interactions, and the effects of different gait configurations. This model will serve as a foundation for the development of model-based controllers (e.g., inverse dynamics control, impedance control, or trajectory-tracking controllers). Gait-generation strategies such as tripod, ripple, and wave gaits will be designed and tested, with attention to stability, smoothness, and energy efficiency.

To support development and de-risk experimental work, the project will optionally integrate ROS (Robot Operating System) and Gazebo simulation tools. Existing open-source packages such as phantomx_description (URDF/Xacro model) and phantomx_gazebo (Gazebo simulation with physics and controller interfaces) may be used as a starting point. These simulation resources will allow rapid prototyping, testing of control strategies, evaluation of stability under perturbations, and validation of the kinematic and dynamic models before deployment on the real platform.

The final phase will involve implementing and validating the selected control strategies both in simulation and on the physical PhantomX AX Hexapod robot. Performance metrics will include trajectory-tracking accuracy, stability of locomotion, robustness to terrain irregularities, and computational efficiency. By combining rigorous modeling, simulation capabilities, and real-hardware experimentation, the project aims to deliver a complete and extensible framework for the control and analysis of hexapod locomotion.

Computer Vision for Robust & Visually-Aware UAV Path Planning in GPS-Denied Areas

Description:

The operational capability of modern Unmanned Aerial Vehicles (UAVs) is built upon a critical system dependency: Global Navigation Satellite Systems (GNSS). This has created a foundational single point of failure, as the use of electronic warfare to jam or spoof weak GNSS signals is no longer a theoretical threat, but a standard operational reality. As Figure 1 illustrates, the prevalence of ”GPS-denied environments” is a widespread problem capable of neutralizing entire autonomous fleets.

The first move in a modern conflict is often to blind an opponent’s positioning systems. This reality creates an urgent and defining engineering challenge. The core problem is no longer if GNSS will be denied, but how to ensure robust navigation when it is. The operational viability of autonomous aerospace systems is now inextricably linked to solving this.

The development of robust, self-contained, and reliable positioning systems is the central enabling technology for the next generation of autonomous systems. This thesis confronts this challenge by focusing on a key component of robust, long-range autonomous missions in GPSdenied environments: the implementation of a predictive algorithm for a visually-aware flight path planning system.

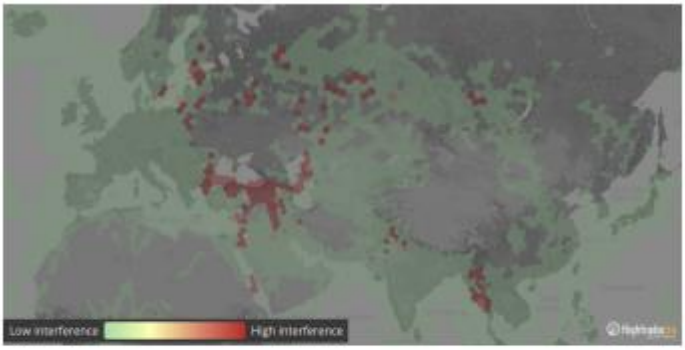


Figure 1: GPS Interference Heat Map from Flightradar24

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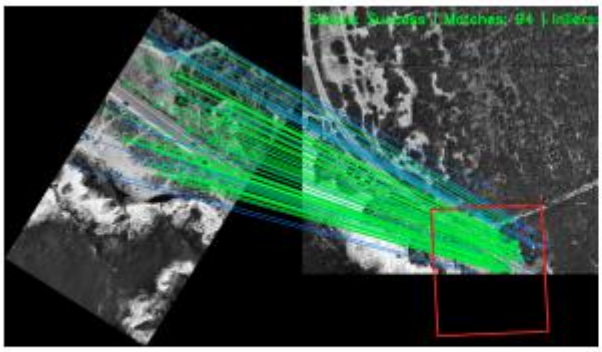

Figure 2: Visual Positioning System

Figure 3: Visual Odometry (VO)

This Research Project:

Visual navigation is an enabling technology for drones in GPS-denied areas, but its algorithms critically rely on a continuous stream of distinct visual features.

In long-range missions, a drone will inevitably fly over visually challenging terrain. Areas of feature starvation (e.g., open water, deserts, snow) or ambiguous, repetitive patterns (e.g., dense forests, agricultural fields) can cause poor feature tracking, leading to large estimation drift and irrecoverable navigation failure.

To enable robust, long-duration autonomous missions, the drone's path planner must become visually-aware. It needs to proactively select routes that avoid areas where the computer vision algorithms are likely to fail. The challenge is to quantify the navigability or feature quality of a large geographical area before the mission begins. This requires analysing large-scale, prior map data (such as satellite or aerial imagery) to generate a predictive heat map.

This prediction task is non-trivial. First, the prior map data (e.g., top-down satellite imagery) often 2 www.zeroindustries.eu info@zeroindustries.eu has a different perspective, resolution, and sensor modality compared to the drone's onboard, down-facing camera. Second, a simple measure of texture is insufficient; a repetitive grass field is highly textured, but not ideal for the vision algorithms. The analysis must learn to differentiate between good features (e.g., corners, unique landmarks, road intersections) and bad features (ambiguous, repetitive patterns). Finally, these maps can be massive, requiring computationally scalable algorithms.

