Hybrid Propulsion System and Aircraft-level Performance Simulation

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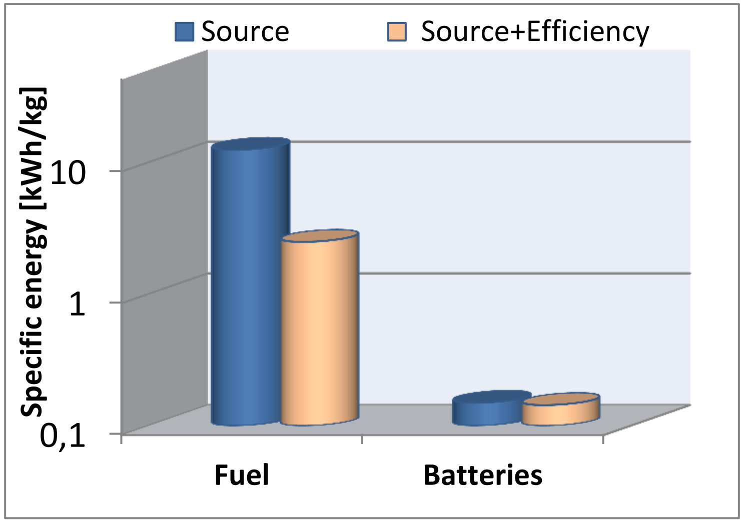
Contents

- Introduction to performance estimation
- Preliminary analysis of flight performance
- HyPSim (Hybrid Plane Simulator)

Background

Analysis of the flight performance when a non conventional propulsion system is considered.
Dependence on the energy sources, system architecture, control logics.

Fuel vs battery (today)



Purposes of the analyses:

- Sizing of the propulsion system components for a given reference design mission (cruise speed, cruise altitude, climb rate, flight programs, etc.);
- Sensitivity analysis of propulsion system performance to different mission parameters;
- Definition of strategies to optimize energy management in each flight segment;
- Definition of critical flight conditions.

Performance analysis for *Hypstair*

Within the *Hypstair* project, two design stages has been faced:

Preliminary Performance Analysis Tool

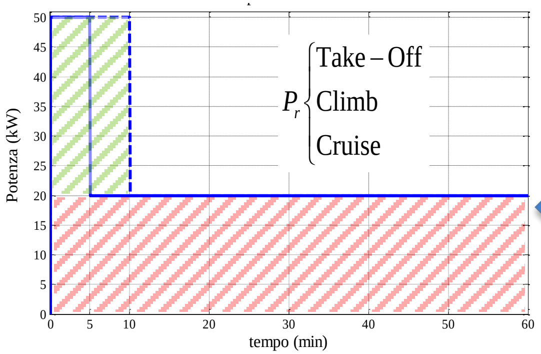
- A set of analytical models to determine the flight performance on the basis of a reference mission profile
- Simple, proper reliability
- Global performance estimation
- Analysis of the battery utilization on specific flight segments (climb, take off) depending on main parameters (aircraft trim)

The Hybrid Plane Simulator (HyPSim)

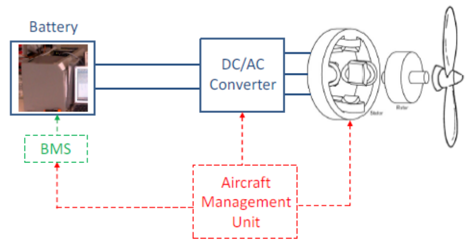
- Introducing the human-in-the-loop effects
- Introducing new mission profiles
- Identification of possible critic conditions in specific flight segments
- Evaluate information on the HMI panel

