MOREALIS – A HOLISTIC APPROACH TO ENHANCE SAFETY FOR MICRO-AIRCRAFT OPERATIONS

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Abstract

Introduced by various European Union member states in recent years, the very lightweight, single-seat micro-light aircraft category (the German "Leichte Luftsportgeräte"-class), with an empty mass of up to 120 kg gained broad popular interest. This is probably caused due to the fact that this class envisions the basic ideas of recreational flight: simplicity through strict weight limitation and low administrative effort, thus low acquisition and operational costs. Furthermore, "LL" aircraft are not required to undergo annual inspections, whereas pilots of this aircraft category are not obliged to pass annual medical examinations, but remain self-responsible for these matters. Despite massive improvement in safety features for general aviation over the last decades, serious or even fatal accidents remain one of the major concerns and require constant improvement. Taking these conditions into account, the *MOREALIS* project aims towards increasing safety for "LL" aircraft configurations by means ranging from improved structural concepts of the airframe, aircraft and pilot health monitoring up to fault-tolerant flight control laws and finally a dedicated automatic emergency landing procedure. This paper therefore presents an overview of the employed methods and respective partner contributions.

Keywords: Ultralight aviation; Pilot state monitoring; Aircraft fault detection; Flight Control; Trajectory Planning

1 Introduction

The class of "Ultralight Aircraft" (UL) within the range of general aviation is characterized by narrow weight margins (e.g. 472.5 kg maximum takeoff weight (MTOW) in Germany), low hurdles for pilots, manufacturers and authorities. The certification of UL aircraft therefore follows a reduced set of structural and operational requirements (i.e. the German *"Bekanntmachung von Lufttüchtigkeitsforderungen für motorgetriebene, aerodynamisch gesteuerte Ultraleichtflugzeuge" (LTF-UL)* as described in [1]), which are compensated for by prescribed total recovery parachute systems (see *§3 Betriebsordnung für Luftfahrtgerät (LuftBO, Germany)* to be used in case of emergency. Taking the concept of simple recreational aviation to the top, the sub-scale class of single seat, UL-aircraft has been introduced in many European countries over recent years. For example, the German "LL"- or “Leichte Luftsportgeräte”-class, as defined in *§1 Luftverkehrs-Zulassungs-Ordnung (LuftVZO, Germany)* and [2] allows for an empty weight of 120 kg, requires only basic examination ("Musterprüfung") of the type aircraft, and no annual inspection of aircraft and pilot. Therefore, the final responsibility lies

with the owner/pilot w.r.t. aircraft technological and the pilots' medical/cognitive fitness. Furthermore, UL-pilots are considered to be less trained, which influences the general situational awareness and capabilities in case of stress and emergency situations.
Most notably, the number of micro-light aircraft over recent years is continuously rising, due to the attractive conditions mentioned above (see Figure 1).

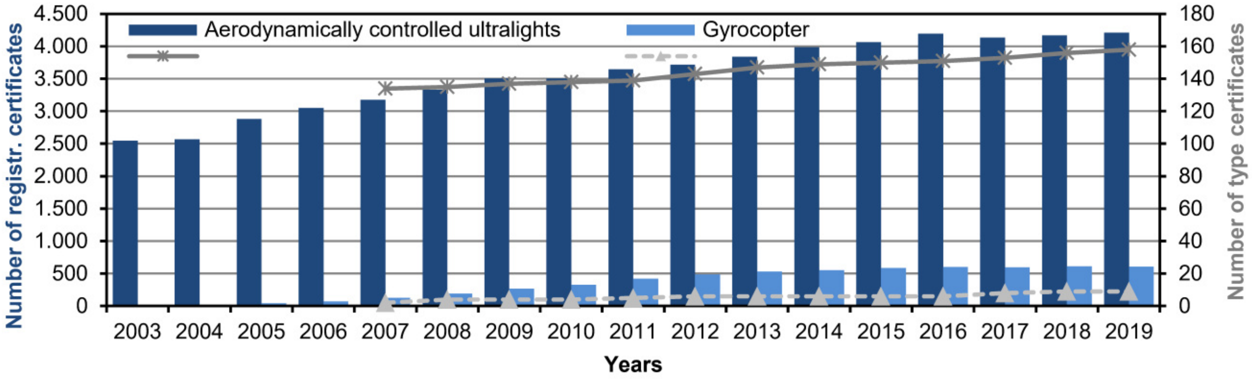


Figure 1 – Registration and type certificates (issued by DAeC) of aerodynamically controlled ultralights and gyrocopters, 2003 and 2019 - Figure taken from [3], © Copyright Federal Bureau of Aircraft Accident Investigation (BFU)

However, this trend comes at the expense of the highest safety requirements typical for aviation, as can be seen in a compilation on UL-class accidents published by the "German Federal Bureau of Aircraft Accident Investigation" [3].

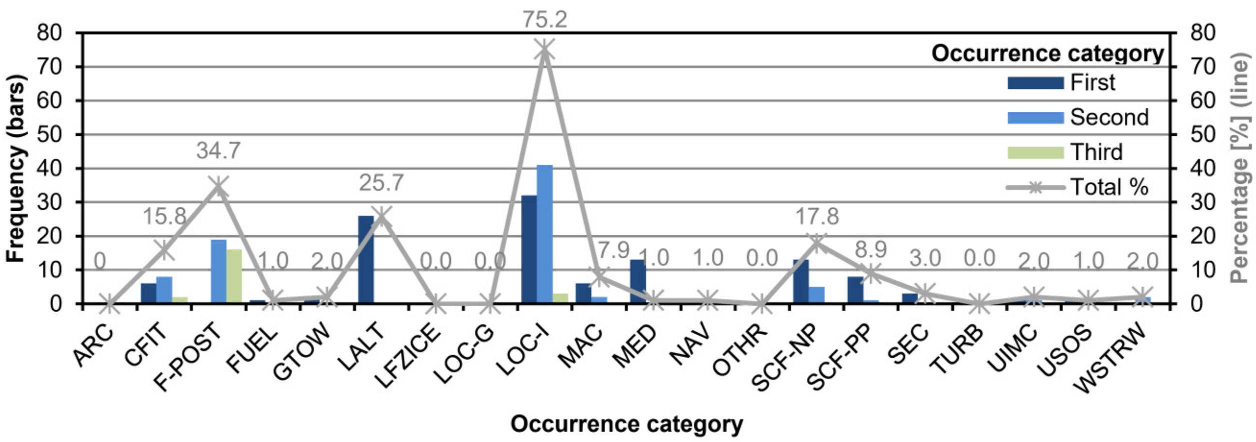


Figure 2 – Occurrence categories of investigated fatal accidents involving air sports equipment, 2000-2019 - Figure taken from [3], © Copyright Federal Bureau of Aircraft Accident Investigation (BFU)

It is clearly visible, that for example the categories "LOC-I" (Loss of Control - Inflight), "LALT" (Low Altitude Operations), "MED" (Medical) and "SCF-PP" (Loss of Power Plant) pose the biggest accident risks in-flight. The color-coded "Ereigniskategorie" (category of event) features thereby the sequence of events: First category ("Erste") is defined as the first incident, potentially followed by secondary and tertiary events (marked with "Zweite" and "Dritte"). In general, "Loss of Control" is significantly leading to lethal accidents.