The goal is to generate a visual navigability heat map from this prior data. This would serve as a cost-map for a higher-level path planner, guiding the drone to favour routes over areas rich in robust features (e.g., buildings, rock formations) and avoid visually degenerate regions. Simply planning the shortest path (a GPS-optimal path) ignores this crucial environmental context and exposes the mission to a serious risk of navigation failure. Therefore, the aim of this thesis is to research and develop a computer vision algorithm to generate this visual navigability heat map from prior map data.

This project will answer the following research question:
How can large-scale map data be processed to generate a visual navigability cost map that is sufficiently reliable to be used by a path planner to improve the robustness of long-duration autonomous missions?

Objectives:

The central challenge is to successfully learn and model the underlying relationship between features in prior map data and the expected performance of computer vision algorithms onboarded on the drone. The goal is to create a predictive tool that is computationally scalable for large-scale maps and generalises reliably to unseen environments.

To achieve this goal, the student will:

• Analyse the literature to draw a consistent state-of-the-art on predicting visual algorithm performance, terrain classification from aerial imagery, and the use of deep learning for satellite image analysis to infer ground-level scene

properties.

• Propose and implement a baseline solution (e.g., using traditional image processing metrics like image entropy, gradient density, or corner detectors) to serve as a benchmark for performance.

• Implement and train an architecture (e.g., Convolutional Neural Networks, semantic segmentation models, visual transformers) to identify the complex correlation between map data and the expected performance of onboard computer vision algorithms.

• Participate in the definition and execution of test flights over diverse terrain to acquire new, relevant test data. This dataset will correlate ground-truth computer vision performance metrics with their corresponding map data.

• Validate the proposed algorithm and evaluate it based on quantitative metrics for predictive accuracy, generality to unseen environments, and computational load.

Design and evaluation of an airship drone

Description:

The main objective of this project is to improve the autonomy and payload of a quadcopter by connecting it to a helium-filled balloon. Subsequently, the addition of solar cells and the resulting adaptations are being considered, again with the aim of increasing autonomy.

There are many applications for this type of drone:
- Inventory of large warehouses
- Aerial surveillance of a room or building
- Guidance for workers in large buildings
- Exploration of urban environments or caves
- Non-invasive crime scene investigation

An initial prototype has been developed at ISAE-SUPAERO and the first results in terms of energy savings are promising.

The aim of this project will be to contribute to the improvement of this system. Improvements could be proposed to the structure of the system itself, for example the type of connection linking the drone to the balloon.

Another set of contributions will consist of working on the drone's control law, which will obviously depend on the structure chosen.

The system will need to be instrumented to enable quantitative assessments of energy savings.

Depending on the type of contribution, one or more scientific publications may be considered.

Compute frozen orbits of Enceladus using hill framework and double averaging éléments

Description:

All research projects supervised by me (JP Sánchez) change the format this year. I will supervise 6 to 8 students working on individual research projects of their choice within the list of key questions that are posted below. The entire group will meet every second week for 2h to present their work and discuss within our MAE RP Research community. We will discuss results and directions of work all together.

All the key questions presented below explore the overlapping fields of Astrodynamics, Mission Analysis, Guidance Navigation and Control, Space Situational Awareness and System Engineering.

Below is the list of key questions proposed for this year. Each key question can potentially become a project if there is at least one student interested in it. Please, attend the information session scheduled for the 27th November at 14h.

- Astrodynamics & Optimization –

1. How can one measure and represent diversity of the solution set for mixed-interger optimization problems?
2. Compute frozen orbits of Enceladus using hill framework and double averaging elements following methodology in Xiaodong Lu PhD Thesis (Polimi)
3. Analysis and comparison of different Lambert Solver Algorithms. Test relative speed and advantages of each process in several computing environments.
4. Low-thrust homotopy –Comprehensive analysis and discussion of Impulsive Telltale methods for low-thrust optimization.
5. Robust Optimal Control – Literature Review – Methods applied for uncertainty optimization. Applications and Exploration of Covariance Steering approach.
6. GTOC13 Analysis. Approaches used and test and improvements on the tools built at ISAE to participate in the competition.

- Mission Analysis -

7. SSA – would a Debris shield collector be of any use or advantage? Feasibility of the Debris Sweeper idea.
8. What is the Upwards to downward mass of all the ADR proposals so far? What is feasible to have in the near future?
9. How possible or likely is it to have an interstellar object fly-by mission in the next 20 to 40 years? Exploration of the expansion of Comet-I concept as an serendipitous interstellar object explorer.

- Deep Space GNC solutions -

10. Asteroid Image Simulator based on POV-Ray, Blender or unreal engine.
11. Velocity estimate errors based on Visual based navigation near asteroids – implementation of an EKF and analysis of realistic performances.