Performance analysis for *Hypstair*

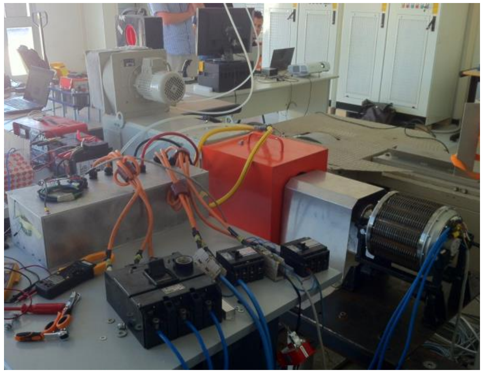
Performance analysis

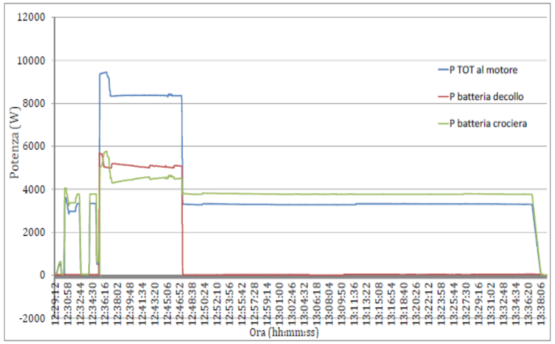


Component sizing



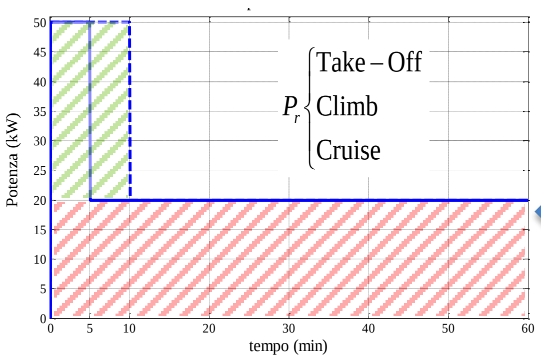
Testing



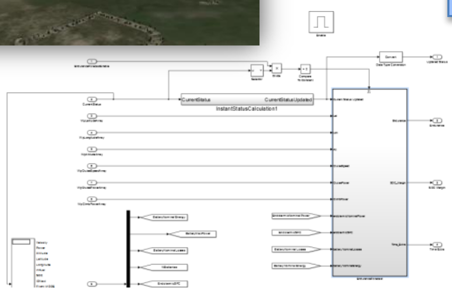


Performance analysis for *Hypstair*

Performance analysis



Simulator



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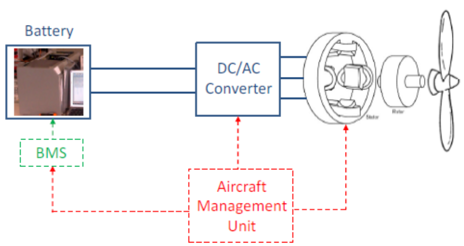

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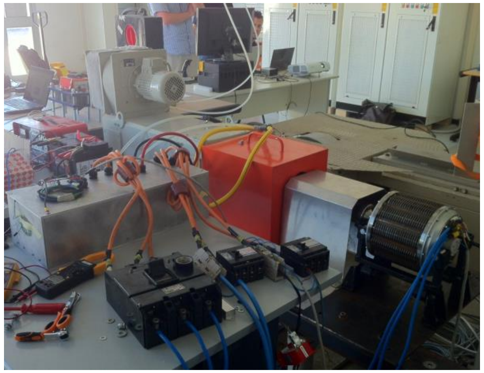
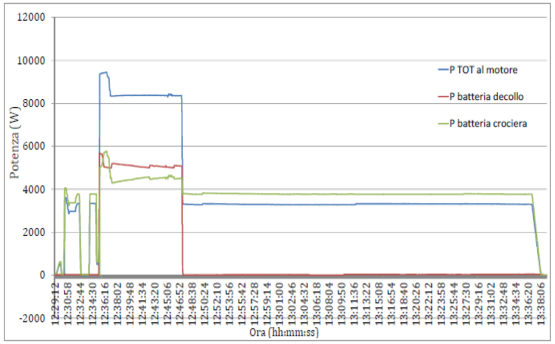




Preliminary Performance Analysis

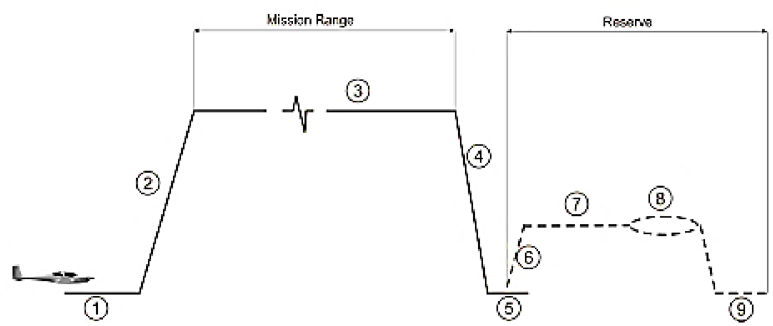
INPUT

- Aircraft data
- Propulsion System data
- Reference Mission

→ **Performance Model** →

OUTPUT

- Speed, Power, Aerodynamic Coefficients, Weight, etc. VS **Time**
- Endurance



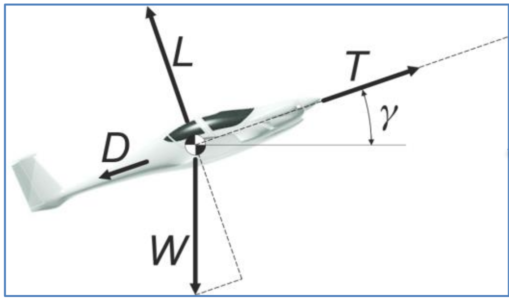
Main features:

- Need to define the entire mission at input level
- Very simple aerodynamics (polar drag)

Two “optimization” problem to solve:

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

Preliminary Performance Analysis



Mission Profile
Regulation requirements

Aircraft
Drag polar, MTOW

Hybrid system arrangements
Max. Wfuel, Wbatt, Pgen etc

Flight mechanics equation
Pflight, Pav,
General flight perf.