As noted before, the simplifications w.r.t. UL-/LL-class regulations are compensated for by the obligation to have an emergency parachute (i.e. a "ballistic recovery system", BRS) on board. This

represents the last resort in a critical situation, most likely causing the destruction of the aircraft. However, this system also has certain disadvantages: On the one hand, when the BRS is employed the aircraft is in an uncontrolled descent and can possibly drift into danger zones (e.g. high-voltage power lines, populated areas) under unfavorable wind conditions. On the other hand, triggering this recovery system can also fail in the event of a medical emergency or cognitive overload of the pilot, as it requires the activation by the pilot. There is therefore a residual risk.
The *MOREALIS* research project aims to address these aspects by providing an intermediate means for emergency situation handling. This can be achieved by combining a health monitoring and troubleshooting system for both the pilot and the aircraft. In cases, where the aircraft is still capable to perform "near nominal" flight maneuvers, this system is intended to prevent the premature use of the ballistic recovery system and perform an emergency descent to a feasible landing strip. In order to achieve the project goals, the following aspects have to be addressed:

1. Monitoring of the aircraft flight state (sensor based fault detection)
2. Sensor-based monitoring of the pilot medical state
3. Interactive determination of the pilot cognitive state
4. Fusion of the available information (e.g. "nominal/near-nominal flight", "degraded aircraft", "pilot incapacitation", "catastrophic conditions") and deducing potential mitigation strategies
5. In case the aircraft allows for "near nominal" flight (only light degradation w.r.t. flight controls), or "loss of power" and pilot stress/incapacitation an automated emergency landing system is proposed
6. The aircraft structure itself needs to be adapted in order to withstand potential emergency landings (e.g. "crash-safe cockpit")

The basic spark for the structure of the *MOREALIS* project was to set up a dedicated LL-class aircraft - namely the *MORFOIS* aircraft configuration, which serves on the one hand as an integration platform for all relevant methods as described and on the other hand aims for the introduction of a new approach to cockpit design within the aircraft design process - providing a strong emphasis on pilot safety in case of a crash.

Figure 3 – Rendering of the *MORFOIS* LL-aircraft within the *MOREALIS* project

The aircraft features the use of a contemporary layout, advanced carbon-fiber-reinforced (CFRP) structure and the mentioned “crash-safe” cockpit (see Section 2). Figure 3 shows the conceptual design of the *MORFOIS* aircraft. Furthermore, a mixed flight control layout is introduced – allowing for auto-flight, as well as pure manual flight, with the pilot being capable to over-steer the automatic flight inputs (see Section 3.2). This means that the classic control surfaces (i.e. aileron, elevator, and rudder) are each split into two surfaces. One is connected reversibly via cables and rods and

used for manual control of the pilots. The other part is equipped with electro-mechanical actuators. The developed flight control system therefore needs to handle the split-flap setup (i.e. cope with simultaneous pilot inputs on the mechanical surfaces) and needs to be robust to failures on the airframe, the sensor and actuator system, and the propulsion. This motivates the use of a hybrid nonlinear dynamic inversion-based control law ([4, 5, 6]) since it inherently compensates disturbances and can handle sensor and actuator failures well.
Based on the dedicated aircraft design, the automated emergency landing system is therefore intended to potentially reduce the necessity for the ultimate activation of the ballistic recovery system. Figure 4 shows the numerous blocks - featuring employed methods and disciplines.

