Design of sustainable UAVs

Some notes from a scientific research

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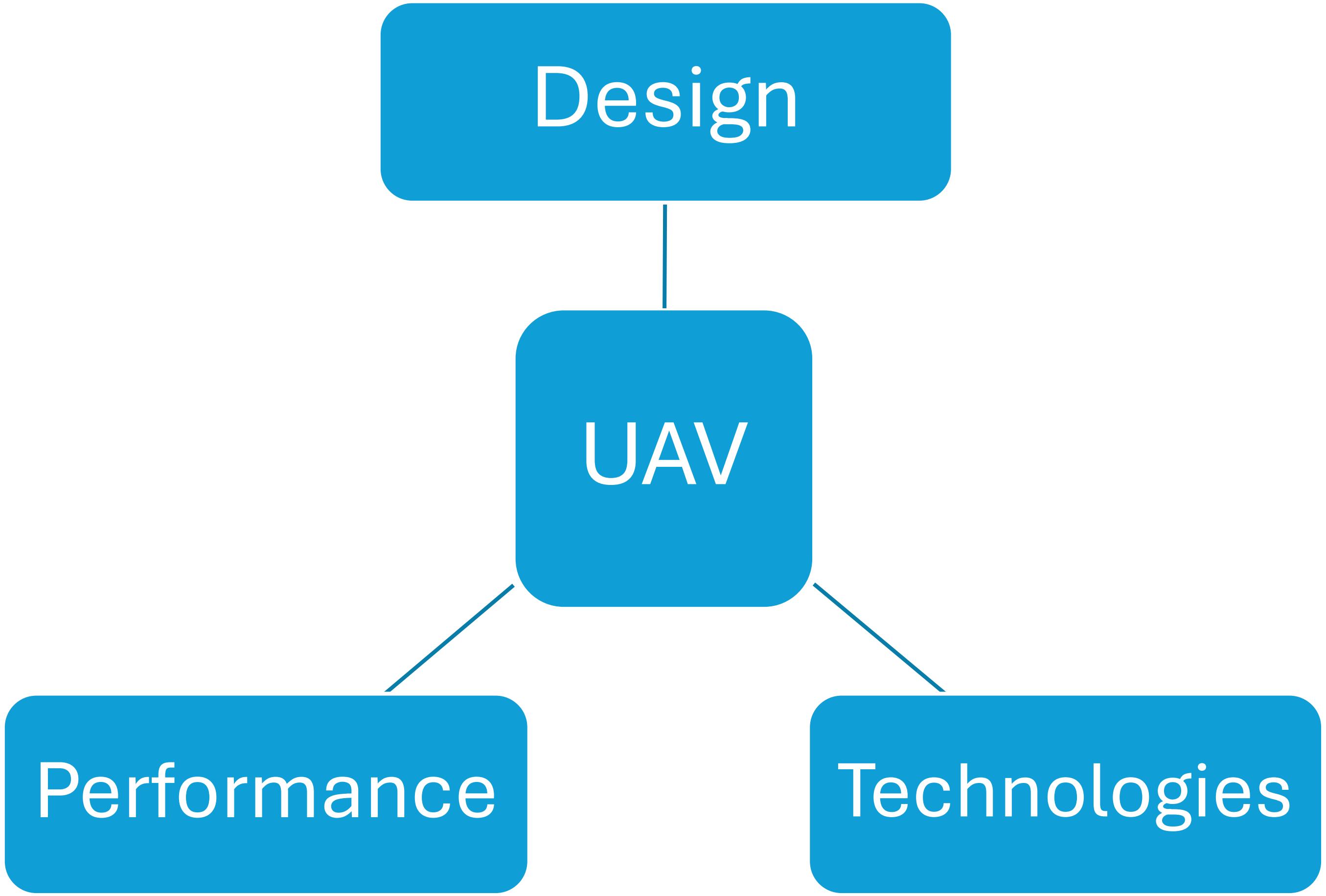
Agenda

1. DAF research group
2. Design
3. Technologies
4. Performance



Danilo Ciliberti

- Aerospace Engineer, PhD
- Former EUROAVIA Napoli local board
- Assistant Professor in Flight Mechanics
- Researcher of Aircraft Design and Flight Mechanics
    - Semi-empirical methods
    - CFD (numerical methods)
    - Wind tunnel tests
    - Flight Simulation
- Co-founder of SmartUp Engineering

DAF Research Group @ UniNa

DAF: Design of Aircraft and Flight Technologies

Fabrizio Nicolosi

Full Professor

Agostino De Marco

Associate Professor

Pierluigi Della Vecchia

Associate Professor

Danilo Ciliberti

Assistant Professor

Salvatore Corcione

Assistant Professor

Vittorio Trifari

Post Doc

Vincenzo Cusati

Assistant Professor

Manuela Ruocco

Post Doc

Mario Di Stasio

Post Doc

Massimo Mandorino

PhD candidate

Valerio Marciello

PhD candidate

+

DAF Research Group @ UniNa

DAF research group: about 18 researchers, including 3 professors, 3 assistant professors, and several post-doc & PhD students.

The group is involved in applied research activities concerning:

- **Aircraft Design** (including hybrid/electric innovative concepts)
- **Aircraft Aerodynamic Design and optimization**
- **Flight mechanics and performance**
- **Wind Tunnel tests**
- **Flight Tests and Flight Simulation**

Deep involvement in European research projects

About 10 projects in 2015-2023 in Clean Sky 2, H2020, Horizon Europe and Clean Aviation, for global funding of about 3 M€

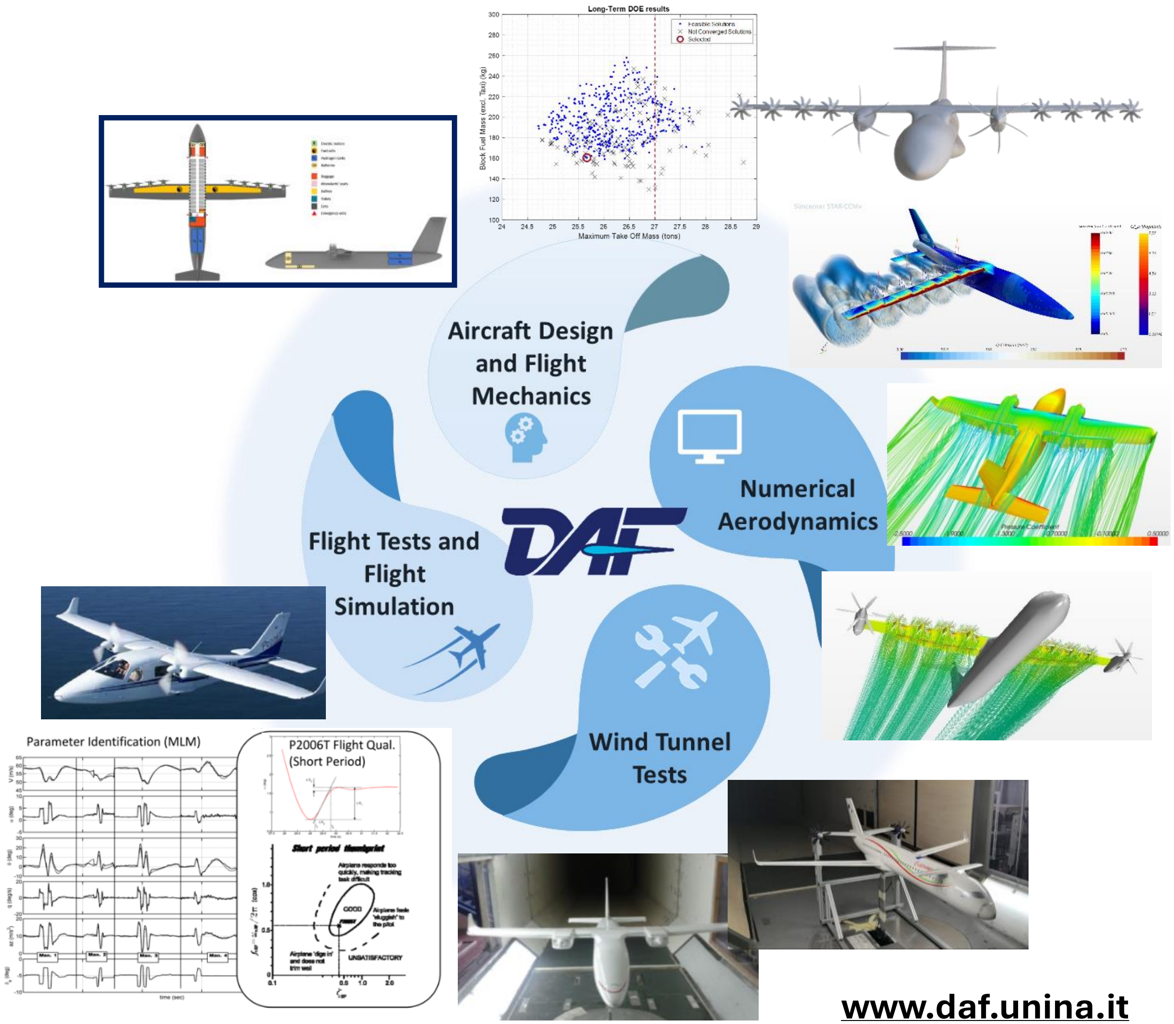
Collaborations

Leonardo Aircraft, Airbus, Tecnam, Piaggio, Bombardier, Embraer, DLR, ONERA, CIRA and several Universities (TUDelft, PoliTo, PoliMi, etc.)