Models for power efficiency
ηsys, ηprop, Generator model

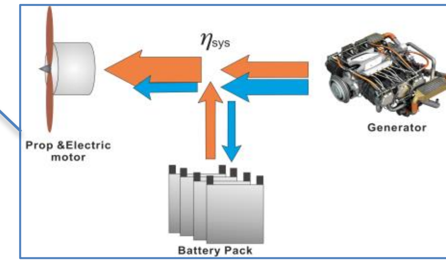
Energy consumption models
Breguet formula
Discharge/charge batteries

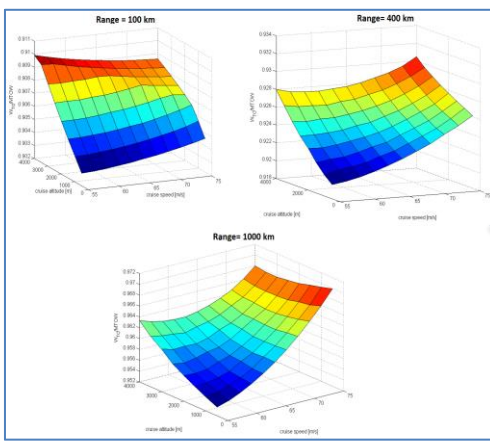
Parameters
Flight programs, v, h, Range, W fuel, EN batt..

Performance meet requirements?
N
Y

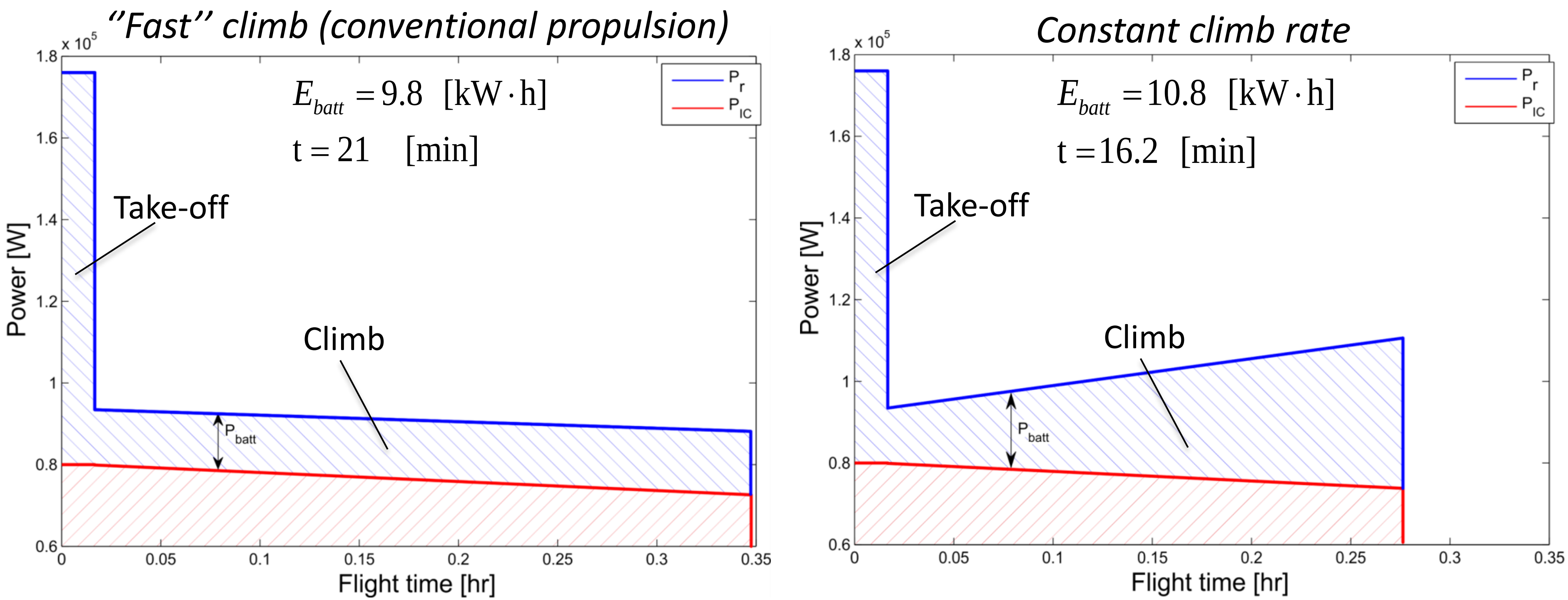
Energy exceed limits?
N
Y

Mission perfomance
Range, mission time, burn fuel, batteries energy etc..