Testing and Design of a Hybrid Rocket Feed System

Description:

AEther is one of the projects being pursued by Supaero Space Section. It consists in developing a hybrid rocket to participate at EuRoC in 2027. The student team is currently in the process of designing and testing the hybrid rocket propulsion system.
The AEther propulsion system uses high-concentration hydrogen peroxide as oxidizer, which is decomposed through a permanganate catalyst bed to then ignite and combust the solid ABS plastic grain. A partnership with ONERA allows the students to perform tests of the system. More details in the paper: *Design and testing of the combustion chamber of a H2O2/ABS student-developed hybrid rocket engine (IAC 2023)*

Objectives
Over the following year, the club will need to perform tests on the already built combustion chamber and feed system. Test results and learned lessons will then be used to design the flight-version of the propulsion system. The current RP will coordinate research activities with a second RP "Testing and Design of a Hybrid Rocket Thrust Chamber", this project will put special focus on the feed system, from the pressurizer tank to the injector. The research project will therefore tackle the following points:

- Literature review on the modeling and design of high-pressure feed systems. Emphasis shall be given to the past work conducted by the students in summer 2025.
- Post-process test results from the November 2025 campaign.
    - Update GriffonSimulator (student-developed code) to be able to reproduce tests.
    - Assess the chemical compatibility of the feed system with High Test Peroxide (HTP).
    - Perform new tests at dedicated supaero facilitie to try and reproduce observed pressure losses.
    - Find source of high pressure losses before the oxidizer tank.
- Interpret results and coordinate with ONERA to perform new tests in order to achieve desired mass flows.
- Design a new version of the feed system, with emphasis on the provisioning of flight-version hardware where possible.
- (if applicable) publish results at an international conference

All work shall be documented to build and keep know-how within the rocket club.

Designing Rough Acoustic Alarms for Cockpit Safety: Assessing Startle Reactions

Description:

The internship is part of a research project aimed at evaluating the effectiveness of rough auditory cockpit alarms in reducing inattentional deafness. Under conditions of high cognitive load and stress, pilots may fail to perceive auditory alarms. This phenomenon has been attributed to an inhibition of the primary auditory cortex. Acoustic roughness appears to offer a way to bypass this mechanism. Indeed, this sound property, known to evoke sensations of urgency and danger, has been shown to increase the activity of neural networks and subcortical structures involved in processing salience and threat-related information.

However, given their high salience and their ability to activate the amygdala, a subcortical structure already hyperactivated during startle (a state characterized by a temporary drop in cognitive and motor capacities following exposure to an unexpected and salient stimulus) rough alarms may also carry the risk of triggering such a reaction in pilots. Project Description: To assess the effectiveness of acoustic roughness in counteracting inattentional deafness, the project aims to test how roughness influences performance in an alarm-detection task in multitasking environment known to promote inattentional deafness. In parallel, it seeks to determine to what extent, and under which conditions, acoustic roughness may trigger or not startle states.

Internship Tasks:
1. Contribute to a state-of-the-art review on the startle effect, including its defining characteristics, the conditions that promote its occurrence, its operational consequences, and the subjective and objective indicators used to measure it.
2. Contribute to the development of a controlled laboratory protocol to evaluate the effect of acoustic roughness on startle reactions.
3. Depending on the advancement of the project, contribute to the development of protocol in ecological settings to evaluate the effect of acoustic roughness on startle reactions.

Objective Measurement of Satellite Operator Attention During Planned and Unplanned Events

Description:

Although several studies have highlighted the importance of attention in reducing human performance, few or no studies have attempted to measure the attention of a satellite operator objectively. One technique that can be used to measure satellite operators' attention is eye-tracking. Eye-tracking is widely accepted as the most direct and continuous measure of attention, given that where one looks is highly correlated with where a person is focusing their attention. Thus, with the fundamental objective of investigating hazard identification abilities and visual attention, as an unexpected alarm of debris in the satellite pathway for satellite operators, this study pioneers the application of eye-tracking technology to the realm of satellite operation safety practices. The study conducts a pilot test to examine the pattern of participants' eye movement and attention distribution when shown a hazardous situation in a satellite control room.

As part of space operations, human efforts require personnel to gain a comprehensive understanding of how control room technologies impact the performance of human operators. Recent advances in technology enable the use of eye tracking technology to continuously measure an operator's eye movements, which correlate with various human performance constructs, such as attention and situation awareness.

This pilot study evaluates whether eye-tracking can sensitively and objectively capture visual attention and situation awareness of satellite operators during routine vs. unexpected events. Developing a satellite control station simulator, participants will perform standard monitoring and procedure execution. The simulator should present planned maneuver tasks and unplanned debris alerts (one at a time) in alternating windows; operators must identify hazards and execute a defined response sequence. We record gaze metrics (fixations, saccades, dwell, transitions), behavioral performance (latency, correctness), and generate heat maps per Area of Interest (AOI). Findings will inform design guidelines for the satellite control Human-Machine Interface, and training focused on hazard detection.