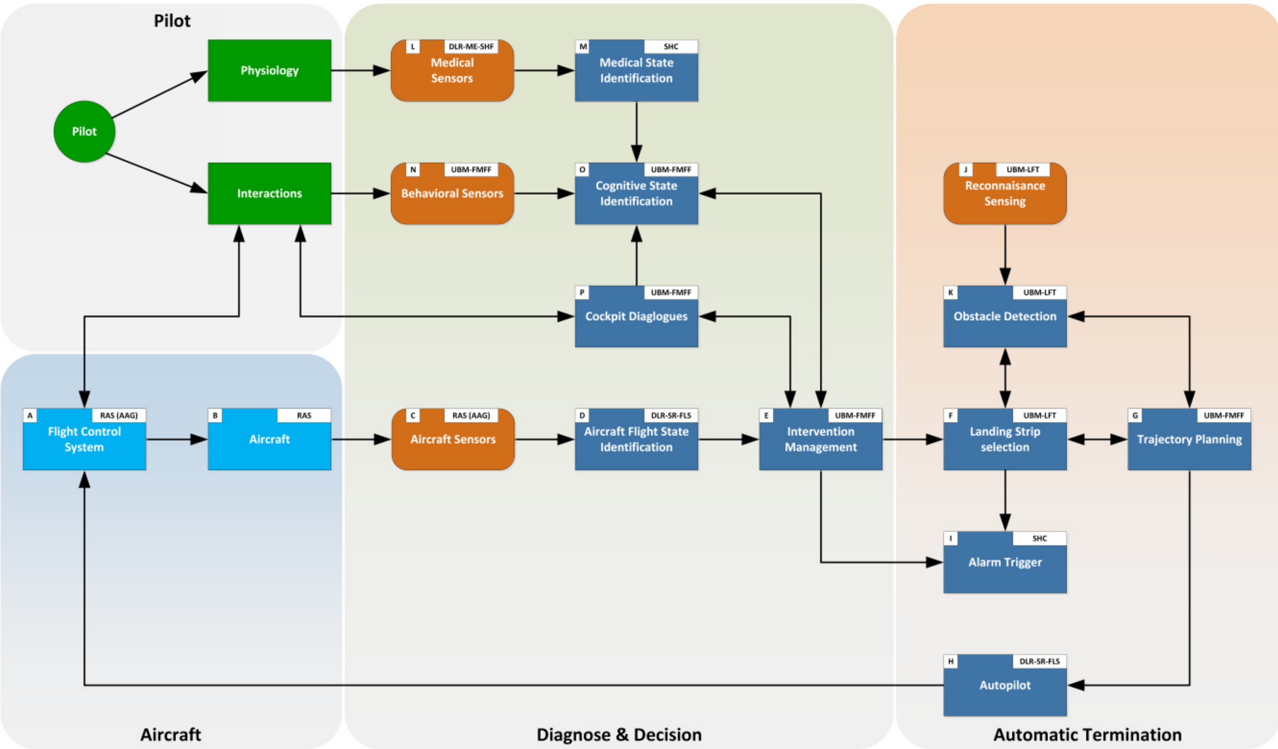


Figure 4 – *MOREALIS* block diagram with automatic emergency descent procedure

- Aircraft related: The blocks designated "A"-"D" and "H" describe the aircraft platform as well as the data flow for the flight control system (FCS), and fault detection, isolation and recovery (FDIR) systems.
- Pilot related:
  - Mental state: The blocks "N", "O" and "P" aim to determine the pilot mental state by means of an interactive process.
  - Medical state: The blocks "L" and "M" facilitate medical sensors and analysis software for the determination of the pilot medical state.
- Intervention Management: Block "E" combines all relevant data sources from aircraft related to medical/cognitive states and aims at the determination for subsequent action:
  - In case only minor degradation is observed, the flight is most likely proceeding "as-planned" or slightly altered.
  - If more severe aircraft degradation is observed (e.g. loss of engine power), the emergency descent procedure is almost immediately triggered
  - Based on the medical and cognitive state of the pilot - as well as the general aircraft state, cockpit dialogues are triggered. If these do not yield sufficient results, the emergency

descent is triggered. An emergency landing is considered beneficial compared to the ballistic recovery system, as it allows for a planned descent (e.g. easy-access for rescue workers, obstacle-free landing).

  - In case of catastrophic degradation of the aircraft (e.g. loss of control, control surface degradation, stalled aircraft), the ballistic recovery system is triggered semi-automatically. The pilot remains in the loop and has to agree to this measure. Furthermore, the pilot can freely trigger the recovery system at any given time - in line with current UL-/LL-class regulations.

- As soon as the "Intervention Management" triggers the emergency descent, the execution of the respective methods is initiated - see blocks "F"-"G" and "I"-"K". A sequence of actions is performed:

  1. Determination of the current aircraft state (w.r.t. degradation, flight performance)
  2. Communication of the altered aircraft flight performance and dynamics parameters to the trajectory planning and flight control components
  3. Selection of pre-planned landing strip and associated trajectory
  4. If applicable: Reconfiguration (control surface allocation, individual gains & limitations) of the flight control law (FCL)
  5. Communication of information on the detected anomalies and provide guidance to the pilot – these can be rejected within a limited time-frame
  6. Activation of the autopilot, following the continuously updated trajectory to the selected landing strip
  7. Declaration of emergency (transponder, ADS-B if available)
  8. In parallel: Continuous monitoring of the landing strip via gimbal w.r.t. upcoming obstacles and of the pilot's cognitive and medical state
  9. Automatic air traffic control (ATC) information, as well as information of medical services, in case of pilot incapacitation

The following sections are intended to provide an overview of each partners' workshare within the *MOREALIS* project:

- SFL Gmbh in Stuttgart, Germany, is in charge of the overall project lead and aircraft conceptual design for the *MORFOIS* "LL" platform. A short overview of the contributions in the context of the *MOREALIS* project can be seen in Section 2.

- The associated partner Rödel Aircraft Systems (RAS) in Mattsies, Germany initiated the *MOREALIS* project.

- The German Aerospace Center (DLR) is participating with two institutes:

  - The Institute of System Dynamics and Control (DLR-SR) in Oberpfaffenhofen, Germany, is responsible for the flight dynamics, fault detection and flight control aspects of the *MORFOIS* flight vehicle. An overview is available in Section 3. For further insight, the two associated publications [7] and [8] are recommended.
  - The Institute of Aerospace Medicine (DLR-ME) in Cologne, Germany, aims at the determination of feasible medical sensors for the utilization within the LL-aircraft class. An overview on the respective work is available in Section 5 and publication [9].

- Amazilia Aerospace GmbH (AAG) in Munich, Germany, supports the partners in the determination of a feasible Flight Control architecture. AAG is therefore closely collaborating with SFL and DLR-SR. An overview of the respective work is available in Section 3.3.

- The University of the Bundeswehr (UBM) at Neubiberg, Germany, is present with two professorships:
  - The Chair of Aircraft Dynamics and Flight Guidance (UBM-FMFF) is working in the field of monitoring the pilot mental state / cockpit interaction, as well as the flight guidance, including the generation of flight trajectories for the emergency descent. An overview on these matters is available in Section 4 and the closely associated paper [10]. Previously published works on using automated planning for context-rich flight guidance can be found in [11] and [12], while the development of a goal-oriented cockpit dialog was published in [13].
  - The Chair of Aeronautical Engineering (UBM-LFT) focuses on two main tasks: The determination of feasible landing strips for the aircraft (e.g. fields, grassland and also available air strips) prior to the flight and the selection & ranking of a subset of distress dependent, suitable landing sites, as well as their continuous monitoring before/during the emergency descent. An overview of these matters is available in Section 6 as well as in the associated paper [14].
- Star Healthcare GmbH in Cologne, Germany, utilizes the available medical data in a dedicated software product for the determination of the pilot medical state. A short introduction to the associated topics is available in Section 5.

2 Design of the *MORFOIS* aircraft

One of the main purposes of the developed *MORFOIS* Ultralight Aircraft in the context of the *MOREALIS* project is to provide a dedicated platform for which the other systems are developed and shaped. Additionally, *MORFOIS* is also an aircraft for which several other innovative features are projected. While some of the these, like the detachable wing and horizontal stabilizer, serve simple operational purposes, there are also some features that are aimed to enhance the safety of the aircraft for enhanced handling qualities at the aerodynamic limits (stall-resistant wing design), in the event of emergencies (ballistic recovery system) or even in a crash scenario (cockpit with reinforced survival cell and additional passive safety features). Figure 5 shows the overall design of the aircraft and its basic features including a representation of the split electrically and mechanically actuated control surfaces.