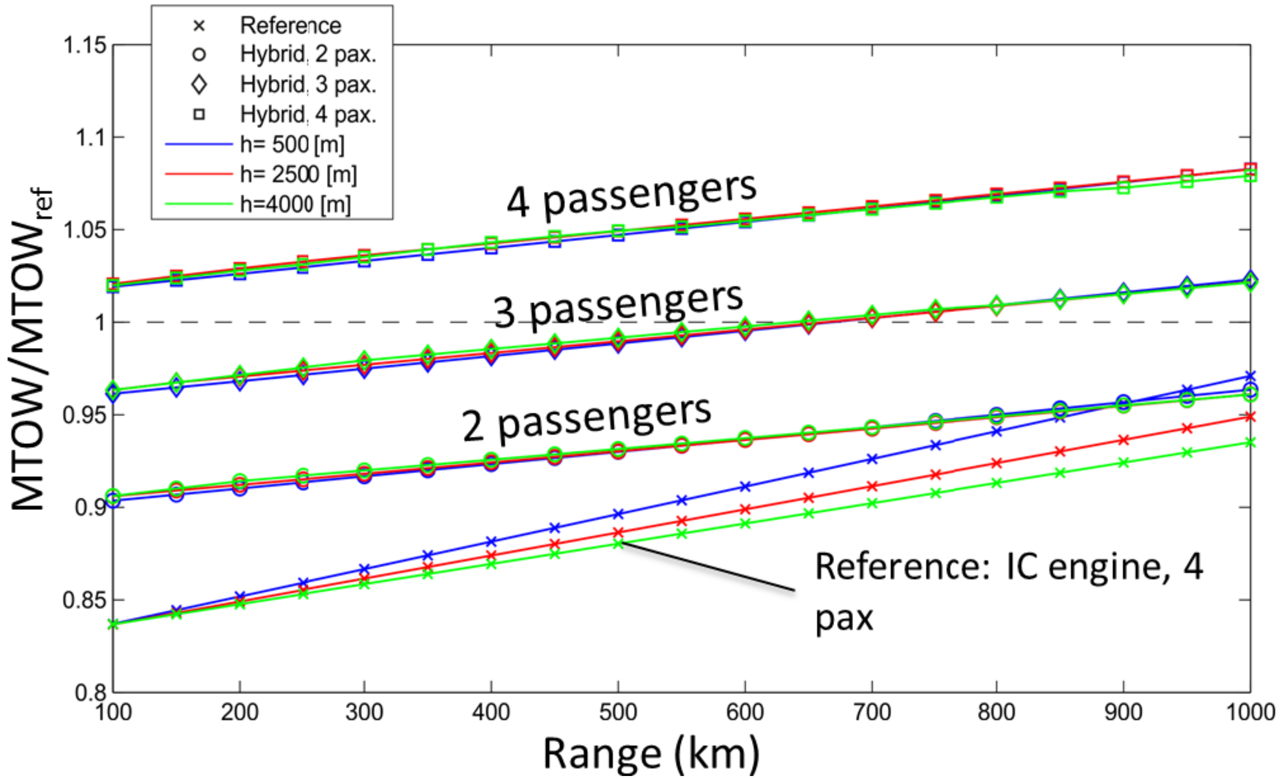


Effects on specific flight segments



Performance during climb depend strongly on the utilization of the battery: the definition of "optimum" climb remains an open problem

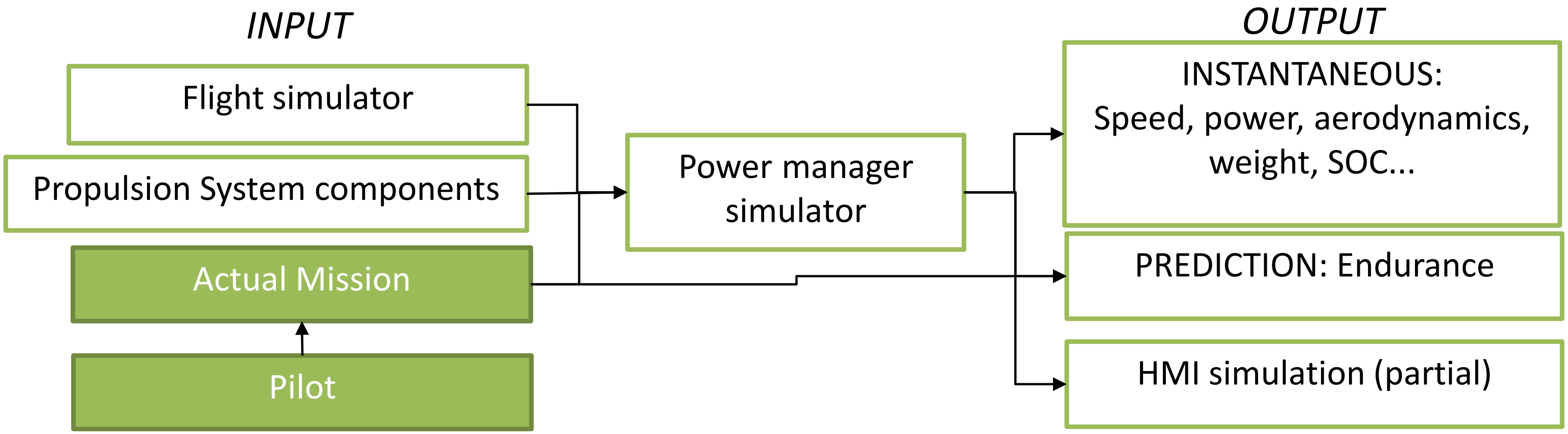
Effects on global performance



- Batteries increase empty weight, limiting payload capabilities

- Weak MTOW vs Range dependency
- Low sensitivity to cruise altitude
- More flexibility in mission definition

HyPSim: introduction



Main purposes:

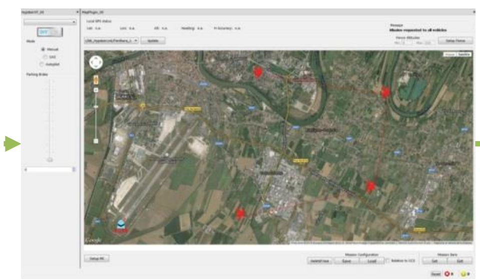
- Introducing the human-in-the-loop effects and different mission profiles;
- Determination of possible critical flight conditions;
- Possibility to include/modify components behavior;
- Guarantee the reproducibility of the experiments.

