Hybrid Propulsion System and Aircraft-level Performance Simulation

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Stuttgart, February 18-19th 2016
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.

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**
  - Graph showing power output (kW) over time (min) with sections labeled: Take-Off, Climb, Cruise.

- **Component sizing**
  - Diagram of battery, DC/AC converter, Aircraft Management Unit, and BMS.

- **Testing**
  - Image of testing setup with equipment and graphs showing power output over time.

Preliminary Performance Analysis

**INPUT**

- Aircraft data
- Propulsion System data
- Reference Mission

**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, W batt, Pgen etc.

Flight mechanics equation
- CL, L/D, % FL, General flight perf.

Energy consumption models
- Broguet formula
- Discharge/charge batteries

Models for power efficiency
- npvs, nprop, Generator model

Parameters
- Flight programs, v, h, Range, Wfuel, EN batt.

Performance meet requirements?

Energy exceed limits?

Mission performance
- Range, mission time, burn fuel, batteries energy etc.
Effects on specific flight segments

"Fast" climb (conventional propulsion)

\[ E_{\text{batt}} = 9.8 \text{ [kW \cdot h]} \]
\[ t = 21 \text{ [min]} \]

Constant climb rate

\[ E_{\text{batt}} = 10.8 \text{ [kW \cdot h]} \]
\[ t = 16.2 \text{ [min]} \]

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

**Effects on global performance**

*MTOW/MTOW_{ref} vs Range (km)*

- Reference: IC engine, 4 pax
- 4 passengers
- 3 passengers
- 2 passengers

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

**INPUT**

- Flight simulator
- Propulsion System components
- Actual Mission
- Pilot

**OUTPUT**

- INSTANTANEOUS: Speed, power, aerodynamics, weight, SOC...
- PREDICTION: Endurance
- HMI simulation (partial)

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

Mission Planner (in-house developed)

Performance Model (Matlab/Simulink)

Flight simulator (X-Plane 10)

OUTPUT
HyPSim: powertrain module

Available power condition (control logics)

Batteries State Of Charge (energy balance with given efficiencies)

ICE efficiency

ICE

Propeller efficiency (actuator disk)

Fuel Amount (SFC given)

Fuel Amount

SOC

Available power condition (control logics)

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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”;

![Image of HyPSim software interface with various plugins activated and a flight simulation layout.](image-url)
HyPSim: the flight planner

Plugins

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

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**

**Batteries SOC [%]**

**Req. flight power [kW]**
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

SoC

Battery power available

Battery power not available

THR2

THR1

Battery power available

Battery power not available

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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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