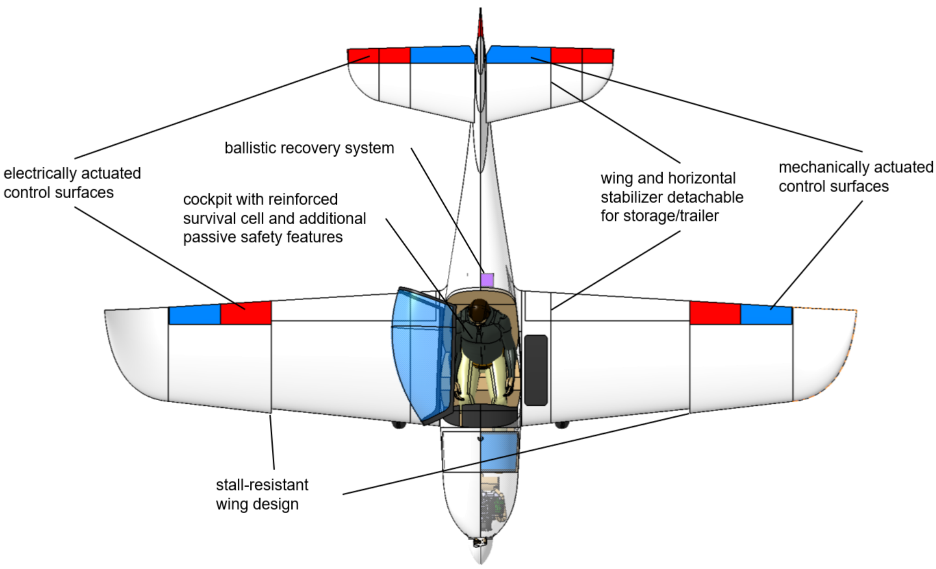


Figure 5 – General overview and basic features of the *MORFOIS* Ultralight Aircraft

The basis for the selection of passive safety features for *MORFOIS* is a research study commissioned by the German Federal Ministry of Transport, Building and Urban Development (BMVBS) from 2007 [15] where (among other sources) aircraft accident reports and statistics are evaluated in order to identify statistically relevant causes for aircraft accidents, resulting injuries and fatalities. In this study, recommendations for passive and active measures to enhance pilot and passenger safety in small aircraft are concluded from the evaluated data. Because this study is from 2007 the results are reviewed and supplemented by an updated evaluation of more recent aircraft accident reports and statistics during the course of the *MOREALIS* research project. From this, statistically relevant safety features are selected to be investigated for their suitability and feasibility in a 120 kg aircraft like *MORFOIS*. Figure 6 shows the preliminary subset of passive safety features that are considered for implementation into the aircraft design of *MORFOIS* with the main goal of implementing cockpit survival cell structure design approaches from other aircraft categories into the design of a 120 kg ultralight aircraft.

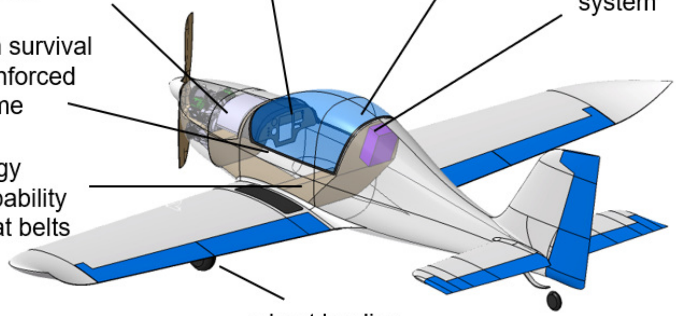


Figure 6 – Considered passive safety aspects of the *MORFOIS* ultralight aircraft

3 Flight dynamics model and control law synthesis

The class of single-seat micro-light aircraft is characterized by its low requirements on airworthiness, concerning both certification and maintenance. Despite the obligatory ballistic recovery system (i.e. parachute), there is a (high) risk for pilot, aircraft and third parties in case of failure. To address this, methods for aircraft monitoring, as well as recovery techniques for the event of failure - also known as fault detection, isolation, and recovery (FDIR) techniques - are developed and implemented in the course of the project. The aim is to facilitate a controlled and safe landing - even in case of flight performance degradation. Similarly, an automated emergency landing shall be conducted in case of reduced pilot capabilities or even in the case of incapacitation (see Sections 4 and 5). As laid out in Section 2, the integration of an electronic flight control system (FCS) for the considered class of aircraft is especially challenging due to weight constraints and redundancy requirements. However, electronically controllable surfaces are required to implement the automated flight controls for failure recovery and automated emergency landing. As a compromise, the vehicle is equipped with two separate flight control systems: a mechanical system for conventional pilot control, and a backup electronic system for automated rescue flight (compare with Figure 8). In addition to the development of FDIR algorithms, two key tasks are the modeling of the unconventional aircraft setup, as well as the assessment of control authority for both separate flight control systems.

3.1 Flight dynamics and performance assessment

Due to the simulation-based development approach, a representative flight dynamic model is essential for the project. The various applications of either open-loop or closed-loop flight simulations are as follows:

- analysis of flight performance and control authority,
- robust/adaptive control law development (see Section 3.2),

- development of fault detection algorithms,
- flight performance estimation in failure cases,
- cockpit assistance system for emergency situations (see Section 4),
- joint simulation, see Section 7.

In addition to the extensive use of the model, the unconventional split surface layout requires a strong focus on the model synthesis and assessment. The aerodynamic model is based on strip theory [16] and was verified with NEWPAN[1], which is based on the 3D panel method, see Figure 7.

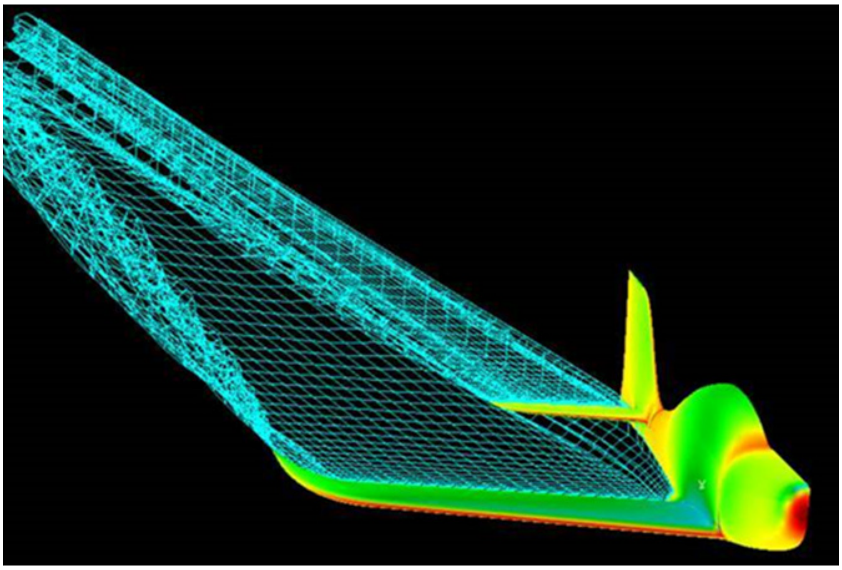


Figure 7 – Visualization of pressure distribution by means of aerodynamic panel method (NEWPAN)

A linear coefficient model is derived and extended by nonlinear relationships to cover off-nominal states, i.e. asymmetric control surface deflections under failure conditions. Furthermore, the weight and balance model captures the effect of variable payload and fuel, which has a significant impact for the type of micro-light aircraft. All sub-models provide interfaces to either trigger failure modes or to introduce uncertainty in the parameters, which allows to cover a broad range of different failure scenarios.