HyPSim: general architecture

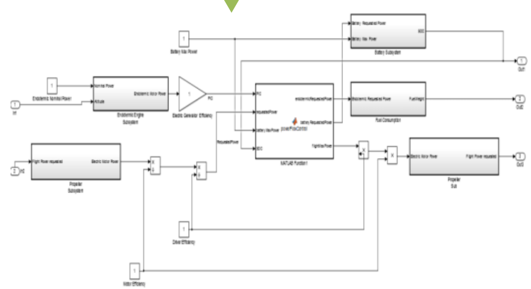
User interaction

Joystick

Flight simulator
(X-Plane 10)



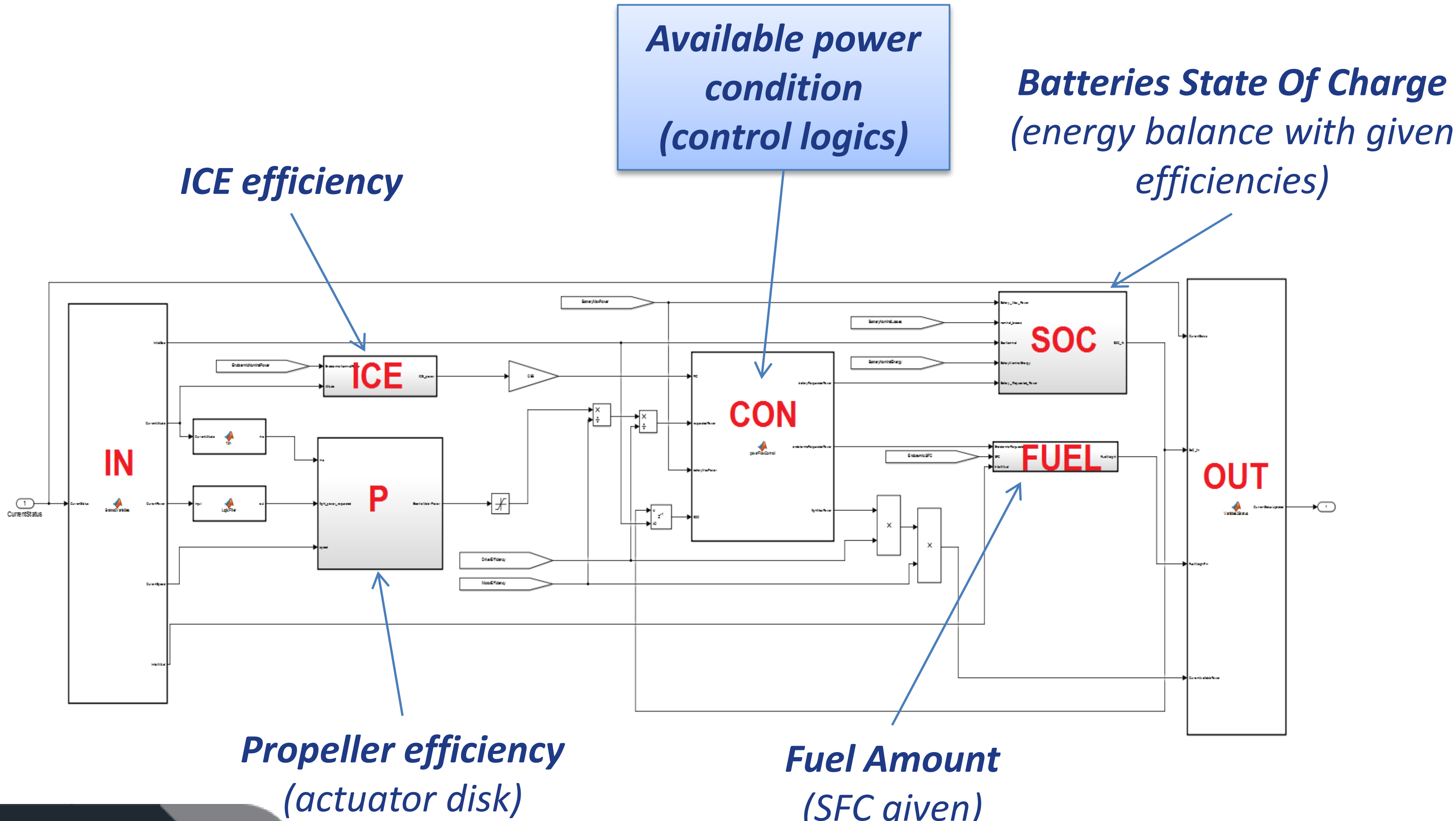
Mission Planner
(in-house developed)



Performance Model
(Matlab/Simulink)

