Dear reader,

I am pleased to share with you the second issue of HYPSTAIR newsletter containing main project outcomes. Partners are successfully addressing challenges of designing and building components of a hybrid drive system, intended for use in small general aviation aircraft.

During the last months, we have developed a **flight simulator** model (HyPSim), used for a hybrid aircraft, and carried out several simulations including interesting insights on possible critical conditions. Alongside, the **human machine interface** (HMI) **components** were designed together with **haptics effects,** which present a new approach in communication between pilot and aircraft.

Complete battery system has been detailed, taking in consideration the necessary power, silent take-off, weight and size for matters of implementations. The design and manufacturing of the **component installation** platform were carried out and followed by analysis of **functional safety** of components.

In upcoming months, partners will be actively working on designing and manufacturing hybrid system components: motor, inverter, generator and control system. All the components and HMI will be integrated into the component integration platform. Testing methods will validate the design of the components and their interactions will be developed. Project will finish with laboratory testing of integrated system. The validation of enhanced level of safety for small aircraft, both through demonstrated reliability of all the components as well as through demonstration of suitability of the proposed HMI to enable safe and efficient operation of hybrid aircraft, will be carried out.

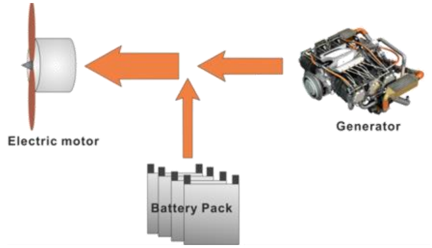
Project's results will help create a **competitive supply chain** for hybrid drive components and **reduce the time to market** for airframe manufacturers willing to introduce hybrid electric drives into their airframes. The amendment of regulations will **reduce certification times and costs** for any future projects utilising hybrid drive technologies.

Dr. Igor Perkon
R&D Pipistrel Ajdovscina d.o.o

Hybrid aircraft performance analysis

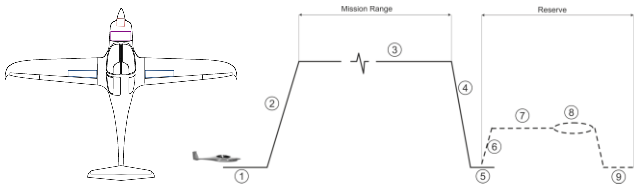
Main goals of the hybrid aircraft performance analysis is to define the operating requirements' limitations and to optimize the use of different energy sources.

A proper design procedure has been carried out, implementing simple but reliable models in such a way that different solutions can be achieved with small computational time.



The operating mode of the entire power train has been varied in accordance to different power levels requested during missions: battery packs provide additional energy during most power demanding flight segments (take-off and climb); while during cruise, the generator gives sufficient power for both the flight and battery recharge.

Overview of the performance model



Implemented performance model allows estimation of consumption of both energy sources during a given mission profile. The best flight conditions have been defined in terms of flight program, speed and altitude in order to maximize the flight range or, alternatively, the weight saving. The energy consumption has been evaluated through the energy balance, taking the efficiencies of all the power train components into account.

Two kind of calculations have been performed:

- ❑ evaluation of maximum achievable flight range with given amount of available energy (fuel + batteries) at take-off;
- ❑ evaluation of minimum energy amount (fuel + batteries) required at take-off in order to fly a given range.

Preliminary results

As a general conclusion, results showed that batteries affect performance only in some flight segments such as climb, when power from batteries is most needed, or first part of the cruise, when batteries recharge. Therefore, differences between the hybrid and the internal combustion (IC) propulsion can be appreciated for short mission range. For long range mission the energetic contribution of batteries is less significant and flight performance is largely dominated by the IC engine used as generator.

Introduction to the simulator Hy.P.Sim

The simulator **Hy.P.Sim (Hybrid Plane Simulator)** is set of software that simulates a flight of an aircraft with a hybrid propulsion system.

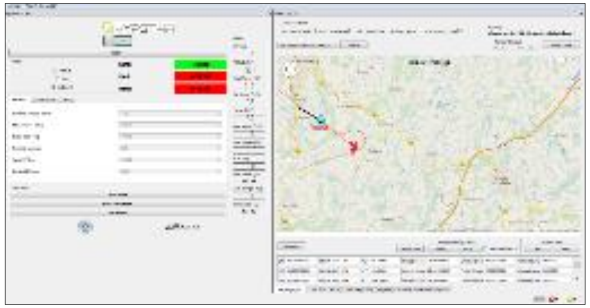
The simulator has been conceived for multiple purposes:

- validation of the results achieved in the preliminary analysis phase;
- evaluation of the performance for general mission profile;
- introduction of the real pilot effects with a human-in-the-loop approach;
- identification of possible critical flight conditions for the power management.