Space operations increasingly rely on complex HMIs where attention management is critical for safety. While eye-tracking has matured in aviation, driving, and process control, it is under-applied to satellite operations. Measuring where operators look—when planned maneuvers occur vs. unexpected debris alerts—provides a continuous, objective proxy for attention and situation awareness.

Main Objectives

- Quantify operators' attention allocation and hazard identification during planned vs. unplanned events in a satellite control environment.
- Determine whether eye-tracking metrics predict response latency and procedure compliance.
- Identify AOIs that drive timely/accurate responses to debris alerts.

Objective (Specific aims)

- Characterize gaze patterns (fixation, saccade, dwell, transitions) across AOIs during planned and unplanned scenarios.
- Compare performance (time-to-first-action, total response time, error/compliance) between planned vs. unplanned events.
- Model attention–performance links using mixed-effects analyses to predict response latency/compliance from gaze metrics.
- Deliver heat maps and AOI-level metrics to guide interface prioritization and alarm design.

General Assumption

- Unplanned debris alerts elicit measurable attentional shifts distinguishable from planned tasks.
- Participants can execute a standardized response sequence (e.g., IDs → ToCA → Ephemeris → Prepare → Upload) within trials.

Early drone detection and localisation

Description:

For the first time, an innovation project will be developed by a group of students instead of a research project. It will follow the same cycle as a research project but using a specific methodology.

This Innovation Project will be based on a real-world case study that would need to be turned into a concrete and tangible solution by a single team of four students, focused on marketing, yet with a robust scientific basis.

Objective:

The goal is to teach you how to lead an entrepreneurial project closely related to your area of expertise, develop your appetite for innovation and entrepreneurship, and respond to and satisfy a customer need in a short period of time.

Goal :

The ultimate goal is to produce a prototype within the allotted time frame that meets a specific and current use case, using agile methods up to a TRL 6-7 (= Prototype ready for demonstration in an appropriate operational environment) within 14 months. Prototype needs to be at planned operational level and ready for demonstration in an operational environment (Activities will include prototype field testing).

The use case:

Drones are everywhere, and while they offer added value in many areas, they can also raise a significant impact on security. Imagine you are at a music festival, a sports event, or even waiting for your flight at an airport.
Suddenly, a small drone appears overhead.

It might just be a hobbyist's toy, or could it be something more threatening?

Drones have become a serious security concern. In recent years, unauthorized drones have disrupted major events, caused airport shutdowns, and even been used for malicious purposes.

They're hard to detect, easy to fly, and can access places we once thought were secure.

At large gatherings, drones can spy on crowds, disrupt emergency services, or even cause panic. Over airports, a single drone sighting can ground flights for hours, if not days, costing millions and putting lives at risk. Governments and security agencies worldwide are now racing to develop ways to detect, track, and neutralize rogue drones.

For the sake of safety, I want to be able to detect promptly and accurately an intrusion of drone.

This project comes across many majors:

✓ Aerospace Systems & control
✓ Embedded Systems
✓ Systems Engineering
✓ Aerospace Structures

Formula stUdent uSing artificial Intelligence for OptimizatioN (FUSION)

Description:

This project takes its roots in the Formula Student club at ISAE-SUPAERO (https://ae-isae-supaero.fr/clubs/clubs-ae), which focuses on the design, manufacturing, and real-world competitive testing of an autonomous electric formula vehicle. While the club itself targets participation in international competitions, this project addresses the academic research topics associated with it, involving collaboration between researchers and PhD candidates from the DAEP department. Specifically, the project focuses on the aerodynamics of a simplified, downscaled version of the Formula Student vehicle.
The primary goal of FUSION (Formula stUdent uSing aI for OptimizatioN) is to develop and evaluate a new optimization framework for aerodynamic design by leveraging both Computational Fluid Dynamics (CFD) and experimental data, with the integration of Artificial Intelligence (AI). This year's focus is on optimizing the design of the front and rear wings of the vehicle. The rest of the race car is considered as fixed during the study.
Traditionally, the aerodynamic design pipeline follows a sequential process (illustrated in black), where 2D parameterized CFD simulations explore the design space to achieve optimal results. A few 3D CFD simulations are then run for validation before the components are manufactured and experimentally tested in wind tunnels.
However, FUSION proposes a new paradigm (illustrated in blue), where AI, particularly deep learning techniques, enables the simultaneous integration of CFD and experimental data. This approach allows for the creation of fast and accurate surrogate models of the aerodynamic behavior, which can be efficiently deployed in gradient-based optimization algorithms.
The primary outcome of this research project is the development of this AI-driven optimization pipeline. This framework will not only enhance future designs for the Formula Student club at ISAE-SUPAERO, but also contribute to academic research at DAEP, providing valuable tools for aerodynamics and design optimization.