Several research contracts with industries for specific design applications (Leonardo (ex Alenia), ATR, Piaggio, Tecnam)

Experimental facilities

- Low-speed wind tunnel for aircraft and airfoil testing
- Flight test instrumentation
- Scaled flight test instrumentation



www.daf.unina.it

SmartUp Engineering: a Spin-Off of the University of Naples Federico II

Together with UniNA

- Research Projects
- Research Agreements
- Publications
- Conferences

SmartUp Engineering

http://www.smartup-engineering.com/

info@smartup-engineering.com

2 Aircraft Design Software JPAD

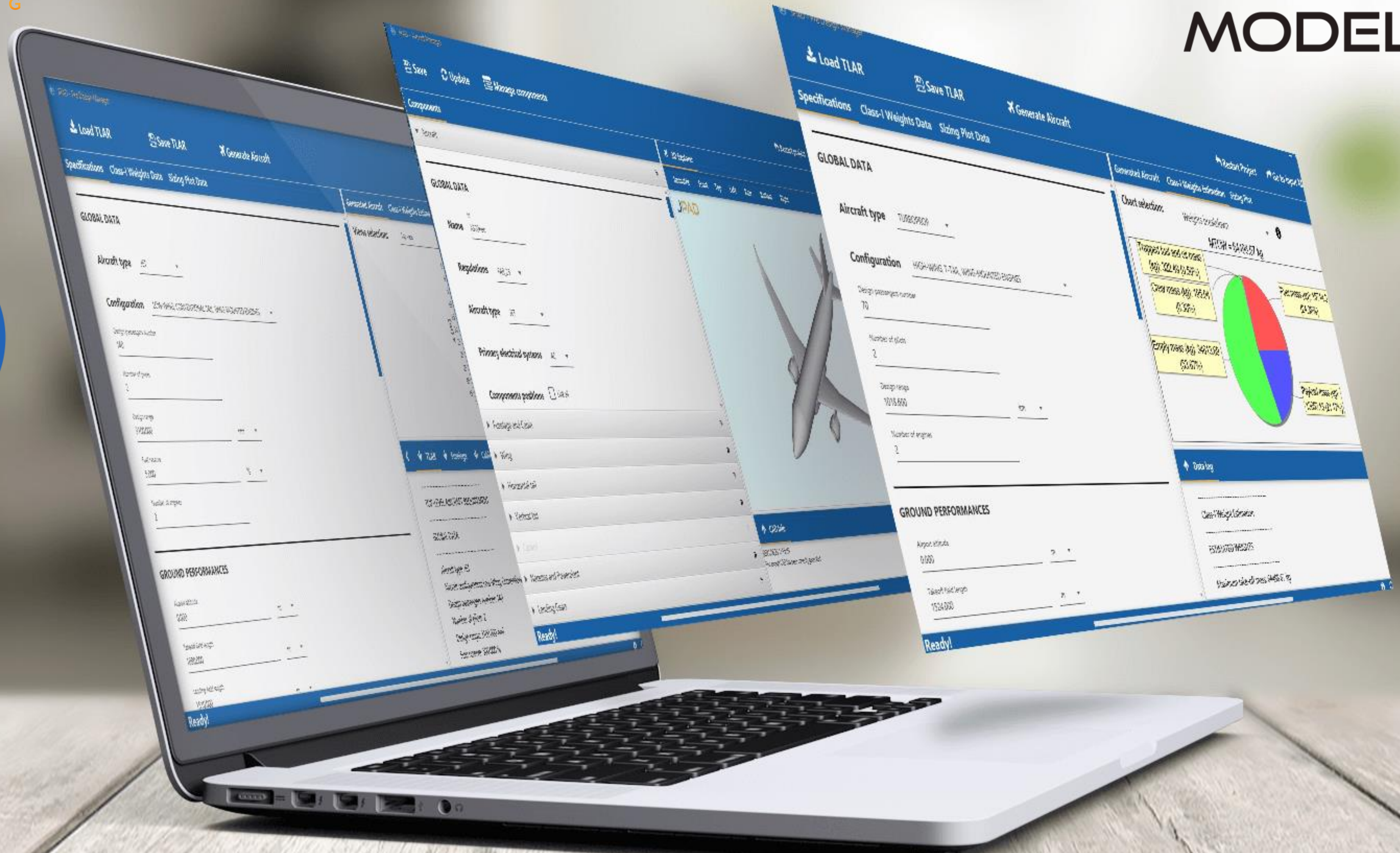
ADAS: Aircraft Design teaching software

1 Flight Simulator Interface JSBSim (Open Source Flight Dynamics)

SMARTUP ENGINEERING

DAF

JPAD MODELLER



“A knowledge-based and versatile pre-processor to simplify aircraft designers' life!”

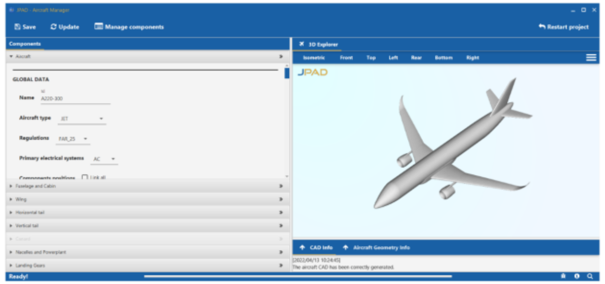
WHAT IS JPAD MODELLER ?