The Hy.P.Sim simulator is composed of three main software applications:

- a **Flight Simulator**, in which the aircraft is visualized and flight data (position, angles, speed, forces, etc.) are calculated;

- a **Flight Planner**, that allows to define mission profile and manages the autopilot mode;
- a **Calculation Tool**, in which the hybrid propulsion system is implemented in order to process flight data and to perform estimations and predictions.



Human Machine Interface for Hybrid Aircraft

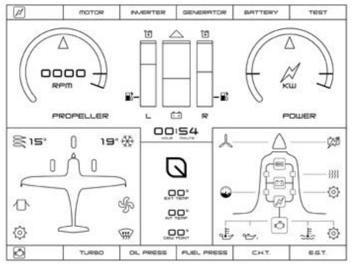
The Human Machine Interface, developed in HYPSTAIR project, is designed to display basic information and failure warnings at a glance. It simplifies reading of information through immediate perceptible graphical encodings and chromatic conventions, correct positioning within pilot's visual field, and especially displaying useful information only at a specific times or profile of mission.

Project has addressed hybrid aircraft as a new conception. Therefore, a lot of information that must be controlled by the pilot have been studied and designed with foundation of ergonomics, laws of perception and sensory psychology. For this reason the new GUIs (Graphic User Interface) have been designed with basic graphics, familiar to professional pilots, additionally addressing design efforts towards representation of instrumentation and a layout which is similar to the analogical instrumentation.

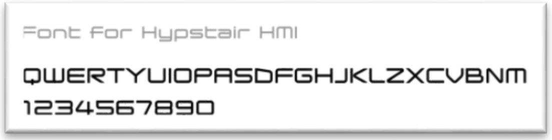
However, it is more immediate in its transmission, as it is designed not only to transmit numerical data, but to reflect and anticipate behavioural trends of the pilot. Throughout the tests and simulations, the best GUI for the HYPSTAIR project has been defined. The latter comply with current customs for information displaying in aeronautics, yet incorporating innovations with systems and regulations from other fields of expertise (aeronautics, automotive and marine).

MBVision

PIPISTREL



Graphic User Interfaces are normed by a reference document that establishes the layout, colours, font placements, applications and use cases.



The HMI of **MFD** (Multi Functional Display) uses a 10.1" display that allows navigation through all the desired features with touch interaction.

The hardware consists of physical buttons that can replace touch interaction in particular flight conditions. This feature is important also because of a backup interaction, which is created in case of malfunction of the display. The research scope developed in the HYPSTAIR project have been used in other projects like IDINTOS (light seaplane), 3 wheel scooters, new engine data instruments.

Haptics interface

The pilot operates the hybrid propulsion system of the electrical aircraft via the linear power lever. All relevant information of the complex powertrain system are provided by cockpit displays. Communication in such complex system may not be intuitive and the pilot may be overloaded with information. Hereupon, the idea was to enable simplified communication and exonerate pilot's workload.

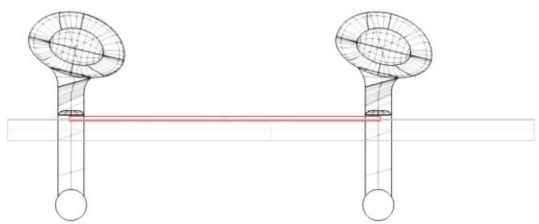
Human haptic perception is faster and more intuitive then the visual one, so we have upgraded the power lever with force feedback that can stimulate the pilot's haptic sense while he or she is holding the power lever handle.

The power lever operates as a haptic interface that can produce numerous programmable effects, stimulating human haptic sense by force. These haptic effects could also be linked to higher-level information.

The pilot provides power demand for the aircraft propulsion system by positioning the power lever. Simultaneously, he or she can receive the information feedback of powertrain system by the force feel. Generated haptic effects are designed based on current power demand and the powertrain system state.

The designed haptic power lever promotes efficient use of energy, enhances level of safety, and provides intuitive control of complex powertrain system:

- increases pilot's awareness of batteries use, and
- warns pilot about system failures.

