POLITECNICO MILANO 1863

FMSlab Flight Mechanics & Flight Systems Laboratory

CONCEPTUAL DESIGN OF A ZERO-EMISSION MINILINER: METHODOLOGIES FOR MISSION IDENTIFICATION AND INITIAL SIZING

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Clean Sky 2 Technology Progress
March 25, 2021

Outline

1. Introduction
2. Scenario studies for electric-powered regional air transportation
3. Preliminary sizing of electric-powered aircraft
4. Wrap-up

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Introduction

The *FMSlab* is a **scientific laboratory** of the Department of Aerospace Science and Technology (DAER), Politecnico di Milano

Flight Mechanics & Flight Systems Laboratory

Main **topics** of interest

- *Aircraft Performance & Dynamics*
- *Aircraft Design*
- *Aircraft Operations*
- *Flight Testing*
- *Flight Instrumentation*
- *Modelling and Simulation*

Electric-powered aviation ongoing projects

- ***MAHEPA*** *(H2020 RIA, GA 723368)*
  - Development and flight testing of two hybrid-electric powertrains
  - Technology scalability and fleet-switching scenario studies
- ***UNIFIER19*** *(Clean Sky RIA THT03, GA 864901)*
  Design of a zero-emission 19-passenger miniliner
- ***SIENA*** *(Clean Sky RIA THT14, GA 101007784)*
  Technological, operational and economic feasibility of propulsion hybridization across all categories of civil aeronautics

FMSlab's **dedicated methodologies and tools** for electric-powered aircraft applications

- **Pure-electric (PE) / hybrid-electric (HE) fixed wing aircraft**
  - Aircraft design methods and tools (**HYPERION** and **TITAN**)
    - Preliminary sizing applicable from UAV to CS-25, including H_2 power-trains
    - Introduction of novel concepts in the design framework: structural batteries, DEP, …
  - Acoustic and chemical emission prediction (**CHANCES** method)
  - Airport battery-recharging and H_2 infrastructure sizing (**ARES** method)
  - Short-haul air transportation scenario studies: demand estimation and network definition (**SHARONA** method)

- **eVTOL and other PAM (Personal Air Mobility) aircraft**
  - Market studies for intercity air transportation
  - Conceptual sizing applicable across widely different configurations

UNIFIER19 – Community Friendly Miniliner

- Clean Sky thematic project (THT03, 2019-2022) on the complete preliminary design of a **near-zero-emission, 19-passenger** aircraft

- **Radical approach**: fully zero-emission configuration
  - Fuel-cell driven
  - Liquid hydrogen on-board storage
- FMSlab engaged in the **full design loop**
  - Market studies and requirement definition
  - Conceptual design of candidate configurations
  - Preliminary design of the final configuration

UNIFIER19

COMMUNITY FRIENDLY MINILINER

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Scenario studies for regional air transportation

In the MAHEPA and UNIFIER19, a focus is placed on scenario studies for future short-haul air transportation enabled by novel environmentally-friendly aircraft

- Rising interest in the exploitation of a mass of **underused small airports** to enhance citizens' mobility throughout Europe

- **New regional transport** applications enabled by electric-powered aircraft
  - **Microfeeder** service: hub-and-spoke (feeding travellers to international airports)
  - **Intercity** service: point-to-point (connecting small cities)

- Key market towards EU's **Flightpath 2050 4-hour-door-to-door** goal
  - Very underdeveloped / non-existing today
  - Predictions needed to define a **possible scenario** and its potential

To analyse future regional air transportation scenarios, the **SHARONA** (Short-Haul Air Route Optimal Network Assessment) methodology has been developed

