Università degli Studi di Napoli Federico II

Dep. of Industrial Engineering

Seminario

I Velivoli a Propulsione Ibrida

Aula Magna Università di Napoli Federico II
27 Ottobre 2018

Considerazioni ed applicazioni relative a velivoli regionali ed il progetto PROSIB

Fabrizio Nicolosi

Dip. Ingegneria Industriale

DAF
Design of Aircraft and Flight technologies
RESEARCH GROUP
www.daf.unina.it

AIRCRAFT DESIGN Research Group @ UNINA

DAF (Design of Aircraft and Flight Technologies)

- Focused on Aircraft Design
- Applied aerodynamics and aerodynamic design of transport aircraft
- Wind-Tunnel tests
- Flight Mechanics
- Flight Dynamics, flight tests and flight simulation

UNIVERSITÀ DEGLI STUDI DI NAPOLI FEDERICO II

DIPARTIMENTO DI INGEGNERIA INDUSTRIALE
SEZIONE INGEGNERIA AEROSPAZIALE

Design of Aircraft and Flight technologies
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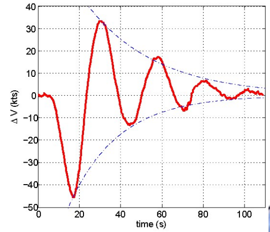
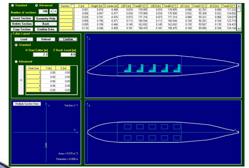
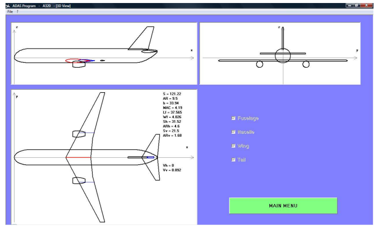
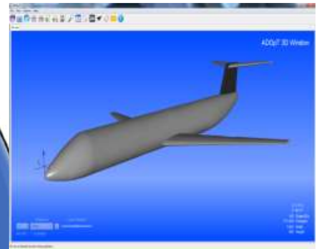
Research activities
FLIGHT PHYSICS