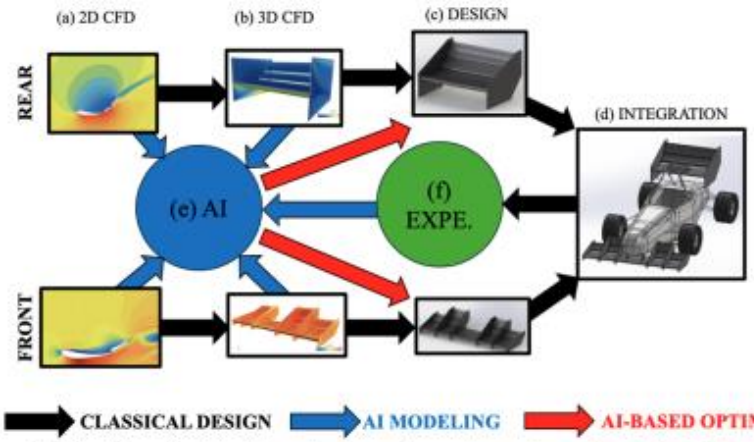

Fig. 1: Classical sequential pipeline (in black) to design a formula student, involving 2D (a) and 3D (b) CFD, from which best candidates are manufactured (c) to be tested experimentally in wind tunnels (f). Each optimized components are then integrated on the final design (d). FUSION introduces AI (in blue) to gather multiple low and high-fidelity data, from both CFD and experiment, to create fast and accurate surrogate modeling. AI-base models allow efficient gradient-based optimization (in red) to optimize the car's components, here the front and rear wings.

Roadmap
This research project focuses on the exploration and development of the **FUSION** concept, an AI-based optimization pipeline for aerodynamic design in Formula Student vehicles. Building on previous works conducted at the DAEP department, which utilized CFD data and genetic algorithms for optimization, as well as recent advancements in AI-driven optimization [1, 2, 3], this project aims to integrate these approaches into a unified framework. The roadmap for the project is outlined as follows:

1. **Literature Review**: A comprehensive review of current research on deep learning techniques for surrogate modeling and optimization will be undertaken. The review will cover various neural network architectures (such

as MLP, Graph Networks, Implicit Neural Representations) as well as techniques for combining simulation and experimental data, known as data fusion). Uncertainty estimation and multi-fidelity methods, with a focus on transfer learning and active learning, will also be considered to enhance the robustness of the approach.

2. **2D Simulations**: Initial simulations will be performed on downscaled 2D front and rear wings with parameterized shapes, using Reynolds-Averaged Navier-Stokes (RANS) models. Particular attention will be given to mesh convergence and CFD quality. Existing setups from the Formula Student club can be leveraged to accelerate this process.
3. **Developing the FUSION Code**: In parallel with the simulation work, the **FUSION** code will be developed in Python. The framework will be designed to accommodate various meshing tools, CFD solvers, and optimization algorithms as backends. Several foundational components already exist, either in Python or Matlab, which will be adapted and integrated into the pipeline.
4. **Optimization Using FUSION**: Once the 2D simulations and FUSION code development are completed, the pipeline will be employed to automatically generate a dataset from the 2D simulations. This dataset will be used to train a deep neural network, which can then serve as a fast surrogate model for aerodynamic evaluations. The trained network will support optimization processes using either genetic algorithms (e.g., NSGA-II) or gradient-based optimization methods.
5. **3D Simulations and Experimental Validation**: Depending on the maturity of the solution, 3D simulations will be conducted on the full vehicle with the optimized front and rear wings. The final configurations can be 3D printed, allowing for experimental validation in a wind tunnel to confirm the performance of the downscaled optimized vehicle. This step will provide a critical link between simulation-based optimization and real-world aerodynamic performance.

LILIENTHAL WP5-2026-2027: Focus on AI methods for OAD & project data management

Description:

The new Lilienthal meta project aims at gathering all ISAE-SUPAERO projects related to glider/motorglider design. Following an initial initiative, the EUROGLIDER project – an electric two-seate motorglider of the CS22 category -, ran from 2014 to 2023 and was based on a partnership between the ISAE institutions and an external association closely linked to the gliding community. A full size test bed - testing the energy & engine chain – was flown in 2019 but ultimately the project stalled because of a lack of industrial funding. Therefore a new project, called Lilienthal, was launched in 2024, specifically targeted to the pedagogical needs of the ISAE institutions which are wrapped in the so-called Design-Build-Fly paradigm:

The selected “starting point” is now an aircraft of the microlight category, called Gaz’Aile2 (http://gazaile2.free.fr/). In parallel to the prime target of manufacturing that reference aircraft (several years effort), the design part of the project will be to study several changes to the initial aircraft. This project LILIENTHAL WP6-2026-2027 will be specifically dedicated to the potential use of AI tools for: (a) consolidation of data set for OAD studies, in the specific situation of a light aircraft inverse design / design, (b)the harnessing and consolidation of input/output data of the Lilienthal project.