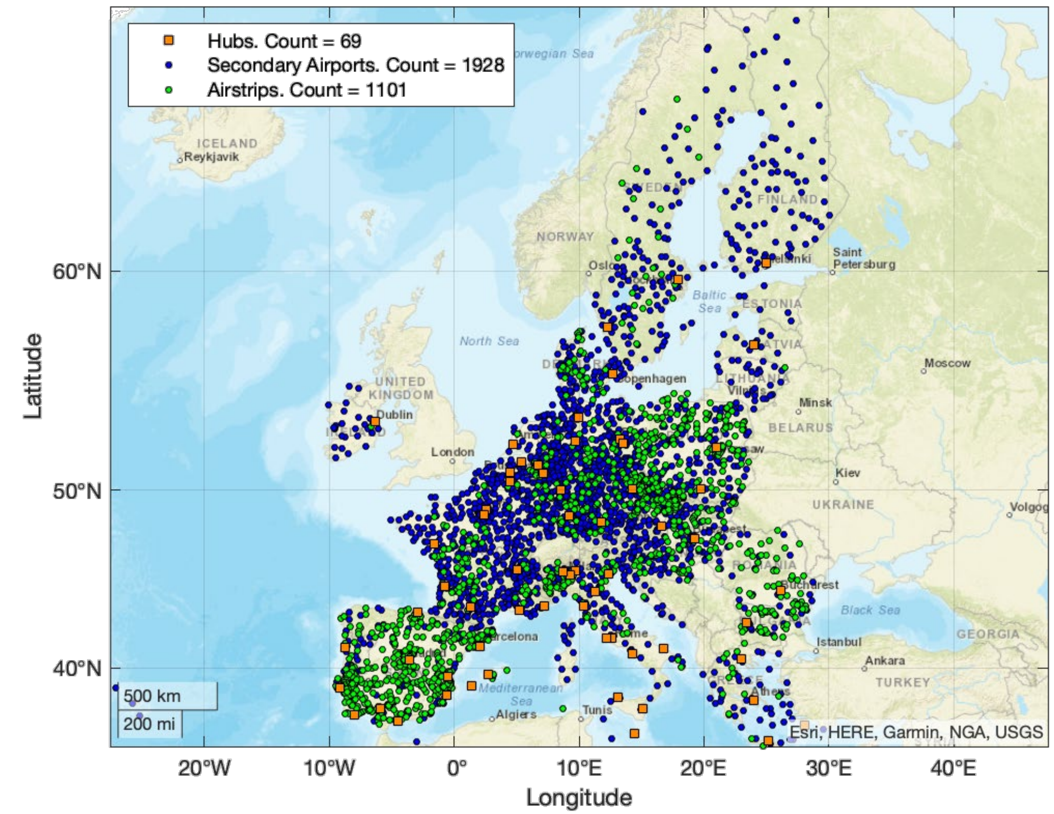
- **Candidate aerodrome and route** preliminary analysis
- Phase 1: **Potential travel demand estimation**
  - Potential Demand Algorithm (PDA) to determine the potential travellers and their location
- Phase 2: **Optimal route network definition**
  - Specialized Location and Routing Problem solution algorithm to capture the potential travel demand

→

- Scenario studies for **decision-making**
- Determination of some crucial aircraft and airport **design requirements**

Potential travel demand estimation

- Analysis of existing **3,098 EU-27 aerodromes**
  - Type: hub, secondary airport, airstrips
  - Runway surface and length
  - Geography: distribution, mutual distances
- **1,376 secondary aerodromes** with runway length over 600 m
  - 1,214 secondary airports
  - 162 airstrips
- Mutual distance: over 90% **within 150 km**



Potential travel demand estimation

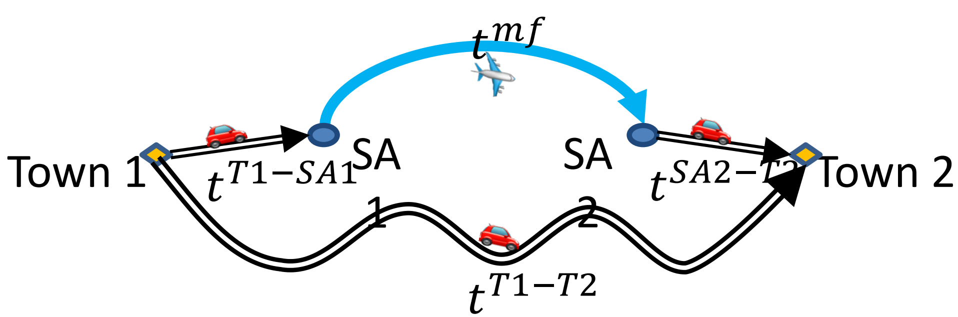
- Assessment of the **competitivity of the micro-feeder or intercity** routes compared to ground transportation and down-selection of potential routes to profitable ones