OUTPUT

HyPSim: powertrain module

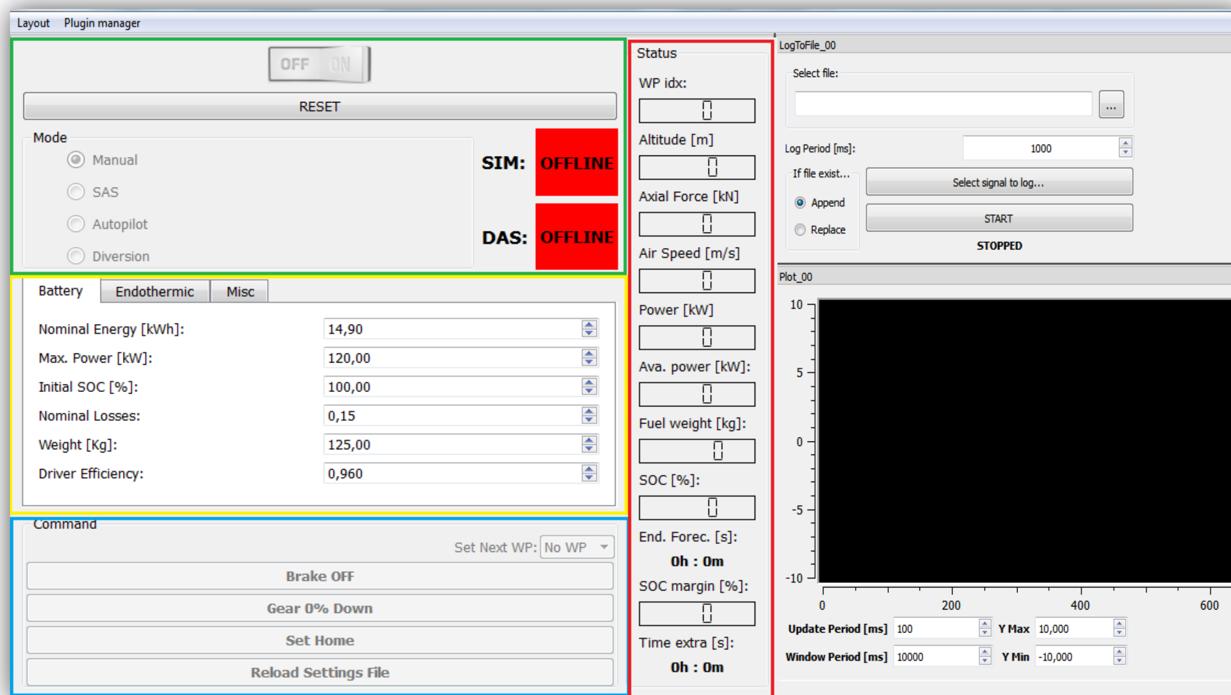


HyPSim: the flight planner

In house software mainly developed to control the flight in automatic mode. Then, several features are added by means of plugins that can be activated/deactivated by the user.

Plugins

- “Hypstair main window”;
- “MapPlugin”;
- **“LogtoFile”;**
- **“Data Plot”;**
- **“HMI visualization”;**



HyPSim: the flight planner

Plugins

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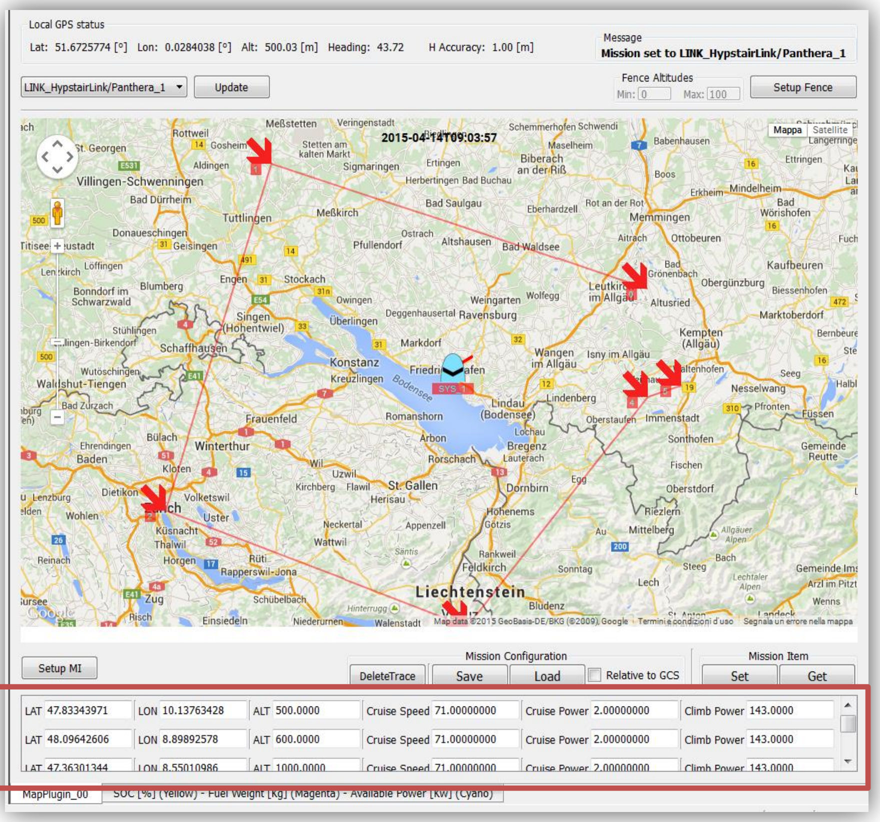