SMARTUP ENGINEERING

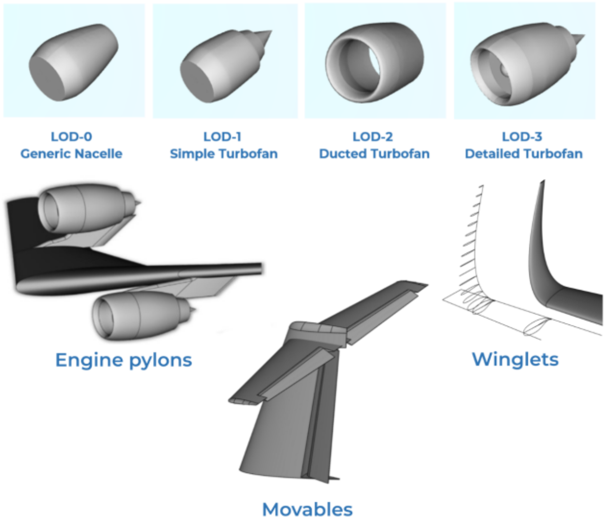
DAF

- SET OF TLAR
- PRE-DEFINED AIRCRAFT MODEL
- EMPTY AIRCRAFT

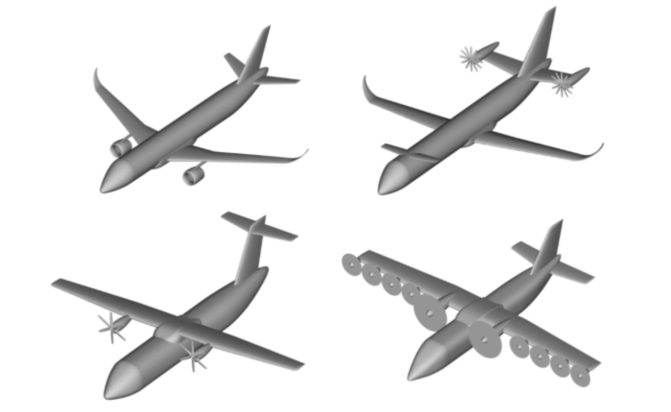
JPAD MODELLER



AUTOMATIC ADVANCED CAD FEATURES



AUTOMATICALLY GENERATED AIRCRAFT MODELS



→ THIRD-PARTY CAD SOFTWARE

EXPORT OPTIONS

FLIGHTSTREAM

TiGL

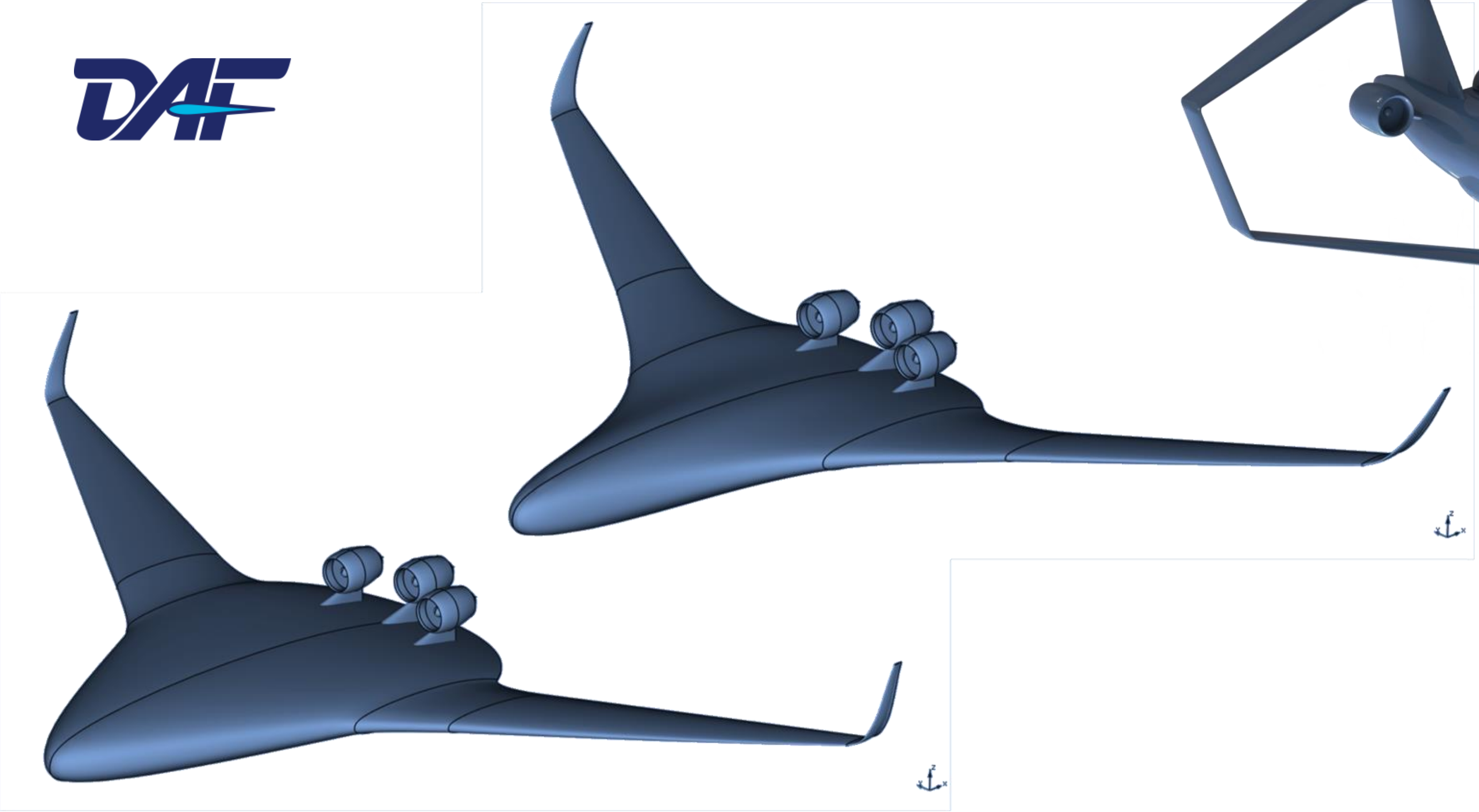
OpenVSP

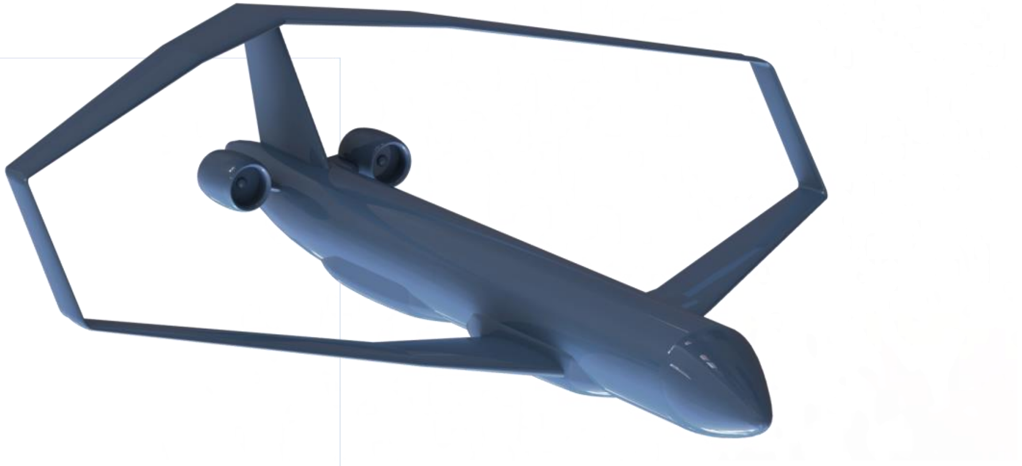
cpacs – A Common Language for Aircraft Design

→ PRELIMINARY AIRCRAFT DESIGN ANALYSES

Unconventional configurations

Features under development

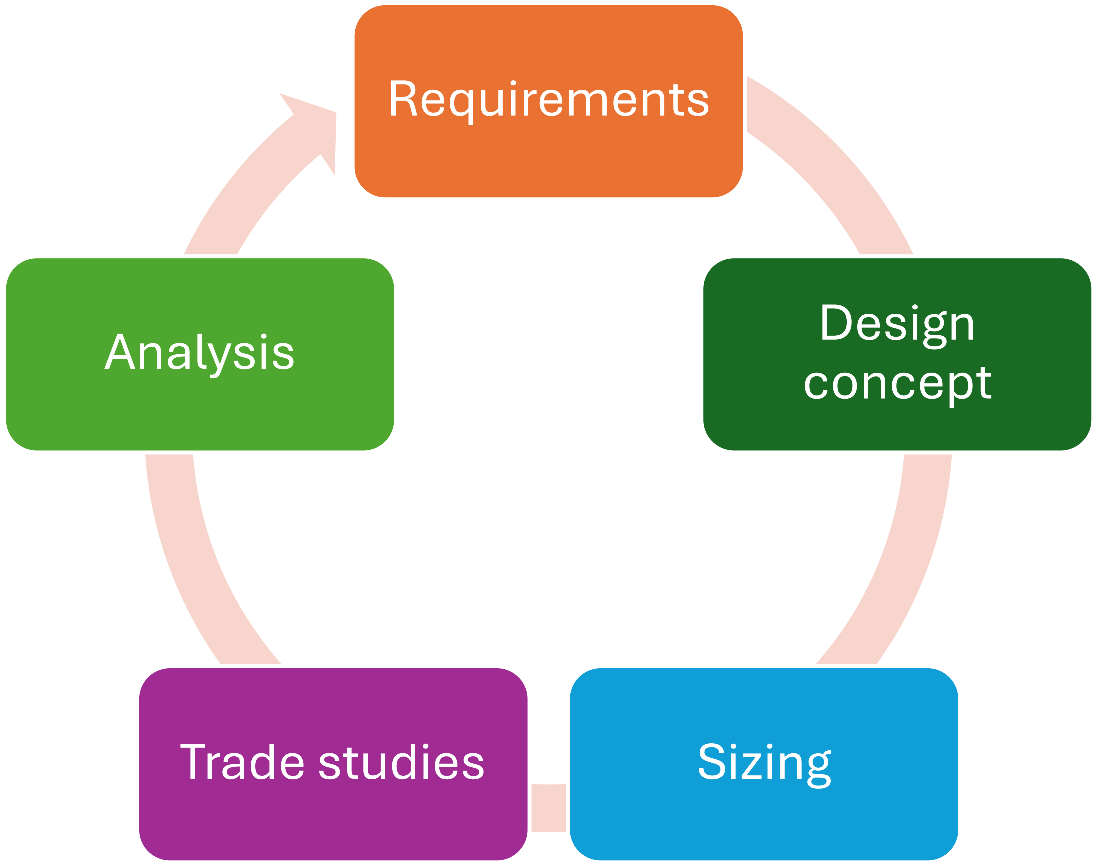




The aircraft design cycle

"A designer knows he has achieved perfection not when there is nothing left to add, but when there is nothing left to take away"