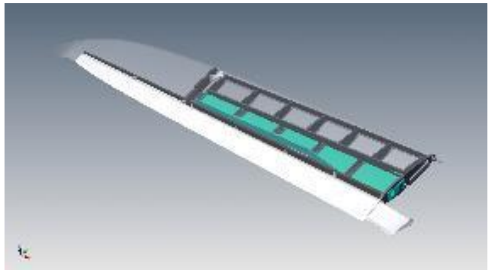


HYPSTAIR complete battery system

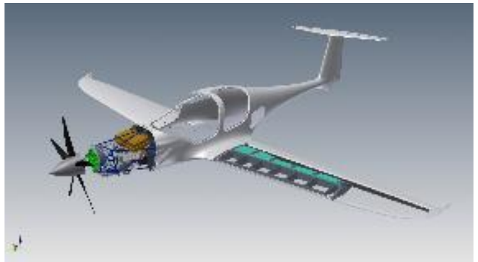
The battery is one of the two energy sources in the proposed serial hybrid powertrain. It is sized so that the aircraft can perform a battery-only low noise take-off, as well as to complement the internal-combustion driven generator to boost segments of flight that require high power.

To do this, the battery is not only a battery, but an elaborate system of elements, comprising the battery cells, monitoring modules, balancing units, safety devices and communication interface to the rest of the powertrain components. The chemistry of the battery cells was carefully chosen for optimum balance between energy storage capability and extremely high power output during the take-off and climb. Special emphasis was put into the safety and reliability of the battery system's operation, as well as the batteries integration features so that it would fit in a typical aircraft's wing – the best location to house a battery on board an aircraft as a combination of safety aspects, volume available and cooling required.

A prototype battery along with a dedicated battery management system has been built and tested for performance. In order to guarantee pilot and passenger safety in case of a battery failure, a safety concept was developed and implemented in the battery.



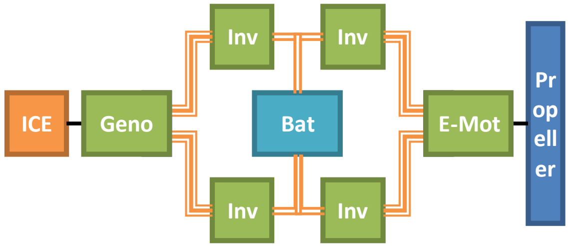
The battery management system communicates with the rest of the propulsion system via two CANbus communication lines. A special CANbus information exchange protocol to the tailored Battery Management System was also developed.



Pioneering field are the failure-mode reaction principles, where some failure cases can be handled by the battery itself, without the intervention of the primary control system, while others are coordinated with the primary control system, i.e. advanced power derating functions.

HYPSTAIR Hybrid Propulsion System Architecture

The HYPSTAIR propulsion system architecture was chosen to maximize safety. Therefore the propulsion system was designed to feature two electrically independent power paths.



HYPSTAIR propulsion system architecture

This architecture ensures that no single electrical failure can lead to total loss of power. The result is a significant increase in safety for single engine airplanes.

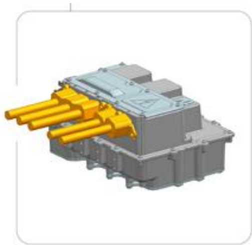
Siemens e-Motor SP150D

- **Powerful** 150 kW max continuous power. 200 kW peak power.
- **LIGHTWEIGHT** best in class power density.
- **EFFICIENT** η= 96% at cruise power.
- **SAFE** Redundant winding system.
- **EASY TO INTEGRATE** Built-in propeller bearing, governor and cooling pump.
- **ROBUST** High coolant inlet temperature: 90 ºC to 105 ºC.

Siemens Generator SG100

- **Powerful** 100 kW continuous power.
- **LIGHTWEIGHT** best in class power density.
- **SAFE** Redundant winding system.
- **EFFICIENT** η > 95% at cruise power.
- **ROBUST** High coolant inlet temperature: 90 ºC to 105 ºC.

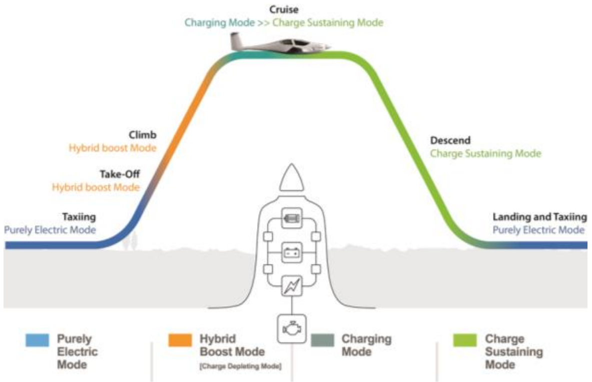
Siemens NextGen eCar-Inverter



- **POWERFUL** 100kW continuous power.
- **LIGHTWEIGHT** power density of 10,5 kW/kg.
- **ROBUST** High coolant temperature: up to 85 ºC.