Objectives:

o Literature review of AI tools adapted to the generic requirements and proposal of a more precise definition of operational needs (capture of requirements). The tools explored could be – among many others -: https://www.litmaps.com/ , https://notebooklm.google/ , https://supaerodatascience.github.io/deep-learning/ , https://localai.io/ ...;
o Study and evaluation of methods on how to significantly improve the quality and quantity of data used in Overall Aircraft Design, for example in relation design codes such as FASTOAD-CS23 aircraft design code (https://github.com/supaero-aircraft-design/FAST-GA);
o Proposal of an aligned data management system for the Lilienthal community;
o To summarize the methodology and findings into a competitive research paper (hints on novelty: AI tools for OAD & DBF communities);
o Typical output: requirements & “sourcing” of a candidate system.

Bio-inspired morphing for efficient and robust gliding - Design Build and Fly

This is the "Design Build and Fly" aspect of the project **Bio-inspired morphing for efficient and robust gliding** (page 110)

Droplet evaporation models for rocket applications

Description:

The study of droplets evaporation is of interest for many applications going from mechanical engineering, chemical processes to natural sciences. This motivates many studies and research that are devoted to their characterization. But despite these large efforts some questions remain opened particularly related to specific conditions for which evaporation phenomena are not clear: high pressure and high temperature conditions.
Droplets evaporation at high pressure can occur typically in liquid rocket engines. To simulate numerically combustion chambers in such conditions, we rely on CFD models using typically Lagrangian approaches to describe sprays. These incorporates models providing the evaporation rate of the droplets and their drag coefficient. However, the models used to describe the droplets evolutions are typically based on models valid from low pressure conditions. Recently some models including real gas effects and eventually non equilibrium approximation have been proposed.
The objective of the present research project is to develop a 1D numerical code for a single droplet evaporation able to reproduce low- and high-pressure conditions starting from available models present in literature. It is the continuation of an ongoing MAE RP (2024-2026).

Development:

- *Bibliography:* overview of available evaporation models in the literature dealing with high pressure conditions and real gas modeling
- *Development:* implement the models in python
- *Analysis:* compare the models and their prediction in different conditions

Analog Missions for Preparing Lunar and Martian Exploration

Description:

As most of the space industry turns towards the Moon in anticipation of the Artemis program, most space agencies and other sector stakeholders are seeking to support upcoming crewed missions. In this context, several system concepts are currently under study. Before being deployed, these systems will undergo qualification on Earth.
Furthermore, future astronaut crews are trained using tools, infrastructures, and environments that are as representative as possible of those they will encounter on the Moon and on Mars.
Analog missions, of varying duration, are organized to simulate future robotic and crewed missions. They provide a valuable framework for astronaut training, equipment qualification, and operational concept development.
Various facilities and sites are used in different countries.
CNES supports and conducts analog simulations: ISAE-SUPAERO teams test prototypes from *Spaceship France* project within the MDRS (Mars Desert Research Station) during annual four-week analog missions; simulations of Martian surface extravehicular activities are conducted in the SENS facilities in Toulouse (SENS – Environmental and Neuro-Sensorial Simulation – EUROSATORY).

Since 2016, ISAE-SUPAERO has been sending a crew of seven analog astronauts to the MDRS every year at the same period, to conduct a four-week Mars simulation. In 2027, the thirteenth crew from the school will conduct scientific experiments and technology demonstrations, with various partners, including research institutes and space agencies, such as *Spaceship France*. The best example of collaboration between *Spaceship France* and ISAE-SUPAERO crews is EchoFinder. This medical imaging system aims to help astronauts perform ultrasounds autonomously, without medical expertise and ground support. Using augmented reality for real-time probe guidance and AI-based organ recognition, it ensures high-quality medical imaging even in microgravity. Tested by ISAE-SUPAERO crews at the MDRS from 2022 to 2024, it will be deployed aboard the International Space Station in 2026 by French astronaut Sophie Adenot, as part of the Epsilon mission.

CNES aims to become more involved in analog missions and to establish an appropriate organizational structure to:
Guide partners towards the right simulation and suitable infrastructures based on study, technological demonstration, and qualification needs,
Implement relevant scenarios in collaboration with the managers of the various areas (infrastructure, instruments, prototypes, studies, etc.),
Develop scenarios with stakeholders,
Provide support during the execution of simulations,
Analyze data and feedback to drive improvements.
The project aims to:
Establish a state of the art of existing analog missions and available resources,
Consult experts and gather best practices and recommendations,
Propose an organizational structure,
Conduct a first trial of this organization with the ISAE-SUPAERO student mission to the MDRS planned in February 2027,
Conduct a first trial of this organization with the next simulation at SENS.

Angiology in Microgravity (AIM)

Description:

Space exploration poses a threat to human health through factors such as reduced gravity loading, radiation and confinement. In 2019, a blood clot was identified in an astronaut's internal jugular vein by accident, during an experiment. Since then, several cases of reverse flow and stagnation patterns have been reported during medical check-ups. This problem raises serious concerns as the detachment of a blood clot could lead to a pulmonary embolism, a pathology that cannot be treated in space. Space agencies, including the European Space Agency, have thus established a task force to investigate this issue and understand how to prevent this phenomenon from happening during a longterm mission.