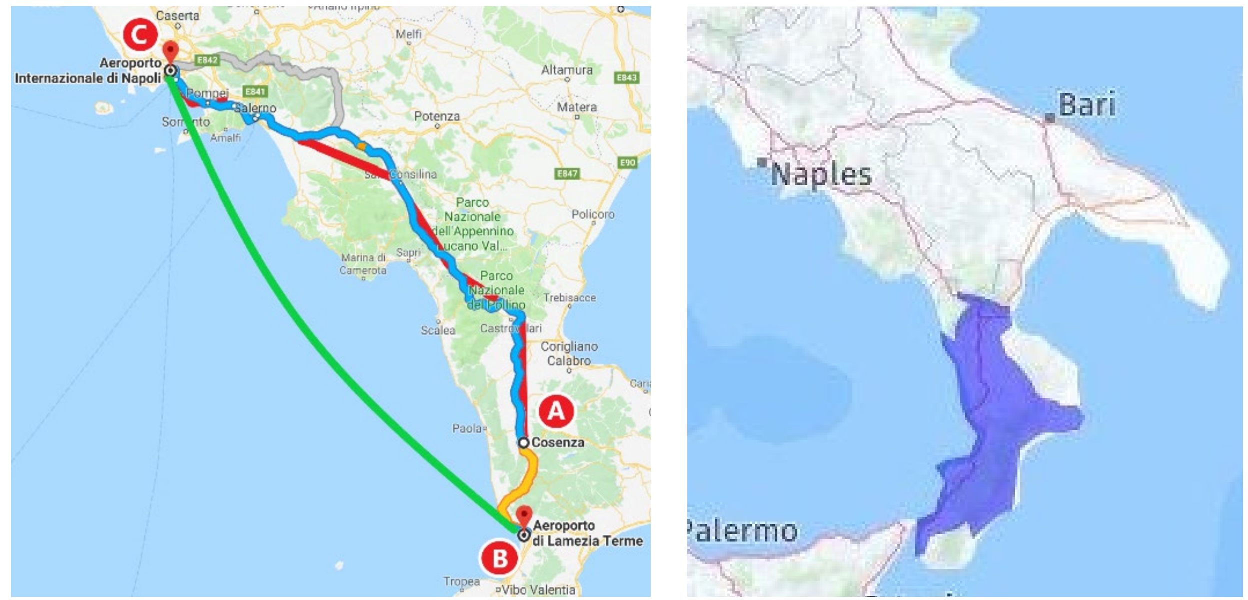
Route catchment area

Based on the time advantage with respect to land transportation

$$t^{mf} + t^{T-S} \leq \frac{t^{T-H}}{k},$$
$$\left|t^{T-H} - (t^{mf} + t^{T-S})\right| \geq t_{ref}.$$

k	1.3
t_{ref}	30 min





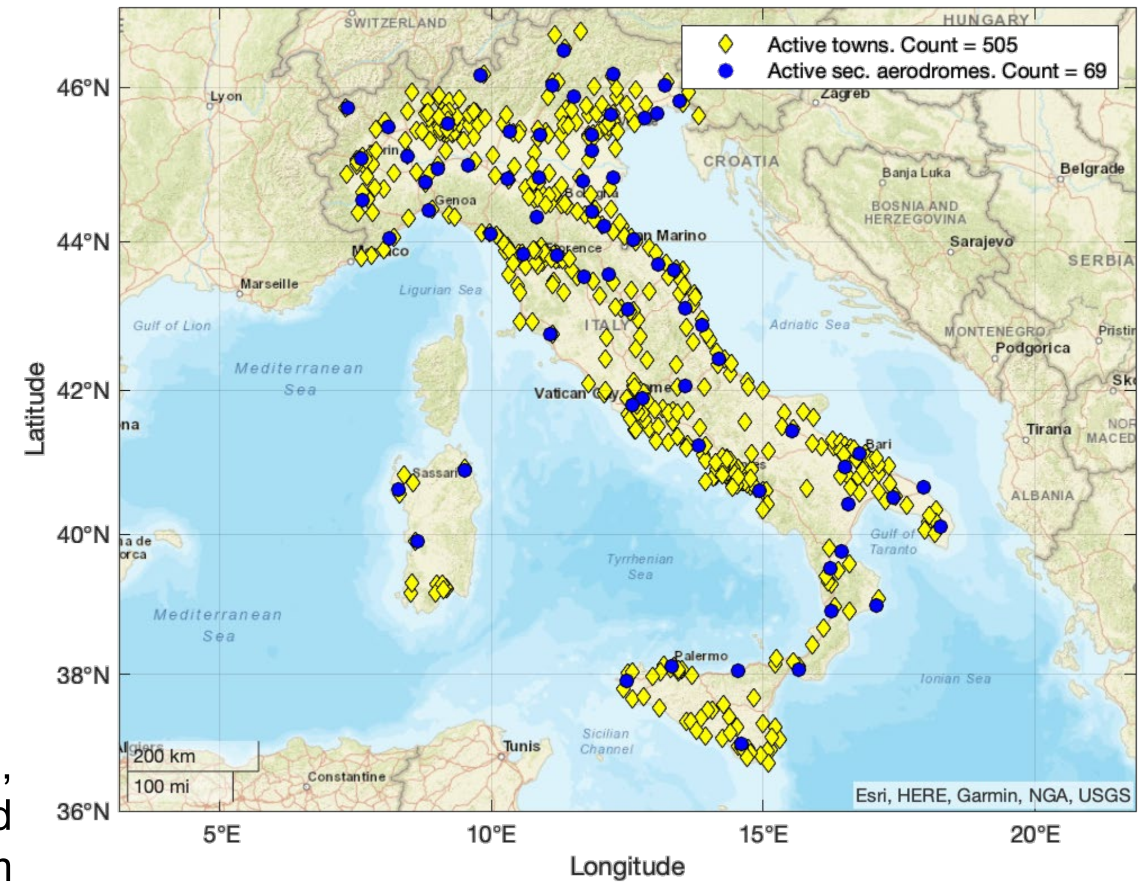
Catchment area example for the microfeeder route between Lamezia Terme and Naples, Italy

Potential travel demand estimation

Intercity service: Italian scenario

- Commuter matrix from 2011 census
- Towns with over 20,000 inhabitants

- 45 case studies
  - Trip distance from 100 to 300 km
  - Cruising speed from 150 to 250 KTAS
  - Cruising altitude 4,000 ft (when possible)
  - Runway length from 600 to 1,000 m