The parallel layout of mechanical and electronic flight controls allows to control the aircraft with each control system individually. In a first approach, the sizing of the split surfaces intends to share control authority equally between pilot and electronic FCS. However, we follow the philosophy to favor pilot controls over electronic control inputs if equality cannot be achieved. Consequently, the mechanic ailerons are positioned outwards, where the lever arm fosters control authority over inboard ailerons, and mechanical elevators are positioned inboard to address the spanwise lift distribution. Nevertheless, the central question for the layout remains, whether the remaining control surface size offers sufficient control authority for both pilot and FCS, and how the flight performance degrades in failure scenarios, i.e. hardover failures. This investigation is presented in [8].

3.2 Flight control law design

The flight control system is based on "Hybrid Nonlinear Dynamic Inversion" (HINDI), which allows a seamless degradation of the controller in case of failure. It is furthermore integrated with a control allocation (CA) scheme to handle the over-determination of control surfaces. While the reversible control system has three distinct inputs, the Fly-by-Wire (FBW) system has four/five. These are, two

[1] `http://www.flowsol.co.uk/` [Accessed: June 2024]

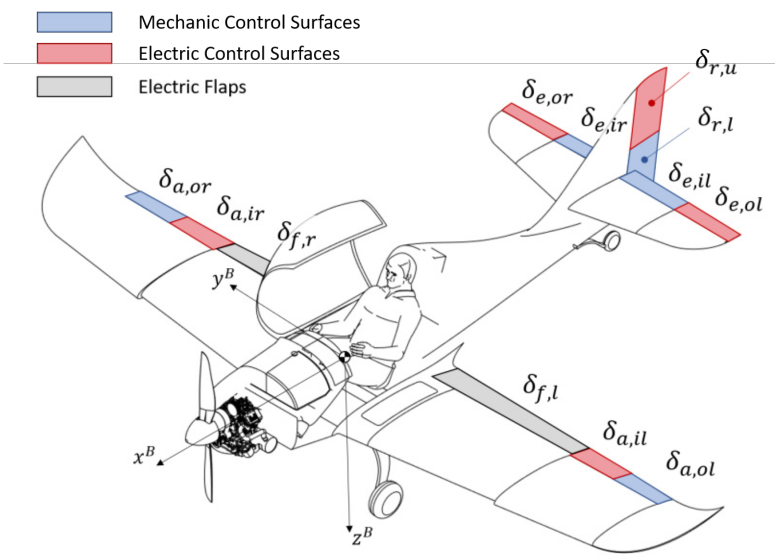


Figure 8 – Mixed flight control layout for ultralight aircraft *MORFOIS*

separate ailerons, one/two separate elevators, and one rudder. Controlling the speed through an auto-throttle is done in simulation, but will not be part of the final system as no actuation is intended there. An in-depth discussion of the employed control law architecture and applications are discussed in [7]. The employed control architecture is presented in Figure 9.

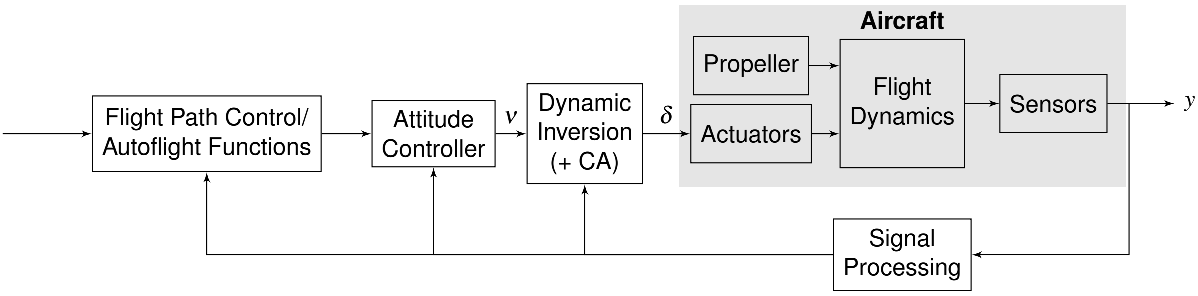


Figure 9 – Control architecture for dynamic inversion-based control system.

3.3 Flight control system design

In the context of the *MOREALIS* project Amazilia Aerospace supports mainly in the areas of:

- Design of an aircraft safety concept
- Definition of a control surface concept and selection of corresponding actuators
- Definition of overall system architecture
- Analysis of remaining continuous flight capabilities after a failure of the Automatic Flight Control System (AFCS) or pilot control inability

The parallel installation and operation of conventional mechanical and actuated control surfaces in a distributed control surface concept raises certain questions with respect to safe aircraft operation. Contradictory control authority requirements in case of AFCS failures or reduced pilot capabilities (even in the case of total incapacitation) require a thorough control surface sizing and control authority assignment to meet aircraft safety and overall project goals. Additionally, the micro-light aircraft category imposes strong limitations on acceptable costs and weight of components for the Fly-by-Wire (FBW) system, while meeting safety standards.

4 Pilot mental state monitoring and cockpit assistance system

Missing redundancy in the cockpit can be a severe safety issue in a single-seat ultralight cockpit, especially given the lenient medical and training requirements. However, this can be compensated with companion technologies (see [17, 11]), of which the emerging exploitation can be seen more frequently in safety-critical systems, such as a driving assistance system in automotive, but also as a pilot assistance system in modern aircraft (see [18, 19]).

FRICO (FRIendly COckpit assistance system) is a key safety feature of *MOREALIS* aimed at leveraging advancements made in companion technologies for making Single-Pilot Operations (SPOs) safer. FRICO adopts a modular architecture to increase its compatibility across platform interfaces, yet retains core functionalities to:

1. provide guidance,
2. be context-aware, and
3. adapt intervention.

Figure 10 depicts the modular system architecture of FRICO, of which the inter-modular communication in a lab setting is based mainly on a ROS2 backbone.