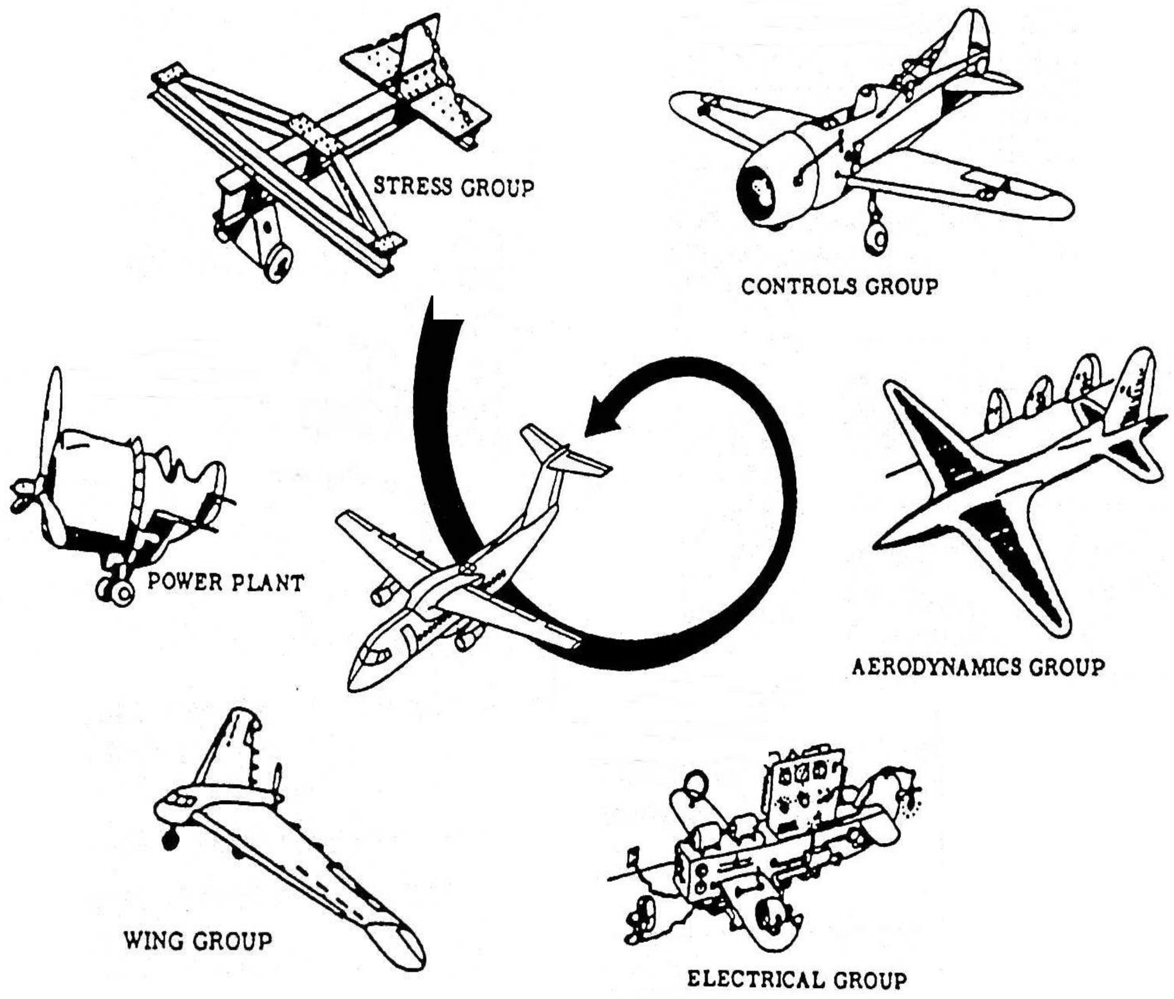
Antoine de Saint-Exupéry,
French writer, poet, and aviator



Based on Raymer – Aircraft Conceptual Design

Design as compromise

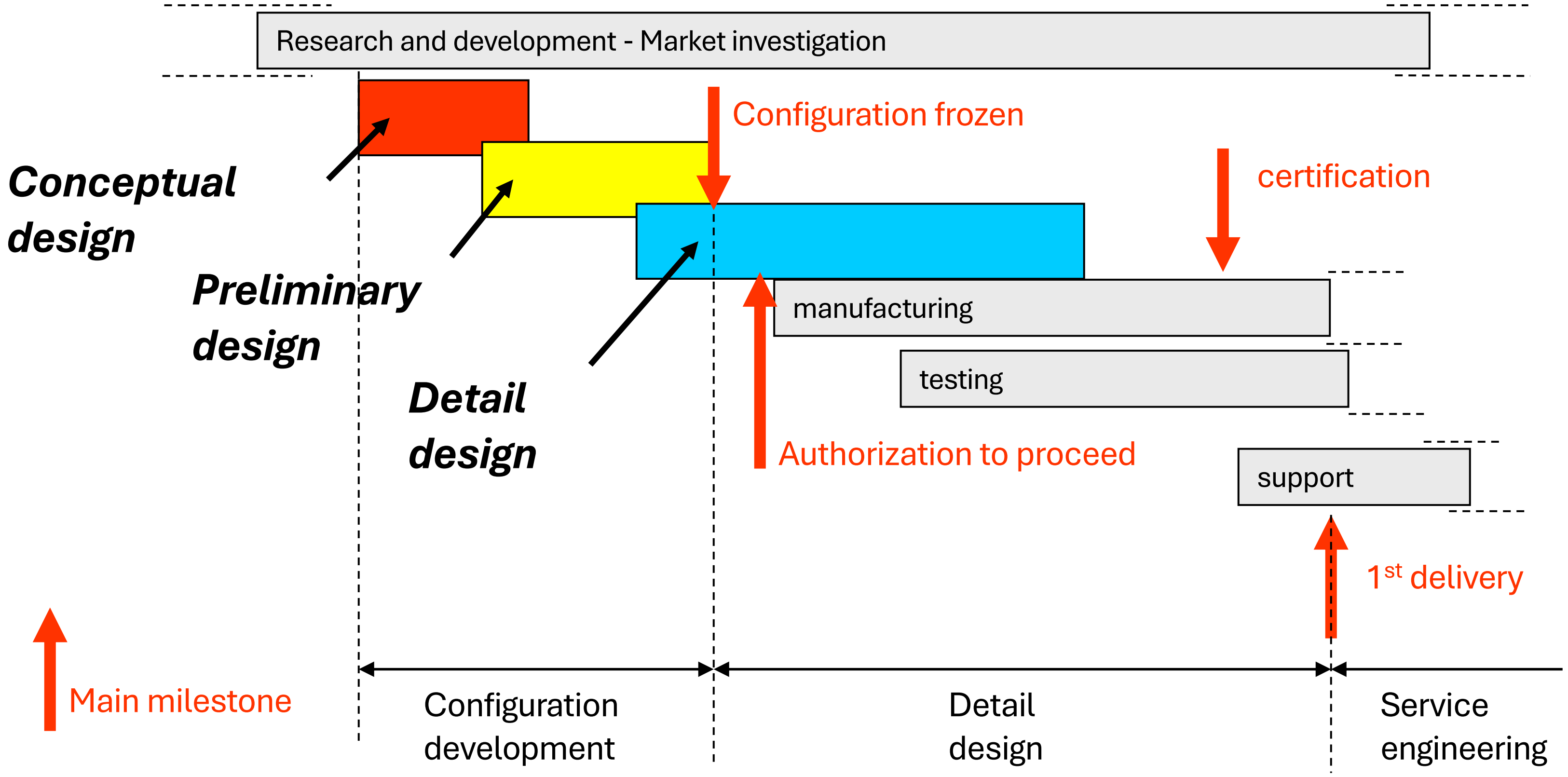
The final design is a compromise of many requirements, where each department or office attempts to prevail…