Objectives:

In this context, ESA Young Professionals are currently working on an experiment named Angiology in Microgravity (AIM), as part of the YPSat-2 program. This payload, which is the continuation of Artery in Microgravity, an experiment developed by students from ISAE-SUPAERO, aims to study haemodynamics in space conditions. It will investigate changes and disturbances in the internal jugular vein blood flow, as well as wall distention induced by long-term exposure to the space environment, with a specific focus on the deep vein thrombosis (DVT) pathophysiology. As DVT is considered one of the most critical risks associated with long-duration missions, it needs to be further investigated to facilitate the search for prevention plans and potential treatments. The payload, which should be launched into space late 2027 during the maiden flight of Space Rider, thus aims at understanding the blood clot formation process in microgravity. Moreover, the AIM experiment will serve as a technology demonstrator for the Particle Image Velocimetry (PIV) technique, that for the first time will be implemented in space to study blood flow dynamics. The research holds potential benefits for terrestrial medicine, as cardiovascular disease stand as the leading global cause of death.

The payload will therefore be built in collaboration with ESA medical team and two institutions:
- The Biomedical Engineering Laboratory team of Politecnico di Torino provides expertise and experience in both designing and operating cardiovascular experiments;
- ISAE-SUPAERO is actively supporting AIM with expertise and experience related to the design of Artery in Microgravity, providing Master's students to support externally the project within the scope of their studies.

Experimental setup:

The experimental setup aims to replicate the system in a simplified way. It includes a reservoir which will host the blood mimicking fluid (made of a water-based background and red blood cells replica), a peristaltic pump regulating the flow rate, the internal jugular vein phantom, a control valve regulating the pressure, as well as sensors required to collect meaningful data. To perform PIV, a high-speed camera will be placed at a right angle to the vein, which will be illuminated by a laser. The images obtained will be used to reconstruct the velocity path of the blood-mimicking fluid particles. A lowspeed camera will allow to obtain 2D measurements of sedimentation, as well as potential clotting or stagnation patterns, observed along the vein. LEDs will be used to ensure the camera has enough light to perform its duties.

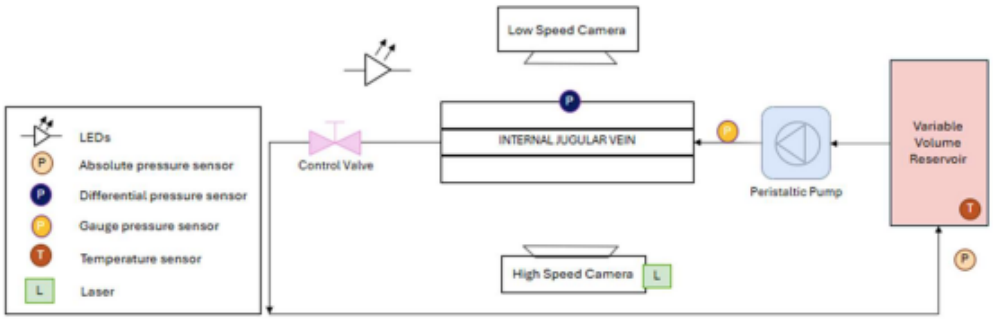

Figure 1 - AIM experimental setup

HERA-WP1-2026-2027: High Aspect Ratio Wing for Future Regional Aircraft

Description:

The new HERA meta project aims at gathering all ISAE-SUPAERO projects related to regional type aircraft design. From some years, ISAE-Supaero has worked with ATR on hybrid regional aircraft and a specific aircraft design platform FAST-OAD-CS25/RTA has emerged from that work. It is very likely that this type of work will be extended through futures collaborations with ATR and other EU partners (new Clean Aviation project HERA).

The purpose of this project is to explore the potential of high-aspect-ratio wings to reduce the environmental footprint of regional aircraft through an innovative Overall Aircraft Design (OAD) approach. Due to their inherent structural complexity, new methods need to be developed to account for the strong coupling between aerodynamics and structures in the wing sizing process. Owing to its flexibility, low computational cost, and validated results against high-fidelity data, OpenAeroStruct has been selected as the reference aerostructural optimization framework. Originally developed for conventional configurations, work is currently underway to extend its capabilities to strut-braced wing configurations and integrate it with FAST-OAD-CS25/RTA for an innovative and integrated OAD approach for regional HAR wings concepts.

Objectives:

o To complete an updated literature review on specific OAD strategy and results for future aircraft concepts: this is a key step as a very substantial effort is currently made all across Europe to demonstrate the feasibility of a new generation of Regional Aircraft.
o To review the specific aspects of high-aspect-ratio wing concepts, with a focus on strutbraced and joined-wing configurations.
o To explore the implementation of joint wing model into OpenAeroSturct.
o To attempt an OAD optimization for low environmental joint-wings/high aspect ratio wing regional aircraft, using the RTA-FAST-OAD code, currently modified for interfacing with OAS code.
o To summarize the methodology and findings into a competitive research paper (hints on novelty: use of high aspect ratio wing for regional aircraft)
o Typical target of publication: EASN conference