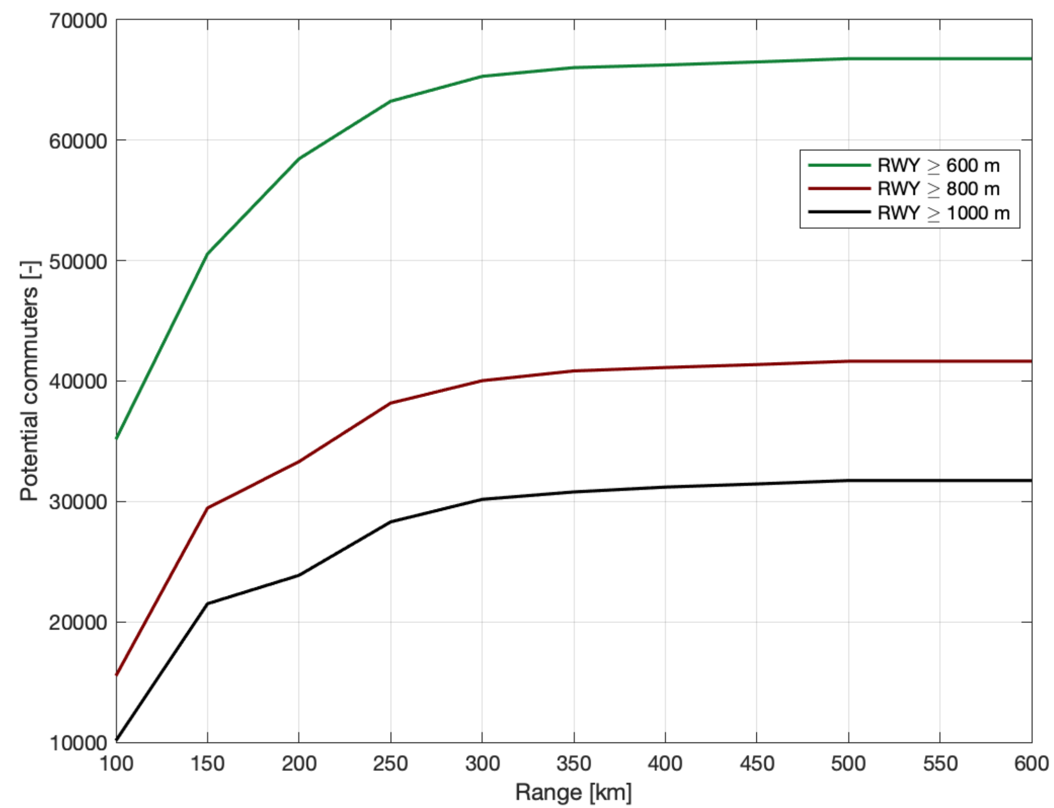
Example: trip distance 200 km, cruising speed 200 KTAS and runway length >=800 m

Potential travel demand estimation

Intercity service: Italian scenario

- Commuter matrix from 2011 census
- Towns with over 20,000 inhabitants

- Potential commuters increase with aircraft range, reaching **saturation at 350 km**



Potential demand example:
cruising speed 200 KTAS,
variable range and runway length

Optimal route network definition

Formulation: Specialized location and routing problem

- Primary goal: maximization of the total demand satisfied
- Secondary goal: minimization of the number of activated airports

Input
- *Fleet of HE aircraft*
- *Set of hubs*
- *Set of secondary airports*
- *Potential demand estimation (route function & catchment areas)*
- *Time horizon (day fraction)*

***Solution** through a Mixed Integer Linear Programming (MILP) approach* →

Output
- *Active routes and secondary airports to be activated*
- *Scheduling of each aircraft*

Optimal route network definition

Microfeeder service: Northern Italy

- Five Hubs considered: Milano-Malpensa (MXP), Milano-Linate (LIN), Bergamo-Orio al Serio (BGY), Torino-Caselle (TRN) and Venezia-Tessera (VCE)
- 45 candidate secondary aerodromes

Number of hubs					5
Number of secondary airports					45
Number of airfields					54
Number of clusters					28
	MXP	LIN	BGY	TRN	VCE
Potential demand (10^3 people)	1,008	1,044	2,243	4,690	3,475
Secondary airports share	52%	44%	45%	53%	49%
Airfields share	48%	56%	55%	47%	51%

Scenario configuration and potential demand assessment

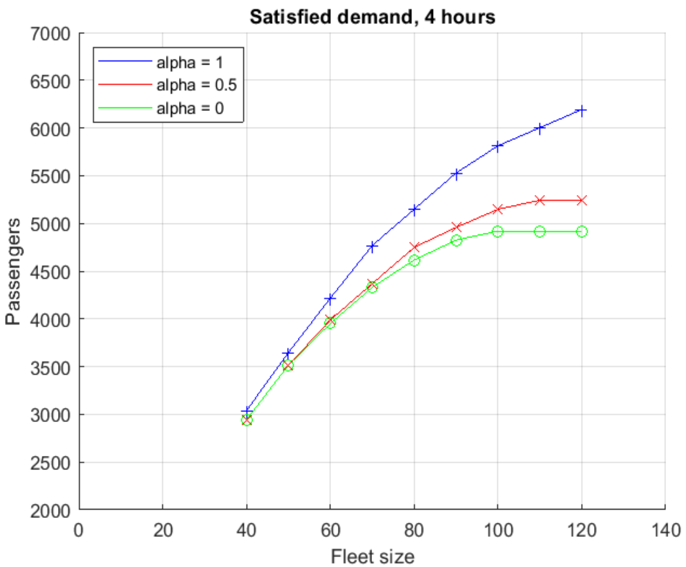
Performed optimization runs

Scenario ID	Time horizon	Fleet size (min-max)
#1	4 h (8-12)	10-120
#2	6 h (8-14)	10-50
#3	12 h (8-20)	10-30
#4	24 h	10-30