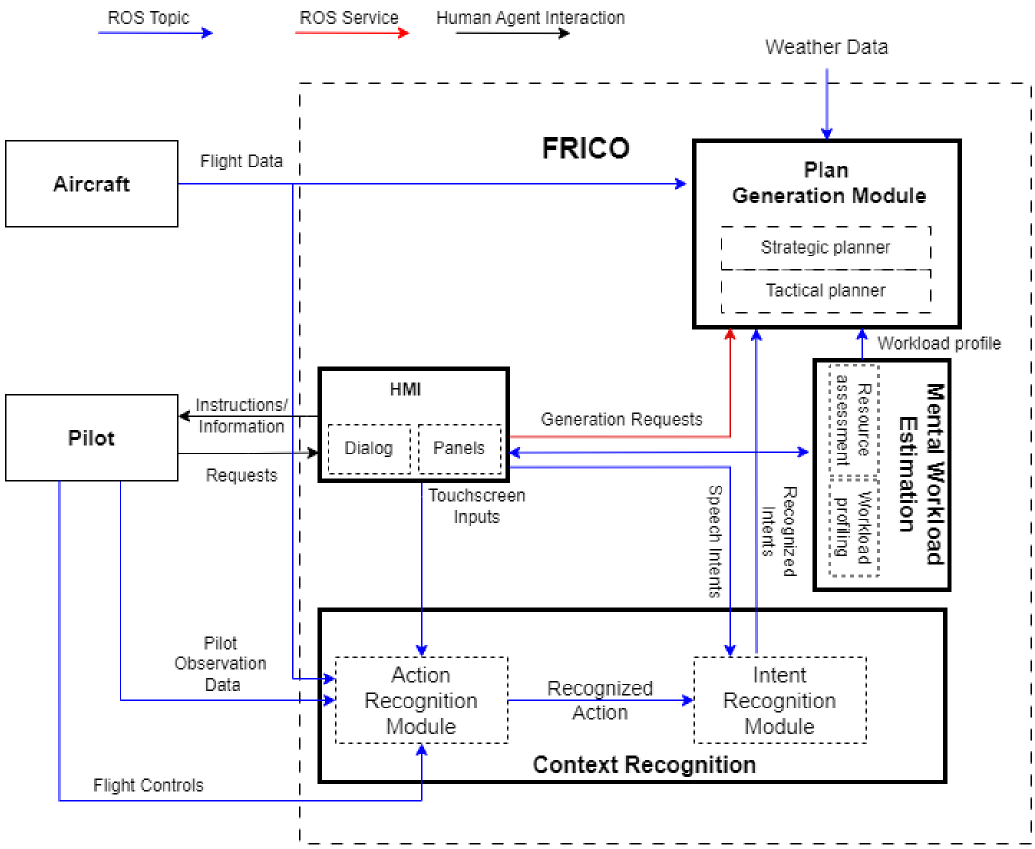


Figure 10 – Modular architecture of the assistance system for the cockpit of a single-pilot UL [20]

The Plan Generation Module (PGM) consists of two submodules, one for strategic planning, the other for tactical planning. PGM exploits AI-planning techniques for computing executable plan suggestions to guide the pilot (in case of emergency). While the strategic planner focuses on task planning using a Hierarchical Task Network (HTN) planner [12], the tactical planner refines the tasks into executable actions using a numeric planner. This division into strategic and tactical planning levels is to reduce the search complexity, so that the search of a plan in a finer discrete space is delimited by the task of which the refinement through planning is required. Providing guidance in emergency situations is required to be timely yet relevant. This necessitates contextual awareness, i.e. plan generation must consider the environment (e.g. weather, other air vehicles in the vicinity, etc.), the aircraft status (e.g. remaining fuel level, remaining thrust, etc.) and the pilot's intents (land aircraft, restart engine, etc.). While information from the former two can be obtained from sensor data, the latter can be either inferred from the evidences obtained from observing the pilot passively (e.g. gaze tracking, interaction tracking) [11], or by engaging the pilot in an active dialog to affirm their intent (for implementation details refer to [21]). The Context Recognition (CR) module is intended for recognizing the pilot's intents.

Beside context-relevant guidance, adaptive assistance is essential so that the pilot is kept in the decision-making and acting loop as the executing agent. Adaptation is tailored to the pilot's mental workload, in order to ensure that his/her workload remains in the optimal range. With the addition of the Mental Workload Estimation (MWE) module, FRICO will use a mental workload resources model to assess the residual mental capacity based on [22] to be exploited for optimising plan suggestions, e.g. by considering mental resources as soft-constraints to be optimised in the plan determination.

5 Medical sensors and processing

Current European rules mandate age limits of 60 yrs. for commercial single-pilot operations and of 65 yrs. for multi-pilot operations (compare with *§3 Betriebsordnung für Luftfahrtgerät (LuftBO, Germany)* and [1]). When not flying for commercial purpose, pilots of micro-light aircraft are not obliged to undergo an annual or semiannual (over 60 yrs.) medical examination by an aeromedical examiner ("Pilot Medical") in order to assess their fitness to perform all flying tasks and risk of in-flight incapacitation due to a medical event. To fly without regular Medicals increases the risk of flight incapacitation and fatal flight accidents for these pilots.

The topics of the *MOREALIS* research project include the analysis and assessment of the pilot's medical condition and cognitive abilities, the integrity of the aircraft, as well as the decision-making based on this and - ultimately - the automatic emergency landing with an aircraft specifically designed to protect the pilot. All data is used as input into an aircraft intervention management system. To detect the pilot's flight capacity, the *MOREALIS* partners DLR, Institute of Aerospace Medicine (DLR-ME) and STAR Healthcare Management (SHC) collaborate on the following topics:

- DLR-ME determines the relevant diagnoses to be monitored and identifies suitable medical sensors.
- SHC collates the data collected in real time in a medical condition app that uses the National Early Warning Score (NEWS) to determine medical fitness in-flight.