Phases of an aircraft development program

The design process is typically structured in three main phases:

Based on Torenbeek – Synthesis of subsonic airplane design

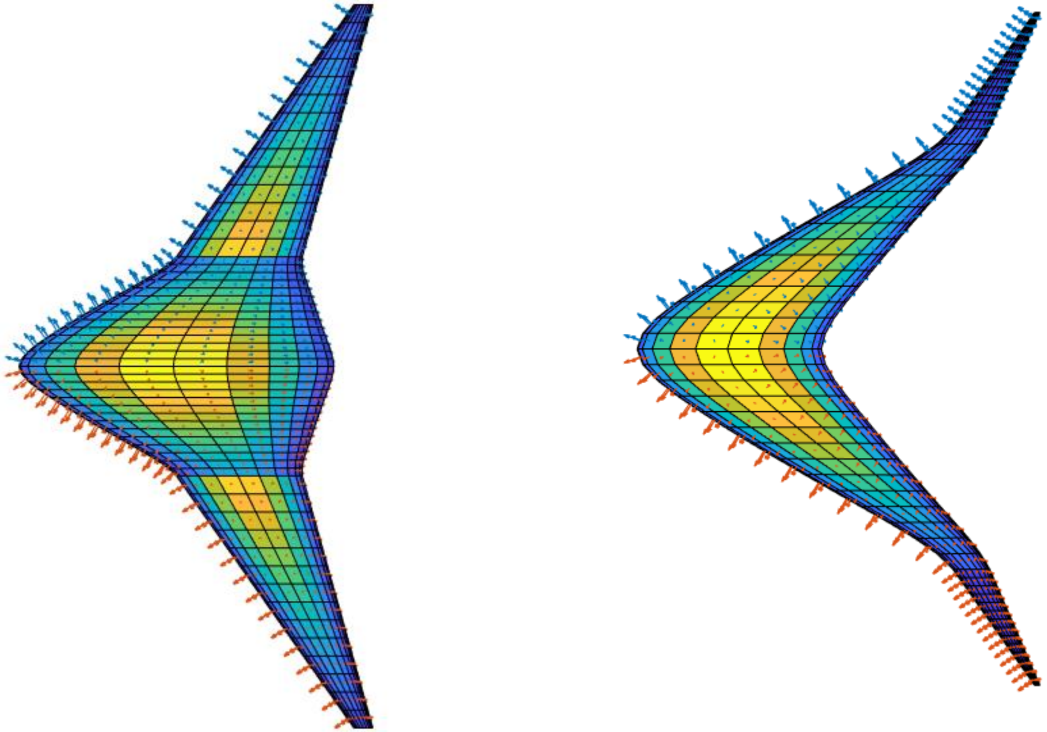


Conceptual design

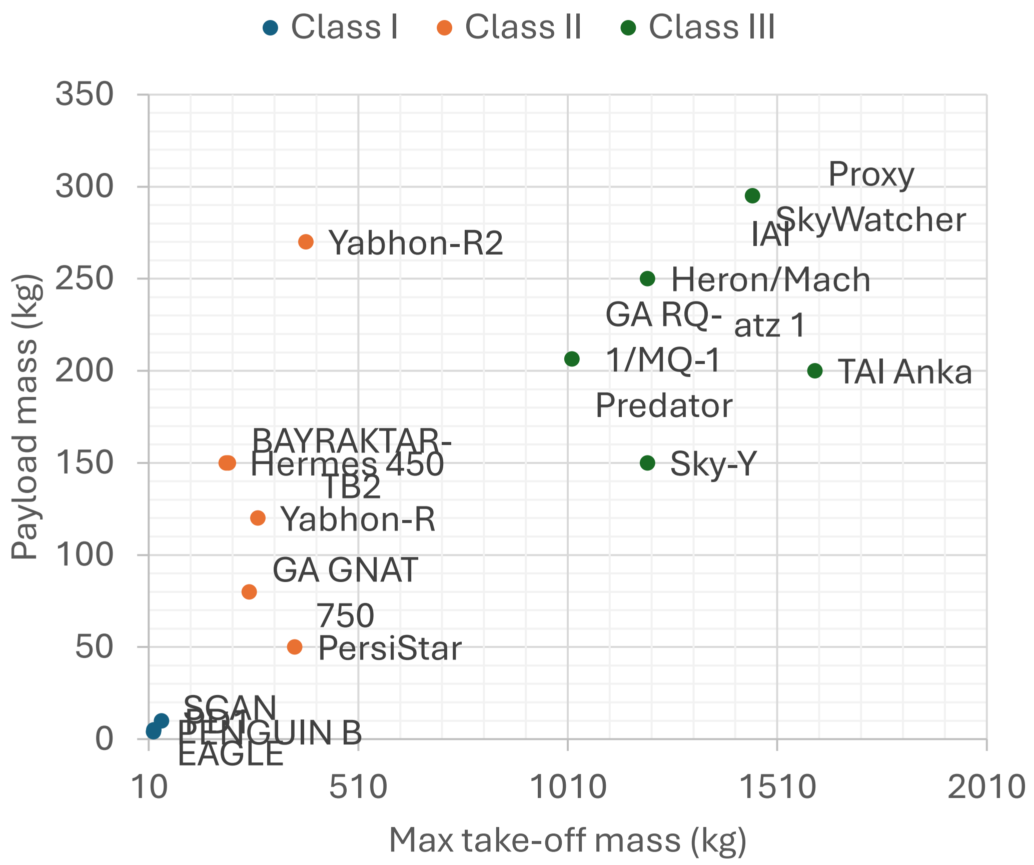
It answers the questions about:

- Layout
- Weight
- Size
- Performance
- Costs

...evaluating many alternatives with a low level of fidelity (sketches, spreadsheets, etc.) and a large use of statistics



Statistics and trade-off studies



CONFIGURATION TRADE STUDY								
		CONVENTIONAL		FLYING WING		BIPLANE		
Attribute	Weighting	Insert Score	Weighted score	Insert Score	Weighted score	Insert Score	Weighted score
Structural Weight	16%	0.6	0.096	1	0.16	0.3	0.048
Manoeuvrability	12%	0.8	0.096	0.5	0.06	0.6	0.039
Passengers Capability	20%	0.8	0.16	0.3	0.06	0.7	0.081
Speed	14%	0.8	0.112	1	0.14	0.4	0.037
Manufacturability	18%	1	0.18	0.25	0.045	0.5	0.065
Take-Off Run	10%	0.9	0.09	0.7	0.07	1	0.083
Reliability	10%	1	0.1	0.5	0.05	0.6	0.055
Totals	100%		0.83		0.59		0.41