Optimal route network definition

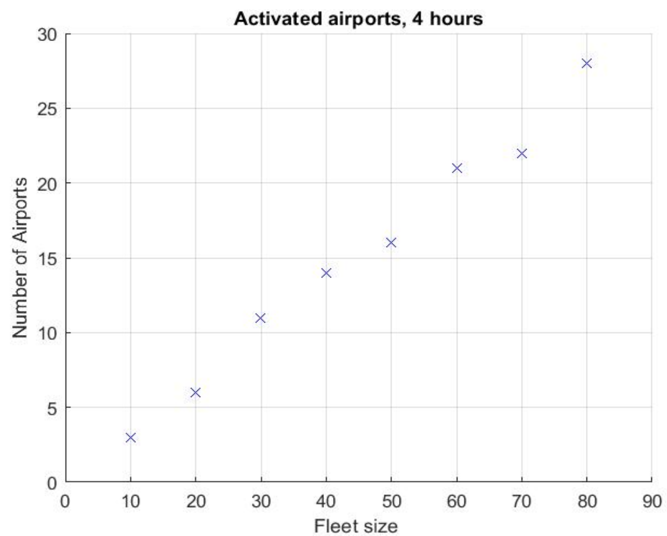
Microfeeder service: Northern Italy

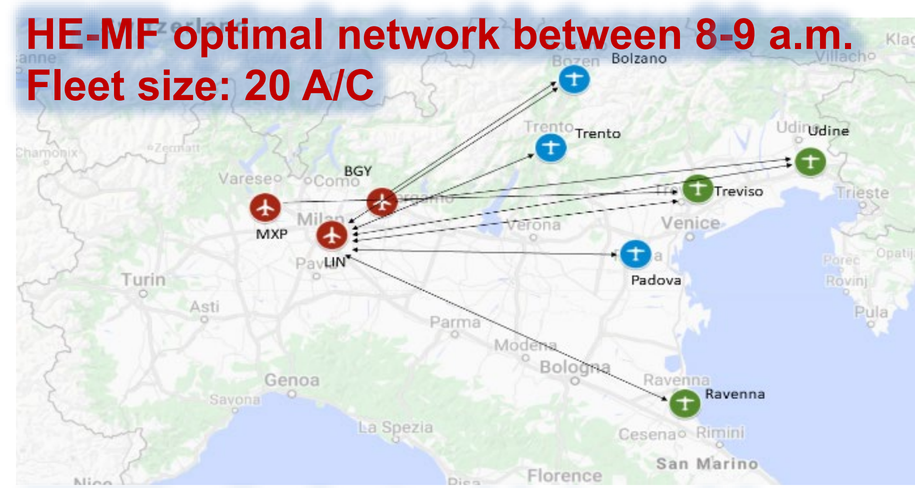
- Scenario #1

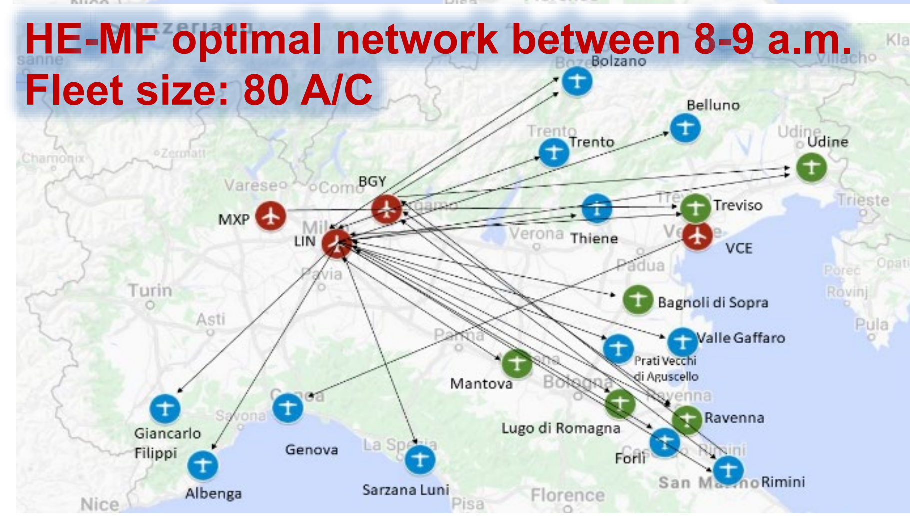


Captured demand as a function of fleet size and route function tuning parameter α

Number of **activated secondary aerodromes** as a function of fleet size







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Novel methodology dedicated to the conceptual design of **innovative airplanes**

- **General**, starting from **mission and certification requirements**
- New **propulsion systems**
- New **configurations**