HYPSTAIR mission profile

The HYPSTAIR propulsion system is able to be operated in different modes depending on the mission segment and the power requested by the pilot.



Typical mission profile and operating modes of the hybrid general aviation propulsion system.

In **Purely Electric Mode** the e-motor runs on battery power alone. This mode is used for taxiing and potentially upon landing. In this mode local emissions are avoided while noise emissions are minimized leading to an increased acceptance of general aviation activities by airport residents.

In **Hybrid Boost Mode** (Charge Depleting Mode) the e-motor is supplied with energy by both the batteries and the generator. In this mode the full system performance is available to the pilot. The Hybrid Boost Mode is used upon take-off, climb and other mission segments with high power demand.

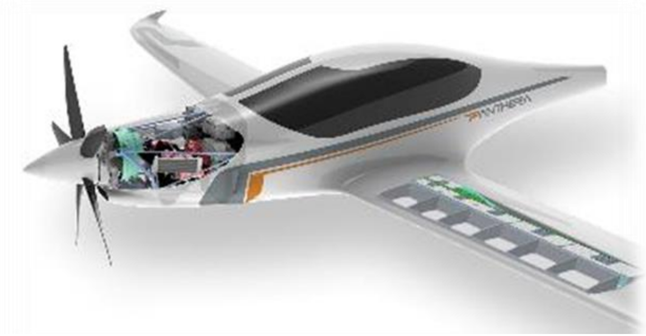
The system enters **Charging Mode** once the batteries have been (partially) depleted and the power requested by the pilot is reduced below the level provided by the generator. In this mode the e-Motor is run on power generated by the generator while excess power is used to recharge the batteries. Hereby energy redundancy is re-established improving safety.

Once the batteries have been fully recharged, the system enters **Charge Sustaining Mode.** In this mode the generator is controlled to generate the amount of power required for the e-motor. The system will be operated in this mode for parts of the cruise and descend.

HYPSTAIR component installation platform

Integrating any set of components in to an aircraft is a challenging task – not only does the volume and weight of the elements have to fit the specific airframe, but issues such as cooling, vibration, radiation, electromagnetic effects, fatigue properties and crashworthiness all have to be addressed. In order to succeed in attaining optimal performance of the powertrain-airframe, the components of the hybrid powertrain were integrated into a special platform with all features an advanced aircraft possesses. The key powertrain components, apart from the battery system, are located in the nose of the platform, mounted on a single consolidated engine mount and represent a typical situation in an aircraft. All necessary cooling provision are also installed in a representative fashion.

The main electric motor powers a five blade propeller, which was designed to maintain low noise properties even when full power is applied. The propeller control is fully automated and linked to the motion of the cockpit's single power lever, as well as to the incident airstream. The internal combustion engine, inverters and cooling provisions are installed behind the e-motor in an optimal arrangement thanks to careful use of CAD techniques and advanced laser guided positioning during their installation. Use of 3D-printed as well as CNC milled components ensure unparalleled precision in how parts fit the overall arrangement below the engine covers.

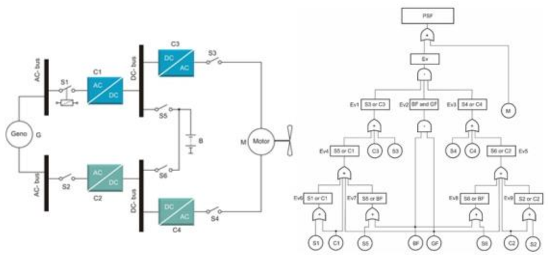


Its novel operating concept complemented large touchscreen display and especially cockpit with the intuitive haptic power lever, have potential to change the way system statuses are communicated to the pilot; by feelings, rather than visual cues.

Functional safety requirements for HYPSTAIR components

The proposed power propulsion system for hybrid airplane has been evaluated according to expected safety integrity level (SIL).

The calculation can be repeated with different information included. In order to improve the SIL level, redundant power propulsion chain has been used, where parts of the propulsion system can be excluded or activated by rearranging the power- flow within the system.