Waypoints definition

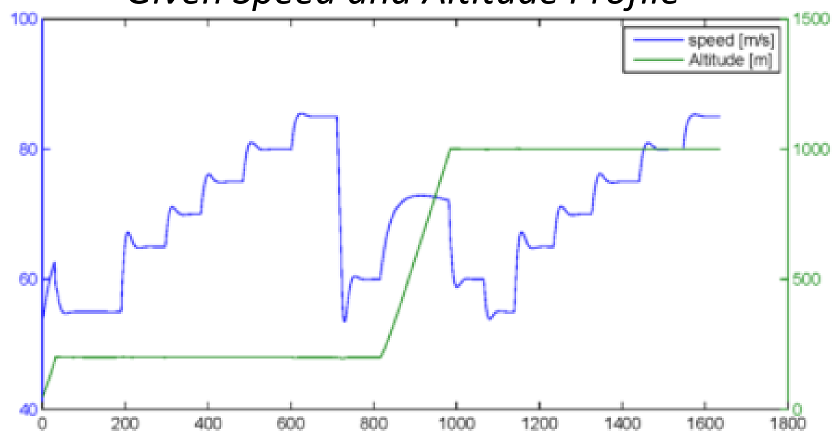
Let’s have a fly!

Example of results

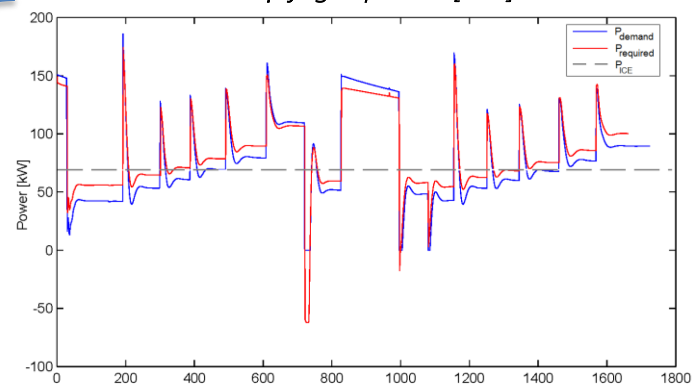
TEST CASE 1: Required power evaluation in steady and dynamic conditions (straight flight)

$$P_{req} = V \cdot D + V \cdot W \cdot \sin\gamma + V \cdot \frac{W}{g}\frac{dV}{dt}$$

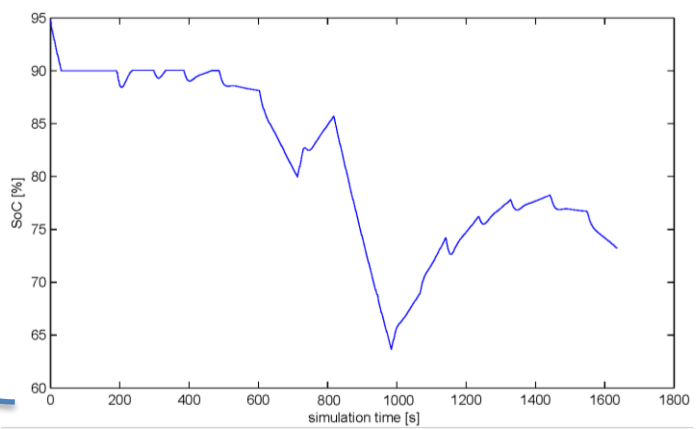
Given Speed and Altitude Profile



Req. flight power [kW]