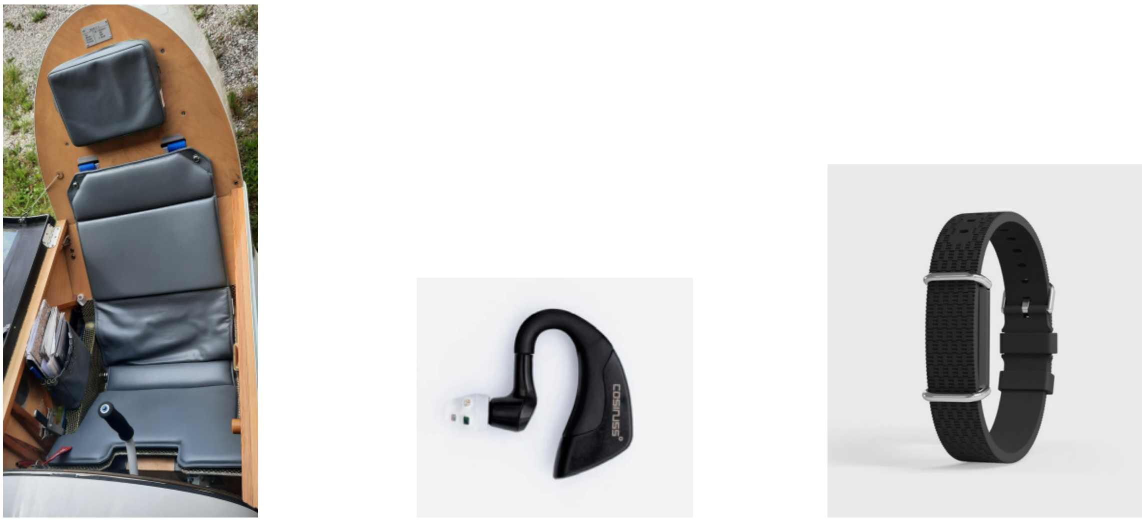
The medical, as well as the cognitive pilot status are subsequently utilized in the aircraft intervention management system.

In order to determine the medical state of the pilot, numerous sensors have been identified and partially tested. The main objective is the capability of the selected sensors for the integration into the *MORFOIS* aircraft, due to strict requirements w.r.t. integration space, energy consumption, comfort etc. Figure 11 presents current candidates for the integration.

Working with the acquired sensor parameters, SHC started developing a panel to control software and hardware (sensors) based on the Apple macOS 13+[2]/iOS 16+[3] operating ecosystems. The following Figure 12 shows the SHC Panel Software which integrates sensors, the activation process and the representation of the sensor values in different colors depending on the specific early warning score. It indicates the critical values with a warning message. These processed results are subsequently communicated to the intervention management system.

A complete overview on the identified medical implications, sensors and evaluation software can be found in the closely associated paper [9].

[2] `https://www.apple.com/uk/macos/sonoma/` [Accessed: June 2024]
[3] `https://www.apple.com/uk/ios/ios-16/` [Accessed: June 2024]



(a) CAPICAL sensor seat (b) COSINUSS 2 in-ear sensor (c) AKTIIA blood pressure sensor

Figure 11 – Medical sensors for aeronautical utilization

6 Landing site selection and obstacle detection

Maintaining flight safety in situations of abnormal aircraft behavior and incapacitation of the pilot requires the selection and maintenance of a series of suitable landing options to allow for a safer emergency landing when required. For this, a module for emergency landing site selection and hazard detection is developed. Its multi-criteria decision making is based on information with various certainty levels which depend for example on their source or their estimation process. The necessary information includes but is not limited to information about potential on- and off-airport landing sites and their environmental properties, the hazard situation on the ground, information about the aircraft operational state as well as the pilot's health condition. The landing site selection process itself is a continuously repeated process highly dependent on potential changes of the local obstacle conditions inherited through sensor information. Furthermore, data fusion must be performed in a reliable and comprehensible way. To account for these requirements, the selection of an appropriate landing site during the flight is implemented as a multi-stage approach, which is implemented using ROS2 as a backbone as shown in Figure 13. In this concept, first a preselection of potential landing sites within the aircrafts endurance is performed from a catalogue of landing options. Additionally in this step, information about the state of the aircraft as well as the pilot's condition are categorized and combined to select distress specific landing sites. This is followed by the removal of unsuitable sites based on the required runway length as well as on sensor-based hazard detections. Finally, the ranking of the remaining sites is performed using landing site type specific criteria, like information

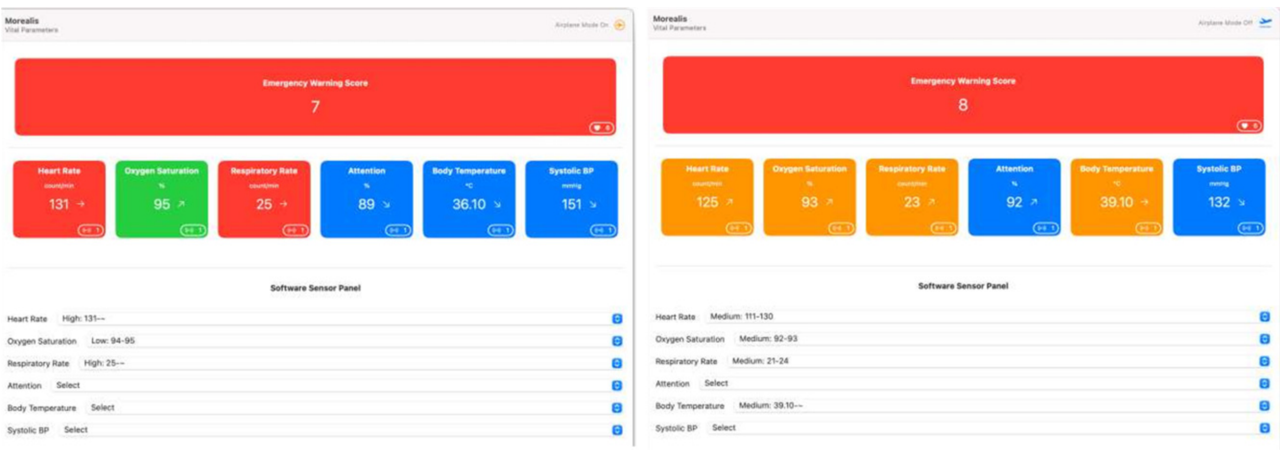


Figure 12 – Panel for medical sensor evaluation - transition of parameters

about the terrain, the environment, the wind conditions, a possible emergency descend trajectory and electro-optical sensor-based hazard information at the respective landing sites is fused to create a landing site ranking for a potential forced landing. This process is performed using a Bayesian Network approach to respect uncertainties of the input information as well as of the derived variables. Details of this approach are shown in [23].

The catalogue of potential landing sites serving as a basis for this approach contains a wide range of information, like their spatial location and necessary additional information like nearby static obstacles, alternative fallback landing sites as well as the distance to emergency facilities. The creation of this catalogue is a costly process and is therefore performed pre-flight. During the process geospatial vector data, digital orthophotos, digital surface models and airport databases are fused to compensate for inaccuracies regarding hazards in the individual databases. The overall approach is described in detail in [24]. Potential hazards on off-airport landing sites require the application of object detection methods to identify obstacles on the ground, e.g. pedestrians, vehicles and animals, as well as of image classification techniques to find hazardous surfaces, e.g. rapeseed and other vegetation. Sensor orientation is determined by combining a sensor path planning approach, to create an observation sequence for the landing sites to maximize obstacle detection performance as described in [25], with a coverage path planning, to achieve complete monitoring of areas [14].