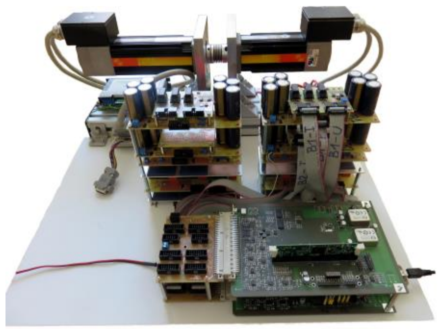
Due to these requirements, a new power propulsion structure has been considered. The hardware and software requirement tracking is mandatory for higher levels of SIL in functional safety related standards.

The software design methods themselves are not strictly defined in DO-178C/ED-12C, but based on the contents of the standard the MISRA C guidelines, 2012 edition, are an excellent tool for this purpose. Furthermore,

variable type	name example	name example (2)
Bool	bl_busy_indicator	bl_BusyIndicator
char_8t	ch_char_value	ch_CharValue
uchar8_t	uch_char_value	uch_CharValue
int16_t	i16_int_value	i16_IntValue
uint16_t	ui16_int_value	ui16_IntValue
int32_t	i32_int_value	i32_IntValue
uint32_t	ui32_int_value	ui32_IntValue
int64_t	i64_int_value	i64_IntValue
uint64_t	ui64_int_value	ui64_IntValue
float32_t	f32_float_variable	f32_FloatVariable
float64_t	f64_float_variable	f64_FloatVariable
enum	en_a_tag	en_ATag
…	…	…

the MISRA C is in accordance with the automotive standards (IEC/ISO 26262), which makes the checking tools widely available for many software and hardware platforms. MISRA C guidelines also take into account the model based software design, for which a special documents are available.

The testing hardware has been designed in a small scale version regarding the level of power, allowing Hardware-in-the-Loop (HiL) operation.



HYPSTAIR Workshop on Current state of art in hybrid propulsion components and future developments

HYPSTAIR project entered into its final stage, counting down its last 6 months. To this point, a lot of progress was made and many issues were solved. Consortium was finally ready to share some development insights to the interested audience.

For that manner, second workshop was organized on **3th September 2015 in Erice, Sicily** in the framework of the »64th Workshop: "Variational analysis and aerospace engineering III: Mathematical challenges for a new aviation", which traditionally invites professionals and stakeholders from around the world.

Second HYPSTAIR workshop held a title: **»Current State of Art in Hybrid Propulsion Components and Future Developments«.** Programme of the workshop was based on the presentations of consortium members and their lessons learned during the project. In order to deliver quality in-depth view on the topics, consortium invited also few external experts from the field.

Beside project partners also Dr. Josef Kallo and Dr. Björn Nagel from German Aerospace Centre – DLR, and Dr. Luciano Demasi from San Diego State University took an active part at the workshop. Themes of the workshop covered state-of-the art of development of hybrid propulsion systems, their advantages and components, fuel cells as battery alternative, functional safety requirements and approaches of quantifying the impact of future technologies.

Second part of the workshop was dedicated firstly to challenges of hybrid propulsion system and twin engine concept.

University of Pisa presented flight simulator model of hybrid aircraft. This segment incorporated also specifics of the HYPSTAIR project, namely HMI and haptic solutions for hybrid aircraft.

It has been recognized by participants that the area of hybrid propulsion technology presents an interesting research topic to be addressed in the future.

Past events

- 20 and 21 November 2014: **Crea©tivity days** (Italy): Presentation of HYPSTAIR project

- 29 November 2014: **IFAM** (Slovenia)
- 27–30 January 2015: **F44 General Aviation Aircraft** (USA)
- 26 February 2015: **Electrisch und Emmissionsfrei Fliegen Symposium** (Germany)
- 12–16 April 2015: **AERO 2015** (Germany)
- 11–14 May 2015: **I2MTC Conference** (Italy)
- 15–21 June 2015: **International Paris Air Show** (France)
- 4th September 2015: **HYPSTAIR project meeting in Sicily** (Italy)
- 9–11 September 2015: **EWADE/CEAS Conference** (Netherlands)

Upcoming events

- 12–14 October 2015: **Symposium on Collaboration in Aircraft Design** (Italy)
- 20–23 October 2015: **Aerodays 2015** (United Kingdom)
- 17–19 November 2015: **XXIII AIDAA Conference + Aerospace & Defence Meeting** (Italy)