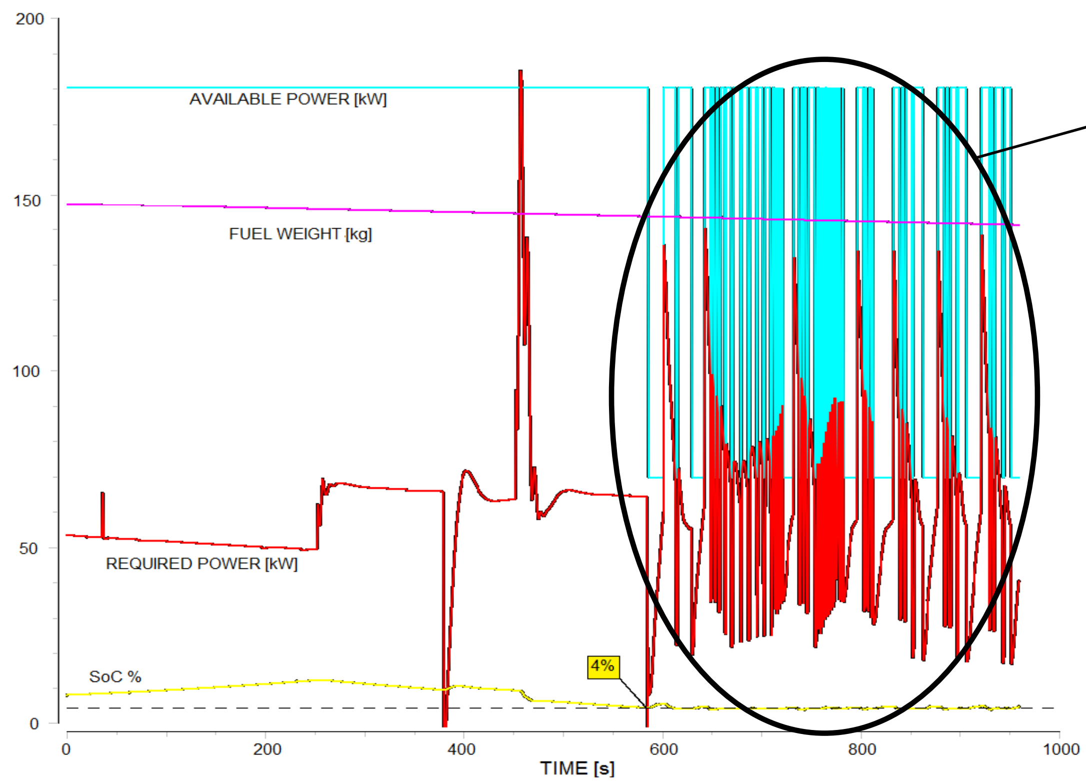


Batteries SOC [%]



Example of results

TEST CASE 2: Fully discharged batteries



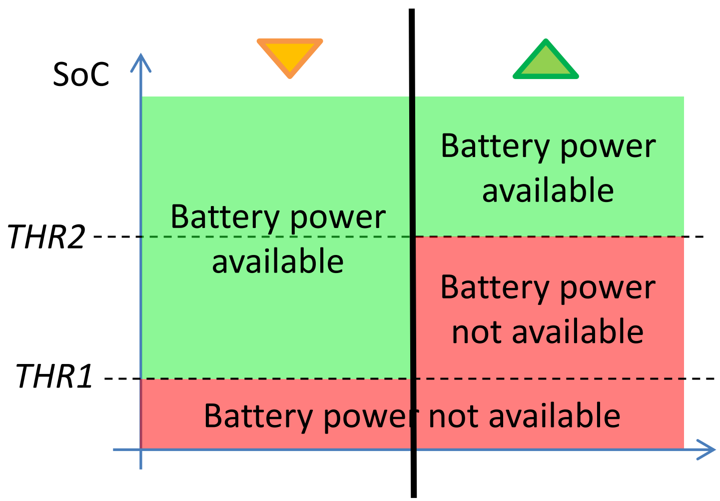
Looping problem:

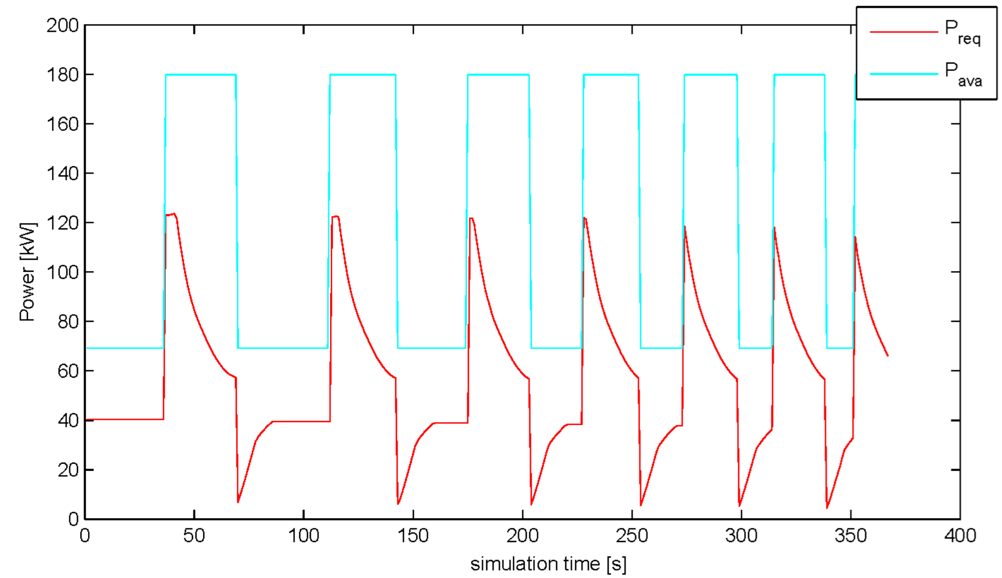
- High speed requirement
- Power required > 80 kW
- Fully discharged condition (SoC < 4%) is reached
- Available power is reduced to 80 kW (only ICE generator available)
- Speed is reduced, hence required power
- Batteries start recharging
- High speed requirement restored

Example of results

TEST CASE 2: Fully discharged batteries

Introduction of a 2nd SoC threshold (e.g. 7%) to reduce charge-discharge cycle frequency





Conclusions

- Flight performance analysis is essential to assess the potentiality of the hybrid and all-electric propulsion systems.

- The definition of optimal energy management remains an open problem.

- A simulator has been set up, reaching the following objectives:
  - HyPSim allows the interaction between the performance models and a human pilot
  - Instantaneous performance can be evaluated and prediction can be performed
  - Main results can be visualized through the HYPSTAIR *HMI*
  - The system has been tested for several conditions
  - HyPSim can be used as a design, training and dissemination tool.

Conclusions

– Further development

- Implementation of more detailed models for the power train simulation
- Implementation of additional control logics for off-design conditions and further testing activities
- Deeper and more complete implementation of the HMI module
- Integration with *haptic* input devices developed within the HYPSTAIR project

Thanks for your kind attention

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