Design and Analysis of a Lunar Communication and NPT Constellation for South Pole Rover and Lander Missions

Description:

Lunar exploration is entering a new phase of sustained robotic and human activity, driven by international programs such as NASA's Artemis, ESA's Lunar Pathfinder, and multiple commercial missions. The Moon's south polar region, in particular, has become a primary target due to its scientific relevance and the presence of permanently shadowed areas that may contain water ice. As mission complexity increases, current Earth-based communication and navigation support is no longer sufficient to guarantee continuous, reliable, and high-accuracy operations on the lunar surface. These limitations highlight the need for a dedicated lunar satellite constellation capable of providing robust communication links and precise Navigation, Positioning, and Timing (NPT) services to landers, rovers, and future surface infrastructure. Establishing such an orbital system is a key enabler for long-term lunar presence and represents a fundamental step toward a sustainable exploration architecture.

Establishing a sustained presence on the Moon requires continuous communication links, reliable Navigation, Positioning, and Timing (NPT) services, and robust data transfer between surface assets and orbital infrastructure. This is particularly challenging at the lunar south pole, where extreme topography, persistent shadowed regions, and variable visibility limit direct line-of-sight communication. Terrain-induced signal blockage, multi-path effects, and intermittent orbital coverage degrade both communication and navigation performance. Developing a dedicated lunar satellite constellation can overcome these constraints, providing persistent coverage, accurate NPT services, and a reliable communication backbone for both surface operations and orbital relay.

Key Points of the Project:

The proposed research focuses on the design and analysis of a lunar satellite constellation aimed at providing robust communication and Navigation, Positioning, and Timing (NPT) services for operations at the lunar south pole. The primary goal of the project is to develop an integrated constellation architecture capable of supporting both surface assets—such as rovers and landers—and potential future bases, ensuring maximized coverage with minimal communication gaps, accurate navigation, and reliable data exchange despite the unique environmental and geometric challenges of the region. The project emphasizes two main technical domains. First, the orbital design of the constellation, which includes determining optimal orbital parameters, satellite numbers, and configurations to guarantee persistent coverage of the south polar region while accounting for topographic shadowing, lunar gravity perturbations, and line-of-sight constraints. This analysis aims to ensure that satellites provide uninterrupted links both among themselves and with surface assets, enabling precise time transfer and navigation support. Second, the research addresses the design of the communication subsystem, considering both hardware and software aspects. This includes evaluating link budgets, waveform design, antenna configurations, and signal processing strategies to mitigate terrain-induced signal loss, Doppler shifts, and multipath effects. The study also integrates navigation functionality, using the constellation both as a communication backbone and as a provider of accurate positioning and timing services for surface operations. By combining orbital optimization with a robust communication and navigation design, the project aims to provide a comprehensive dedicated framework for a lunar constellation that can overcome current limitations in lunar connectivity and positioning, paving the way for sustained and autonomous operations on the Moon.

Objectives of the Project:

The primary objective of this project is to design and analyze a lunar satellite constellation that provides reliable communication, navigation, and positioning services for operations at the lunar south pole. The work aims to deliver a comprehensive framework integrating orbital architecture and communication system design, with particular attention to the constraints imposed by lunar topography, shadowed regions, and the limited number of satellites that can be deployed without overloading surface resources. The project tasks can be divided into two main domains: Mission Analysis and SANS-related design tasks.

Mission Analysis: This component focuses on the evaluation of various orbital options to optimize coverage of the lunar south polar region. Initial modeling starts with simplified 2 assumptions regarding satellite motion and visibility,

progressively introducing real mission perturbations such as lunar gravity anomalies, orbital eccentricities, and line-of-sight restrictions due to terrain. A key goal is to minimize the total number of satellites while ensuring sufficient coverage and connectivity for both rovers and landers, thus avoiding unnecessary saturation of lunar orbits while maintaining mission effectiveness.

SANS-related design tasks:

This domain addresses the communication and navigation system design, leveraging knowledge from courses such as wireless transmission techniques, random signal processing, and satellite-based navigation.

Main tasks include:

- Design of the communication subsystem: including link budget analysis, antenna and transceiver design, power allocation, and frequency selection. The design must account for lunar-specific challenges such as high path losses, absence of atmospheric propagation, and thermal/environmental constraints on surface hardware.

- Signal design considering lunar topography: developing waveforms and modulation schemes that are robust to signal blockage, multipath effects, and Doppler shifts due to satellite motion. Special attention will be given to ensuring reliable signal acquisition and tracking for surface assets in shadowed craters and uneven terrain.

- Navigation and positioning algorithms: implementing strategies for accurate positioning and timing, integrating inter-satellite links, satellite-to-surface measurements, and signal processing algorithms. The goal is to provide precise Navigation, Positioning, and Timing (NPT) services to surface rovers, landers, and potential future bases, compensating for the absence of Earth-based GNSS support.

Together, these tasks aim to produce a holistic design of a lunar satellite constellation that can support both communication and navigation operations in one of the most challenging environments in the solar system, providing a foundation for sustained lunar exploration.