Extensively applied in the MAHEPA (2017-21) and UNIFIER19 (2019-22) studies

- MAHEPA: conceptual analysis of 19-pax and 70-pax **hybrid-electric (HE) aircraft**
- UNIFIER19: full design loop for a **hydrogen-driven 19-pax** aircraft

Implemented in the HYPERION and TITAN **software suites**

- **HYPERION**: Preliminary sizing and sizing mission time simulation
- **TITAN**: Complete configuration initial design and performance verification

Modelling capabilities

- **Propulsion alternatives**
  - **Conventional** (reciprocating engine, turbine engine)
    - Thoroughly validated:
      from two-seater VLA to ATR72
  - **PE**: Pure battery electric
  - **ICE-HE**: Internal combustion engine hybrid-electric
  - **FC-HE**: Fuel cell hybrid-electric
    - GH2: Gaseous hydrogen tank
    - LH2: Liquid hydrogen tank

- **Configuration options**
  - Traditional aft tail, canard
  - Distributed Electric Propulsion (**DEP**), wing-tip propellers
  - Strut-braced wing

- **Mission simulation**
  - Time-marching simulation for sizing mission and off-design conditions
  - Multiple power & energy management strategies

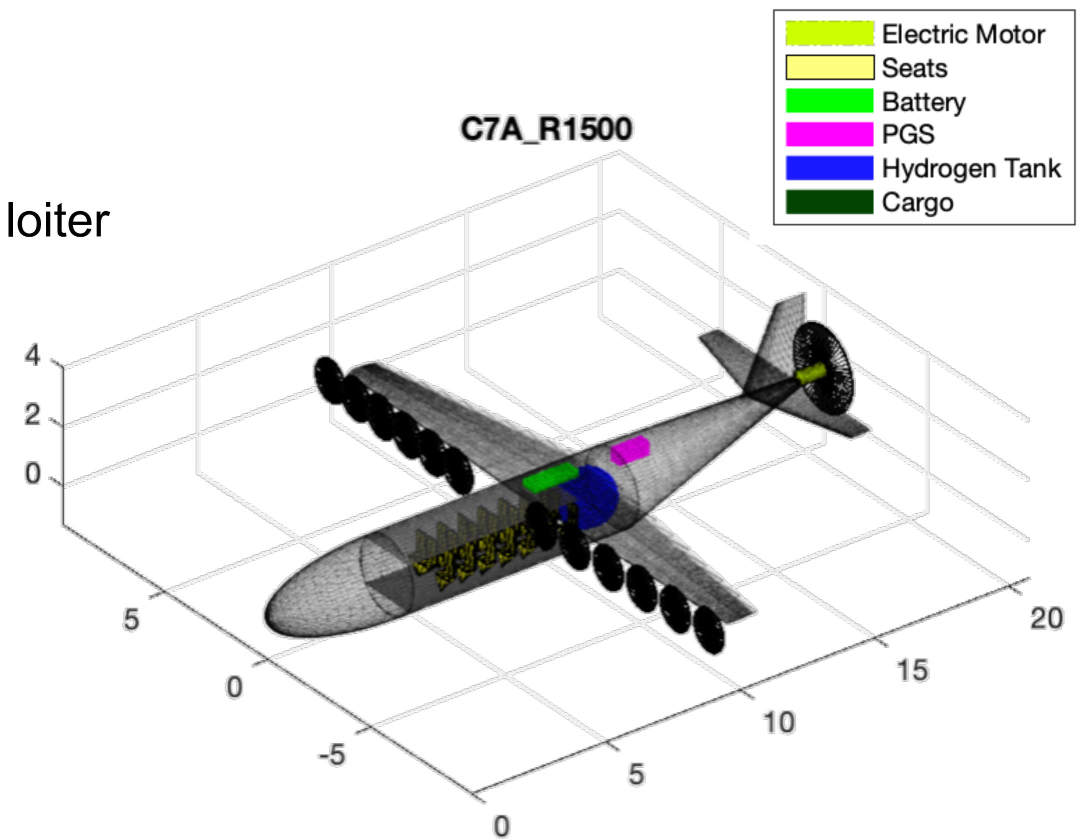
Example application: 19-pax FC-HE commuter

PGS (Power Generation System) = FC system

Main requirements
- CS-23 compliant, non pressurized
- Field length: 800 m; cruising speed: 140 KTAS
- Range: 1,500 km + 100 km diversion + 45 min loiter

Technology
- Battery Specific Power: 1.670 kW/kg
- Battery Specific Energy: 0.260 kWh/kg
- PGS power density: 2.130 kW/kg
- LH2 tank (gravimetric index 61%)