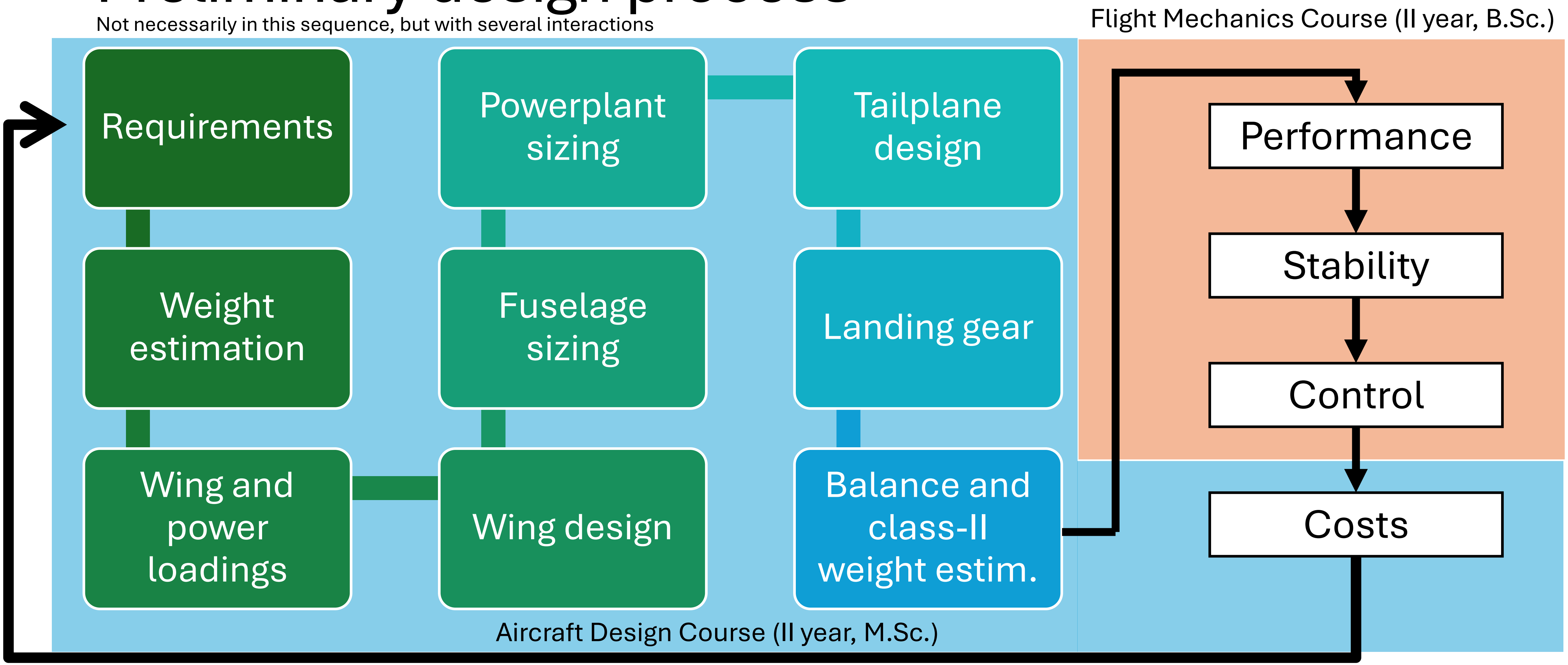
Excerpt from DBF theses

Preliminary design

- The preliminary design phase starts when the major changes in the proposed design solution are over
- At this stage you have already decided if the aircraft will be a blended wing body configuration or a conventional design
- This phase gets as input the baseline configuration, which is the output of the conceptual phase
- The purpose of this design phase is to develop the baseline configuration, until sufficient understanding such that the design can be frozen and the detail design phase can start
- Confidence has to be shown that the aircraft can be built on time at the estimated cost, because... HERE YOU BET YOUR COMPANY!

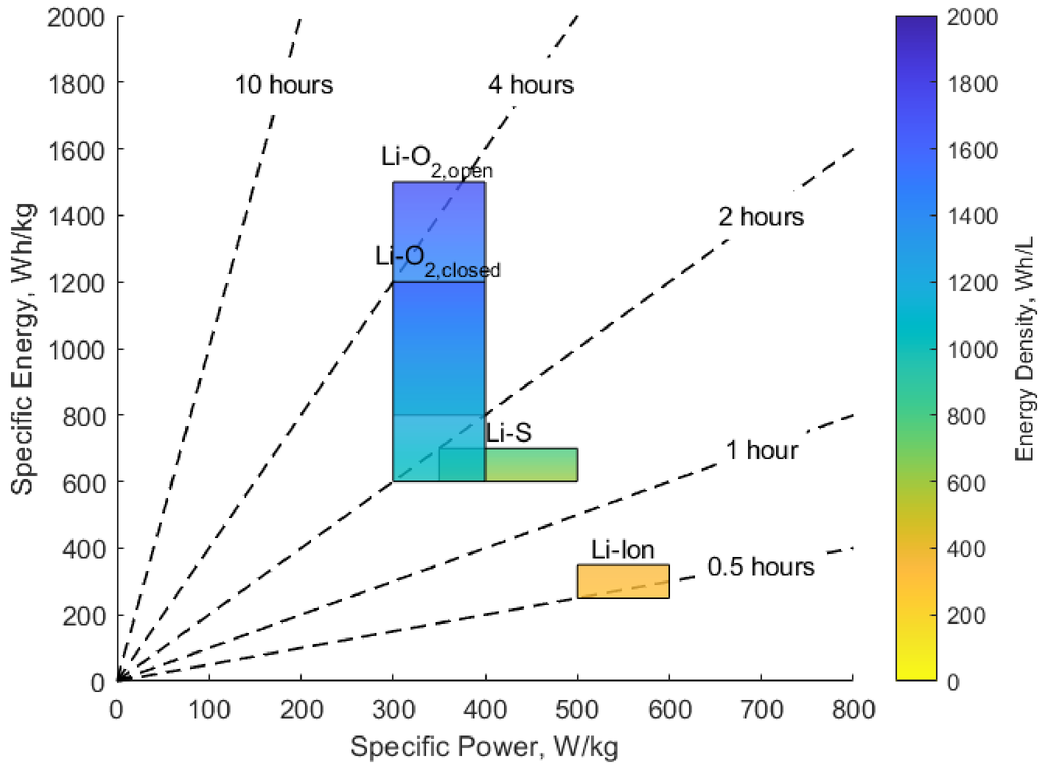
Preliminary design process

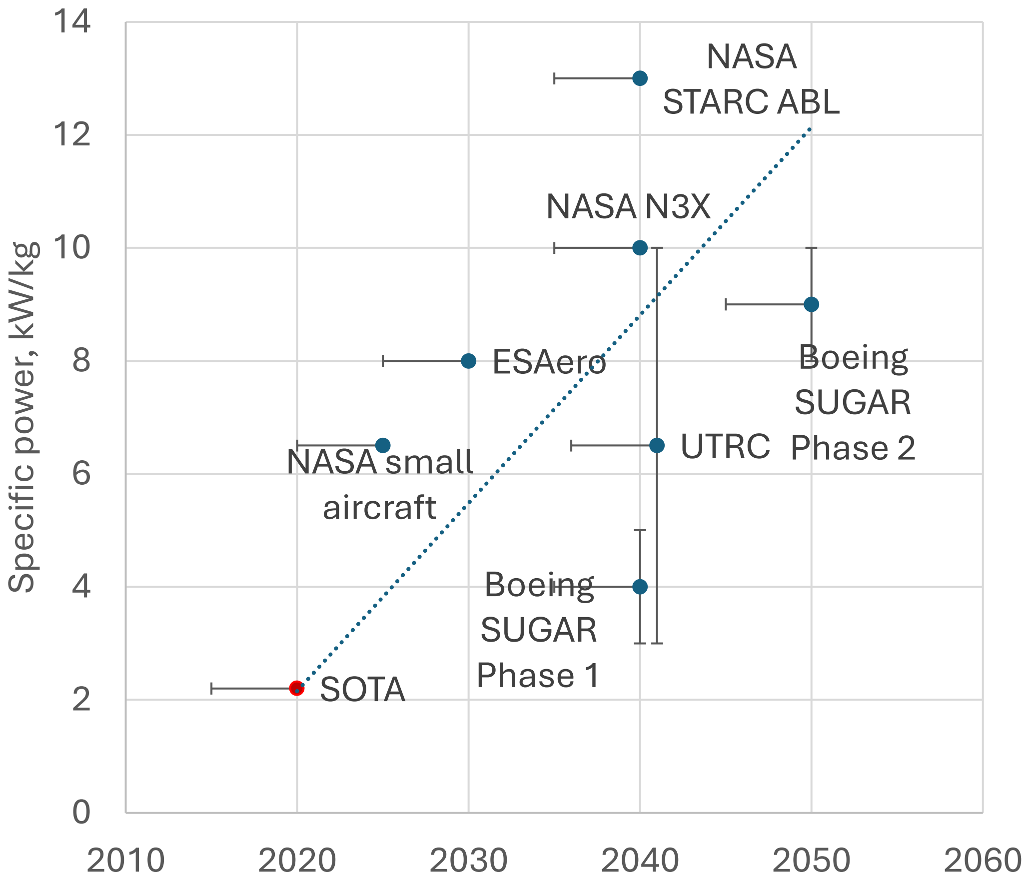
Not necessarily in this sequence, but with several interactions