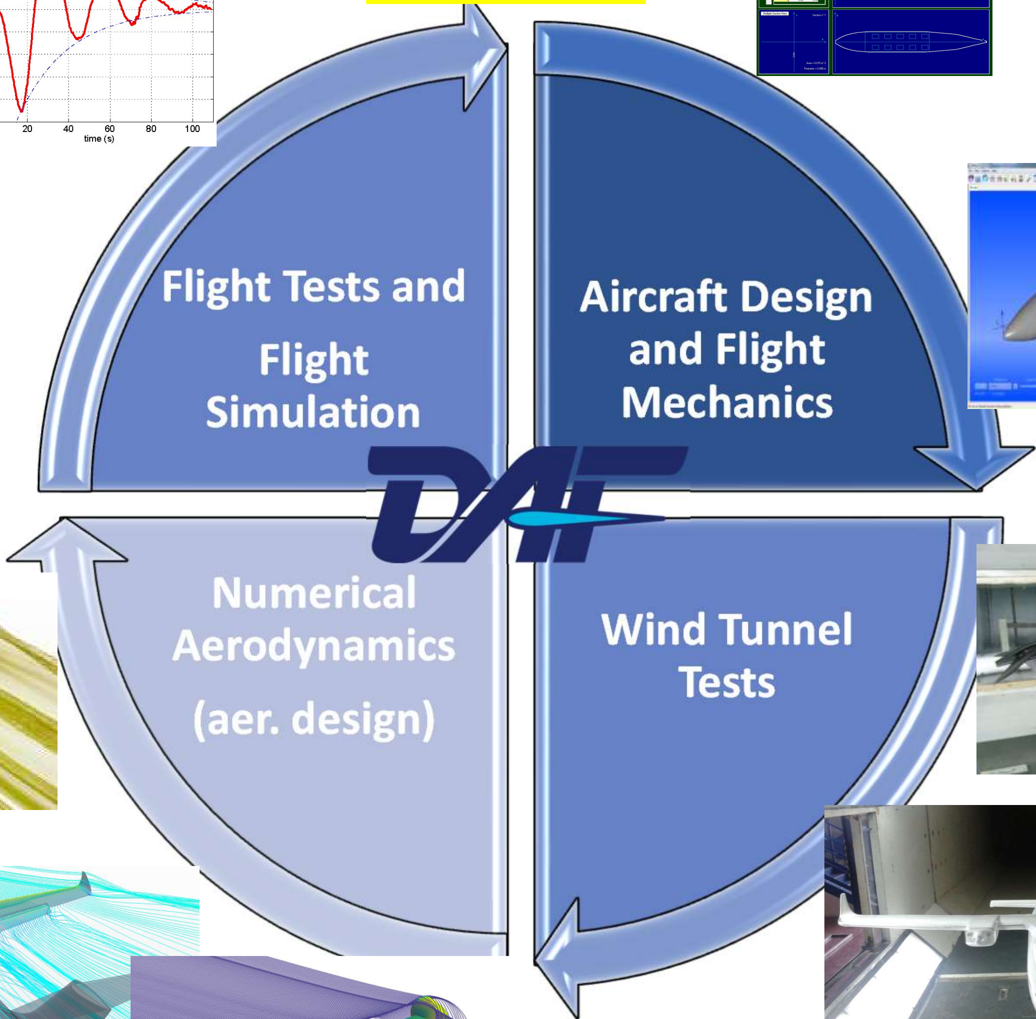
P2006
Flight Tests

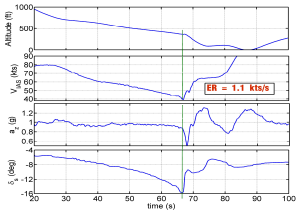




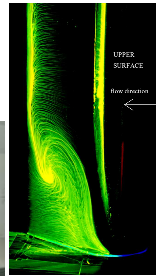




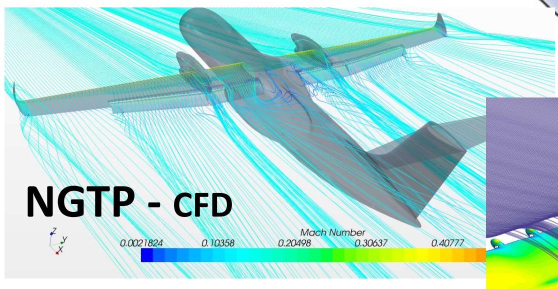




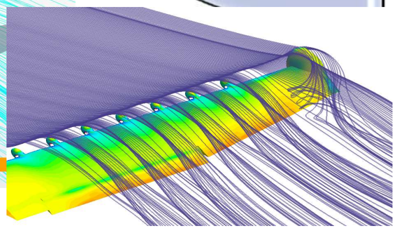
P2012 - CFD



P2012
WT Tests



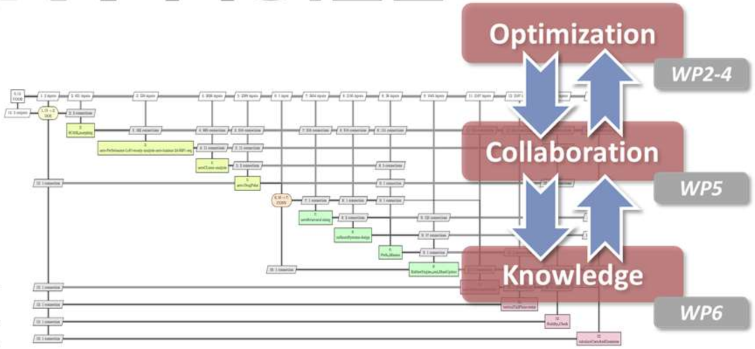
NGTP - CFD



RECENT PROJECTS on AIRCRAFT Design – DAF Group

- **AGILE Project (H2020)**

DLR, ONERA, NLR, Airbus DS, Bombardier, Leonardo, Fokker, CIAM, TsaGi, POLITO, TU Delft, UNINA.
Innovative 3rd generation aircraft design framework with collaborative architecture



- **IRON Project(2016-2021) (Clean Sky 2)**

Leonardo, CIRA, ONERA, TU Delft, Avio GE, Dowty propel
Design of an Innovative 130 pax Regional Turboprop with

- ***ADORNO* Project(2018-2022) (Clean Sky 2-CFP)**

UNINA, MTU Aero Engine as Topic leader
Aicraft Design and nOise RatiNg for regiOnal aircraft

- ***PROSIB* (2018-2021) (PON – financed by MIUR)**

Leonardo, UNINA, UniPisa, CIRA
***PRO**pulsione e **S**istemi **IB**ridi per velivoli ad ala fissa e rotante*