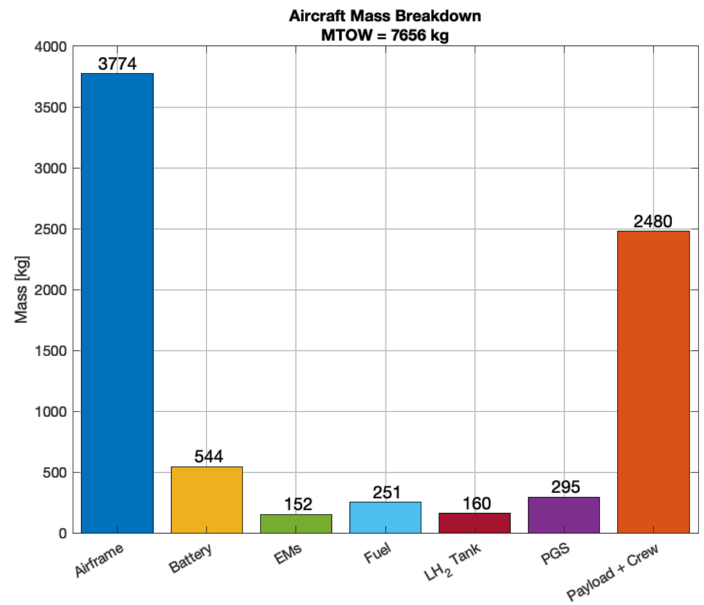
Configuration
- Traditional tail aft
- DEP + tail-cone propeller

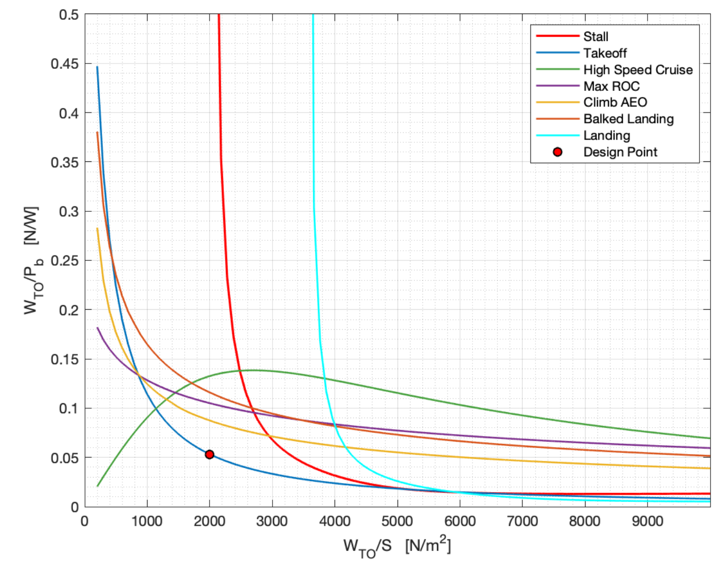


Example application: 19-pax FC-HE commuter

Preliminary sizing

- MTOM: 7,700 kg
  (CS23 limit: 8,626 kg)
- Wing surface: 37.6 m^2
  (not DEP-optimized)
- Electric motor power:
  1,100 kW + 700 kW DEP
- PGS power: 600 kW





Sizing matrix plot including the effects of DEP

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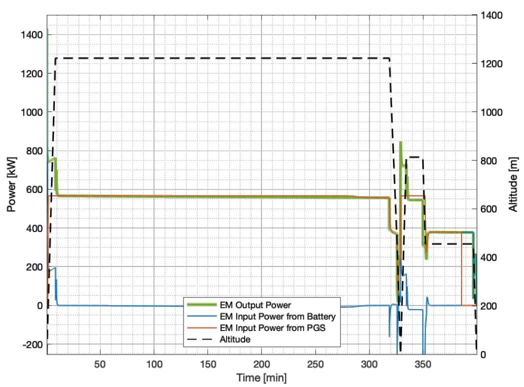
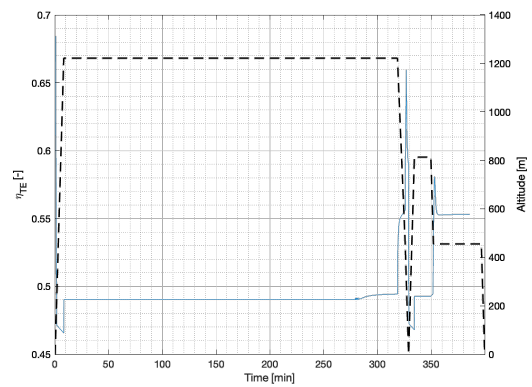
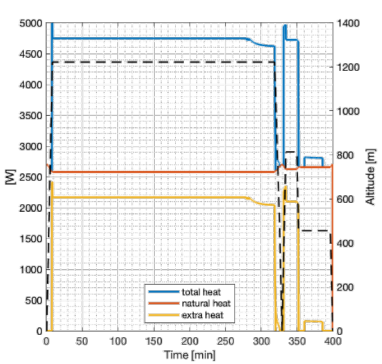
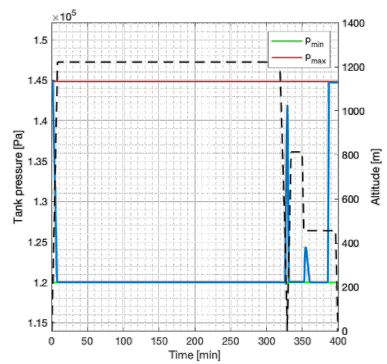
Example application: 19-pax FC-HE commuter