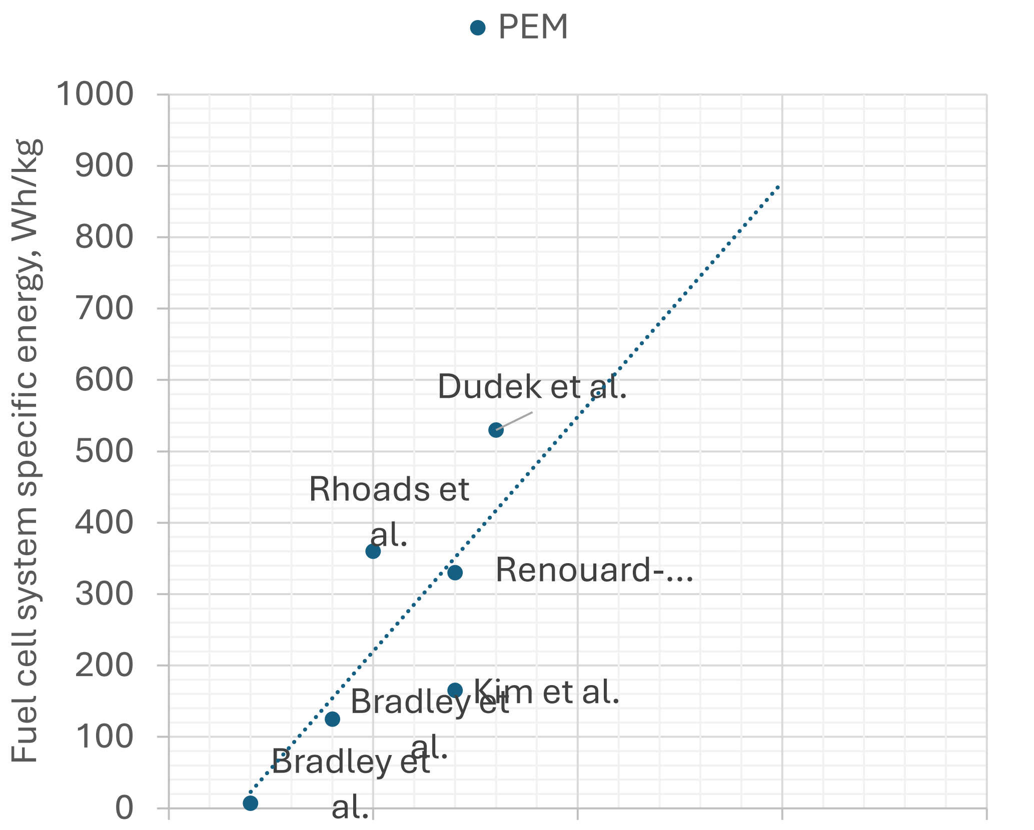
Battery and motor technologies for a sustainable flight

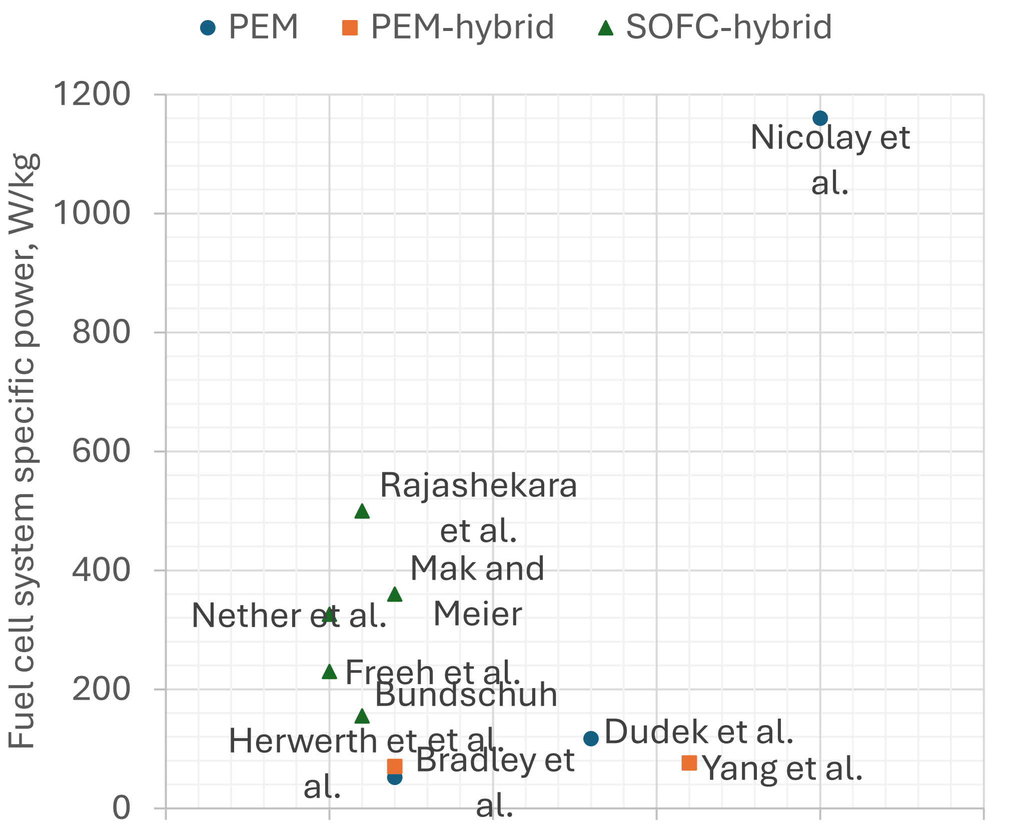
Forecasted battery technology by 2035





Fuel cell technology for a sustainable flight





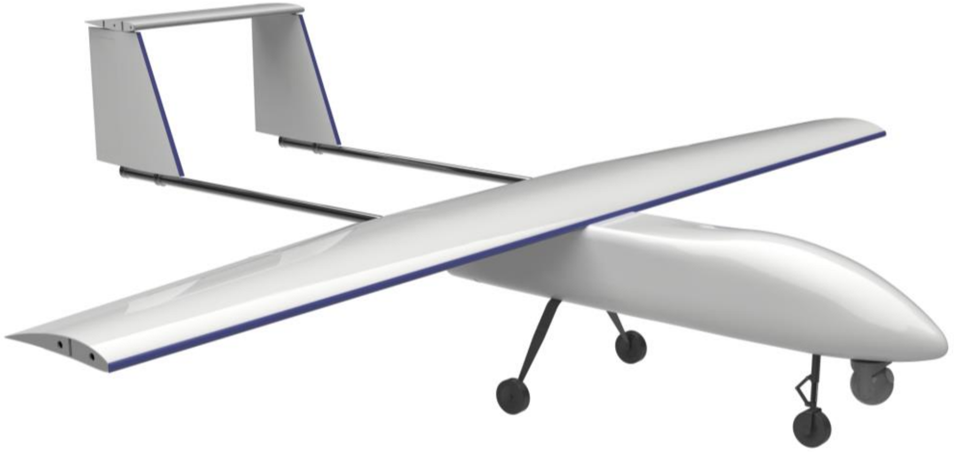
Case study

A customer asked for a fixed-wing UAV with medium aspect ratio and 18 hours endurance… but it had to be full electric!

We were aware of the impossible requirement and immediately negotiated down to a realistic value of 4 hours endurance!

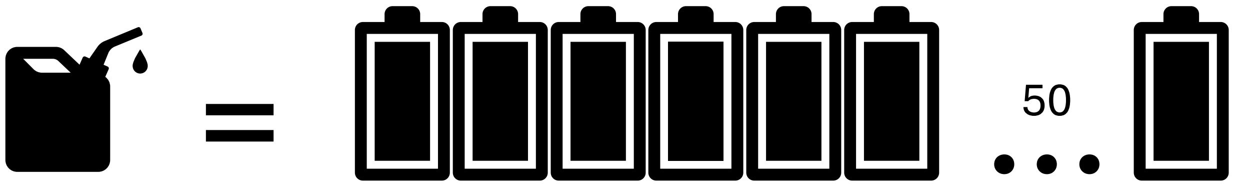
Specific energy (per unit of mass):

- battery pack = 200 Wh/kg
- fossil fuel = 11000 Wh/kg



Not the actual geometry! This is only an example!

1 kg fuel ≈ 50 kg batteries!