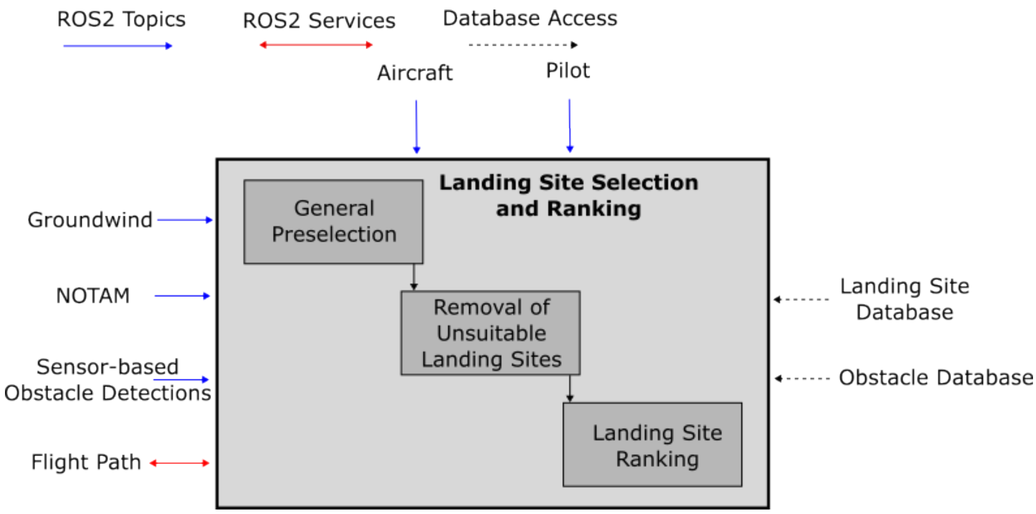


Figure 13 – The architecture of the ROS2 backbone for the landing site selection and ranking [23].

7 Integrated Simulation

In order to integrate all relevant partner contributions into a single context for demonstration purposes, a joint real-time simulation setup is currently under development. Based on the ROS2 framework [26], it features the ability to perform nominal flight, as well as degraded conditions, as envisioned in the overall project concept.

Embedded nodes are derived in a programmatic manner from Python and/or C/C++ source code. In the case of the flight control elements these are generated by the MathWorks "Simulink ROS2 toolbox"[4]. The exchange of data between nodes and partner domains is organized by ROS "topics".

As the setup and exploration of the respective functionalities of the joint simulation framework is still ongoing, respective results will be published at a later date.

8 Conclusion

Enhancing the very lightweight, single-seat micro-light aircraft category with additional means of emergency handling options is the core idea within the *MOREALIS* project context. The described holistic environment aims at providing an "intermediate" layer of protection for the UL and LL aircraft,

[4]`https://de.mathworks.com/help/ros/` [Accessed: June 2024]

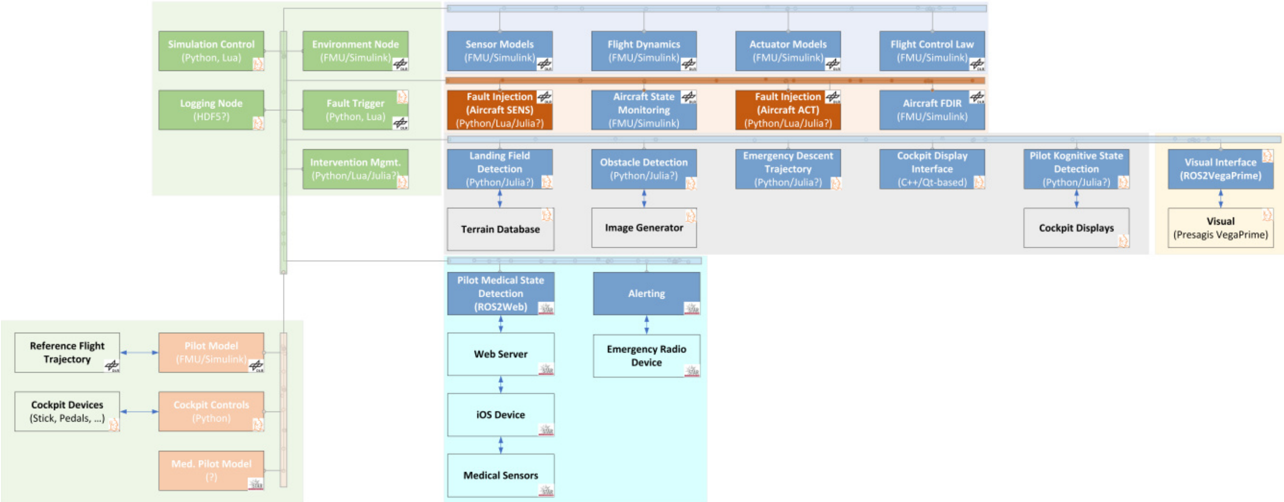


Figure 14 – ROS2 based simulation architecture within the *MOREALIS* project

as it potentially prevents the use of the ballistic recovery system in a number of dedicated emergency scenarios. This is achieved by the application of a multitude of methods and disciplines intended for the derivation of a complete state of the aircraft and pilot. The underlying disciplinary information is available in the context of the mentioned publications in Section 1.

In general, the sensory information is continuously monitored and processed and utilized for decision making within the "intervention management" node. In cases of aircraft degradation, and selected pilot states, the subsequent emergency descent activities allow for a landing in an online determined landing strip. The actual descent is planned due to the availability of landing strips in the close vicinity, utilizing a trajectory which reflects the aircraft capabilities. In the case of "loss of engine power" this would result in an unpowered, yet actively controlled descent trajectory with the respective vertical sink rate.

Finally the flight is controlled using the onboard electronic flight control system, which utilizes the generated descent trajectory. The aircraft is therefore equipped with active control surfaces. One half of these split surfaces is hard wired by rods and cables to the pilot stick and pedals, the other half is controlled by actuators. It is worth mentioning, that the pilot always has the control power to over-steer the FCS control inputs. Furthermore, the presence of the FCS-system opens up the possibility of utilisation in nominal operation. However, electronic flight control systems are currently not regularly permitted within the context of UL and LL aircraft. Therefore, the described architecture and methods can be considered as proposal - further discussion with responsible legal and certification bodies is required.

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11 Copyright Statement

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