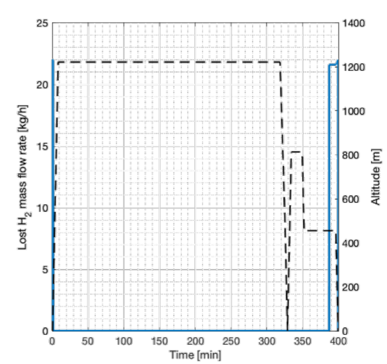
Sizing mission time simulation

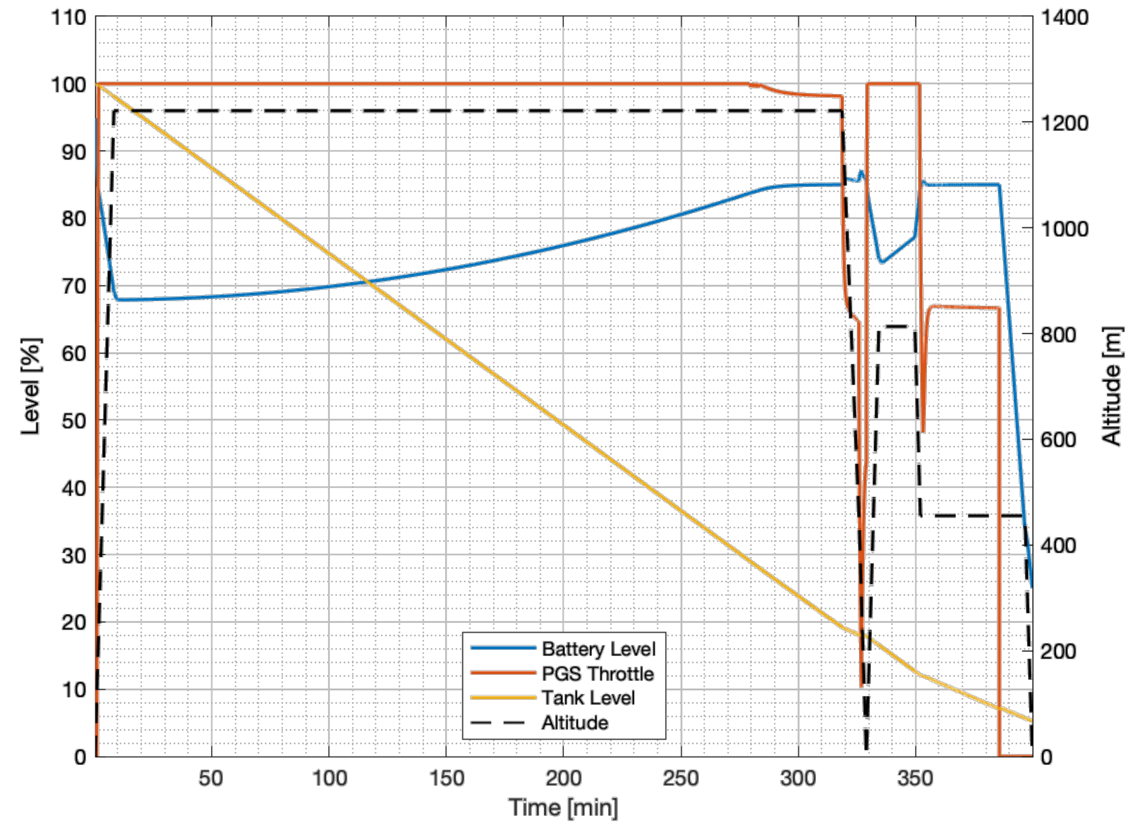












Novel methodologies devised for **electric-powered aviation** studies

- **Scenario studies** for future market analysis of regional air transportation
- **Conceptual/preliminary design** methods for innovative aircraft

Software suites

- **SHARONA** (Short-Haul Air Route Optimal Network Assesent)
  - Potential travel demand estimation
  - Optimal route network definition
- **HYPERION + TITAN** design tools for electric-powered aircraft
  - Preliminary sizing, sizing mission simulation
  - Configuration initial design, performance verification

Publications

- **Scenario studies** for future market analysis of regional air transportation
  - Trainelli L., Riboldi C. E. D., Rolando A., Salucci F., "Methodologies for the Initial Design Studies of an Innovative Community-Friendly Miniliner", *IOP Conference Series: Materials Science and Engineering*, **1024**, 012109: 1-8 (2021). doi:10.1088/1757-899X/1024/1/012109
  - Salucci F., Trainelli L., Bruglieri M., Riboldi C. E. D., Rolando A., "Capturing the Demand for an Electric-Powered Short-Haul Air Transportation Network", AIAA paper no. 2021-0869, AIAA SciTech Forum, January 11–15, 2021. doi:10.2514/6.2021-0869
- **Conceptual/preliminary design** methods for innovative aircraft
  - "A General Framework for the Preliminary Sizing of Serial Hybrid-Electric Aircraft" (to be published).
  - Trainelli L., Riboldi C. E. D., Salucci F., Rolando A., "A General Preliminary Sizing Procedure for Pure-Electric and Hybrid-Electric Airplanes", Aerospace Europe Conference (AEC 2020), Bordeaux, France, February 25-28, 2020.

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Thank you for your attention!

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