Statistics and trade studies

Here we selected:

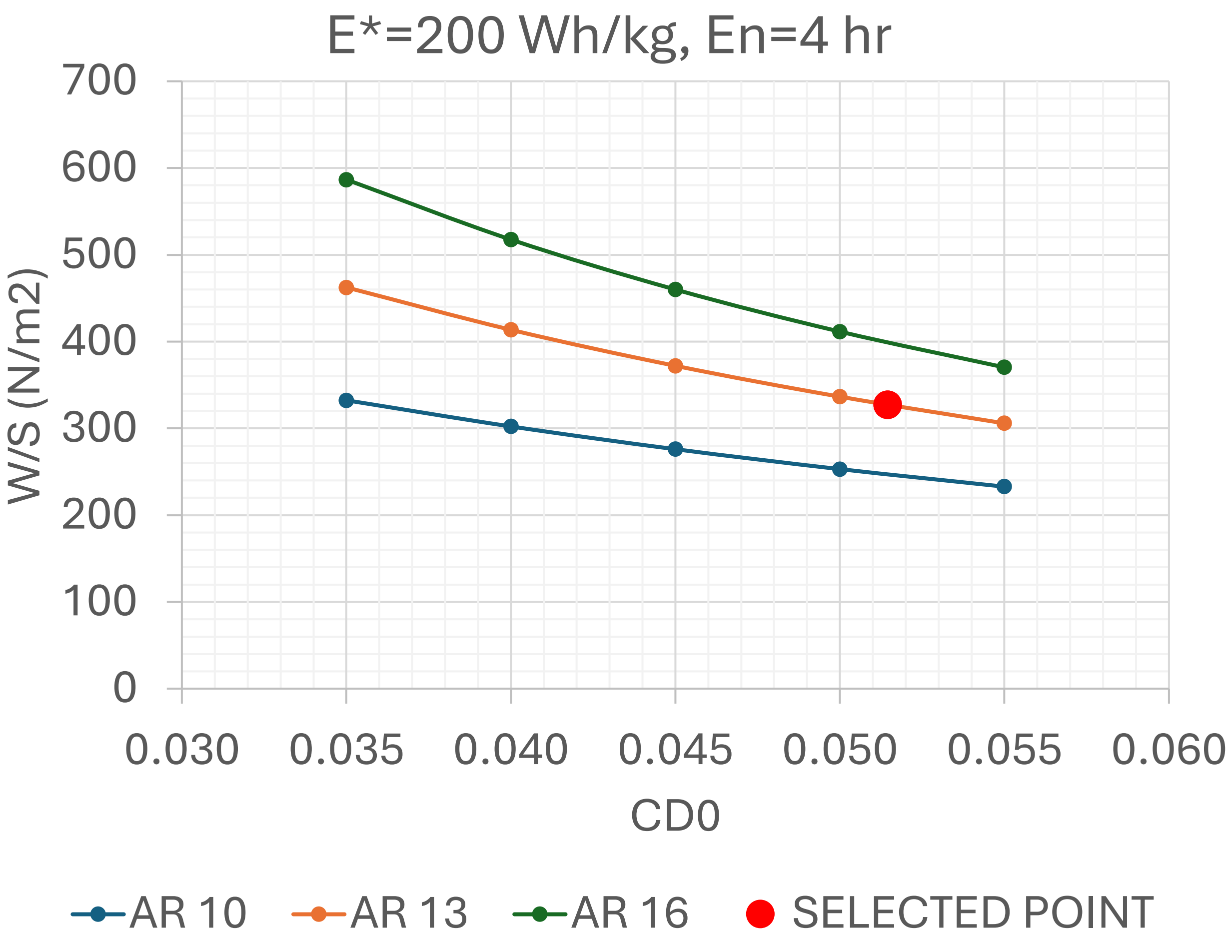
- a battery technology of 200 Wh/kg
- an endurance of 4 hours

We applied the Flight Mechanics equations:

- vertical equilibrium (lift)
- parabolic drag polar

We investigated the relationships among:

- wing aspect ratio
- zero-lift drag coefficient
- wing loading



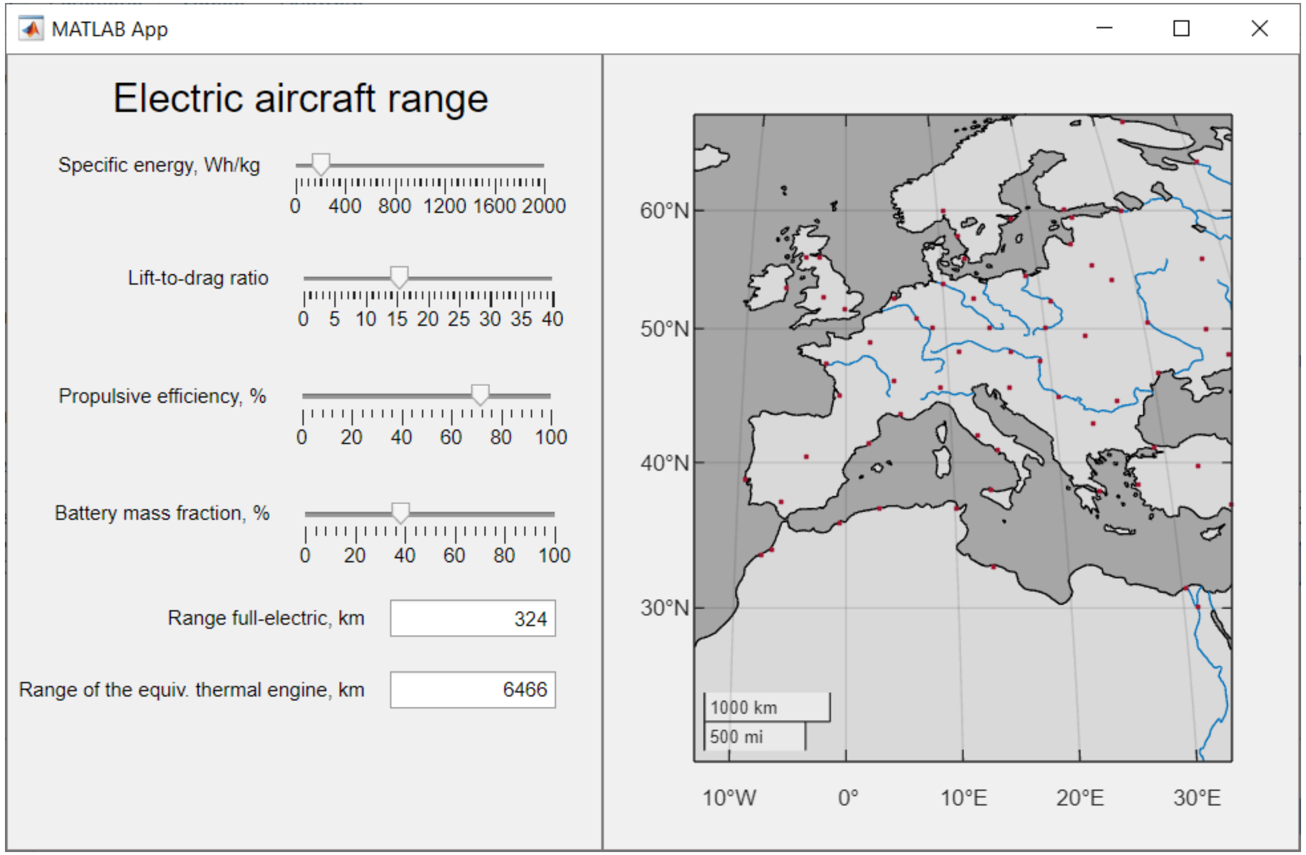
MATLAB App

Breguet formula for the range of propeller-driven aircraft:

$$R = 603.5 \frac{\eta_p}{SFC} \frac{L}{D} \ln \frac{m}{m - m_{fuel}}$$

Range formula for electric aircraft:

$$R = \frac{\eta_p E^*}{g} \frac{L}{D} \frac{m_{batt}}{m}$$



What I did *not* tell you

- The aircraft design is not only Aerodynamics, Flight Mechanics, and Weight estimation
- A deep understanding of Materials, Structures, Systems, Engines, and Regulations is needed
- With UAV, Systems and Electronics are even more important than usual

Conclusions

You now have a faint idea of UAV design for sustainable flight. To get a thorough understanding:

- Take your classes, all of them if you can, even those you don’t like (sooner or later they will be useful)
- Read some theses about RC and UAV aircraft from my UniNa webpage: http://wpage.unina.it/danilo.ciliberti/#theses
- Get a book like “Design of Unmanned Aerial Systems” by Dr. Mohammad H. Sadraey

Thank you for your attention

Any questions?