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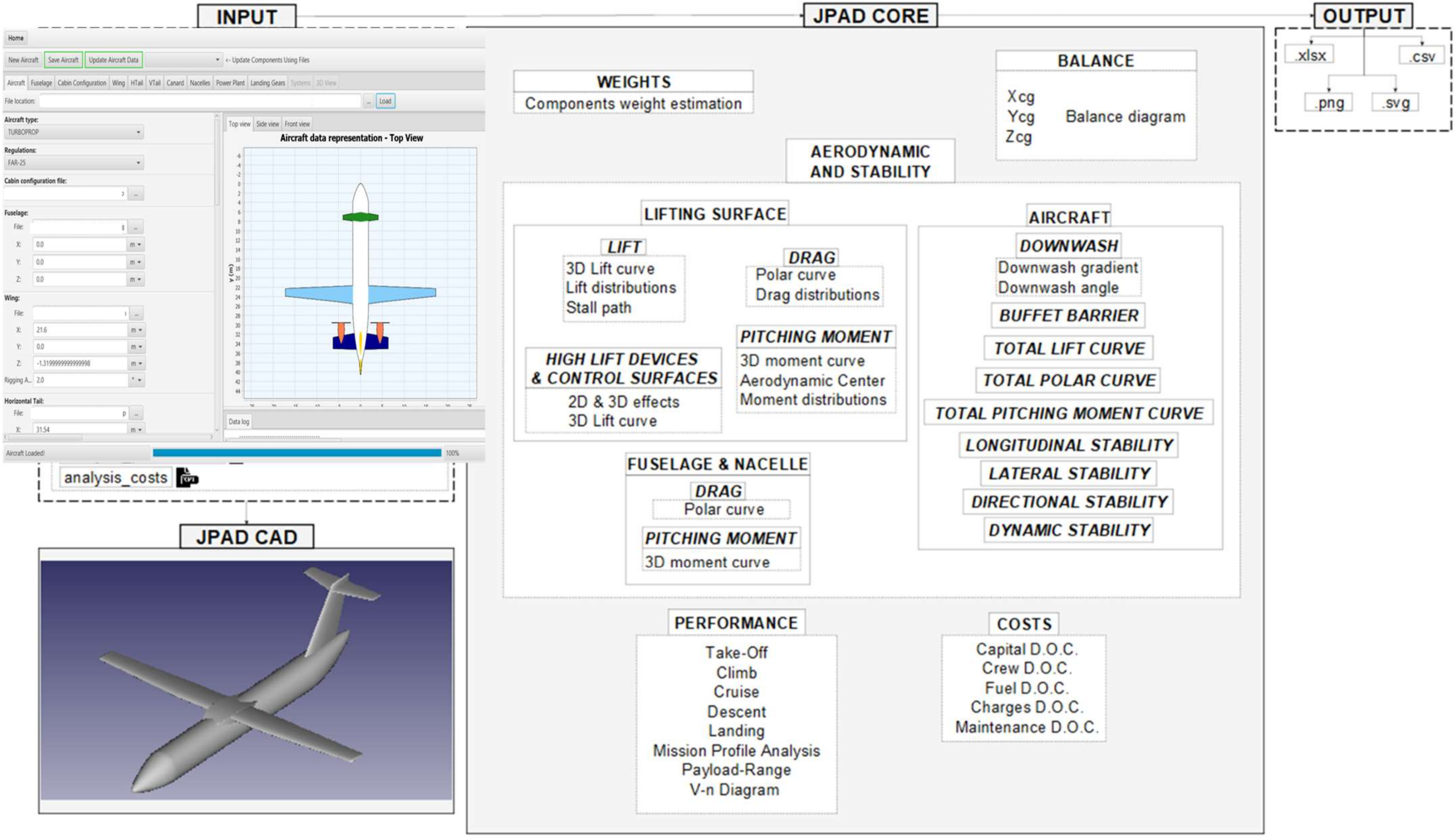
DAF

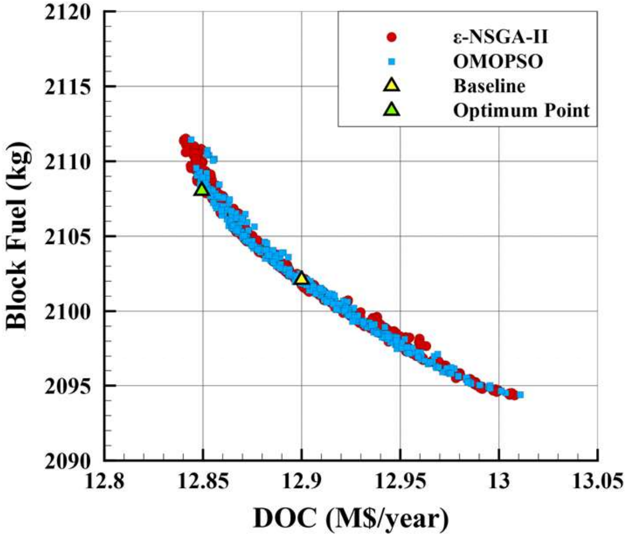
JPAD (Java Program for Aircraft Design)

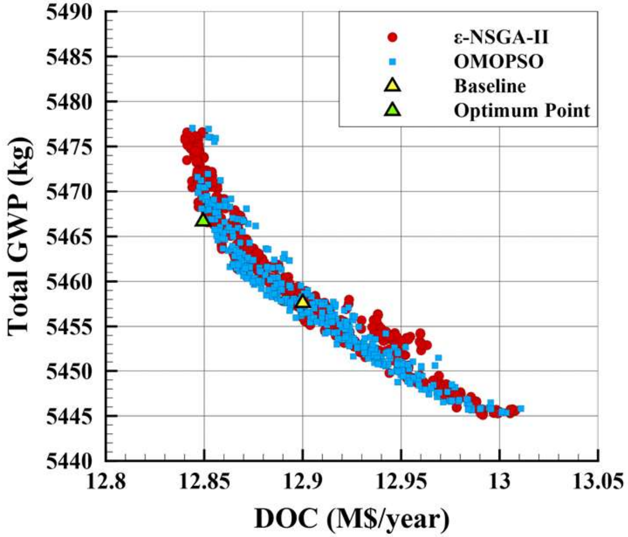
Developed by DAF Group

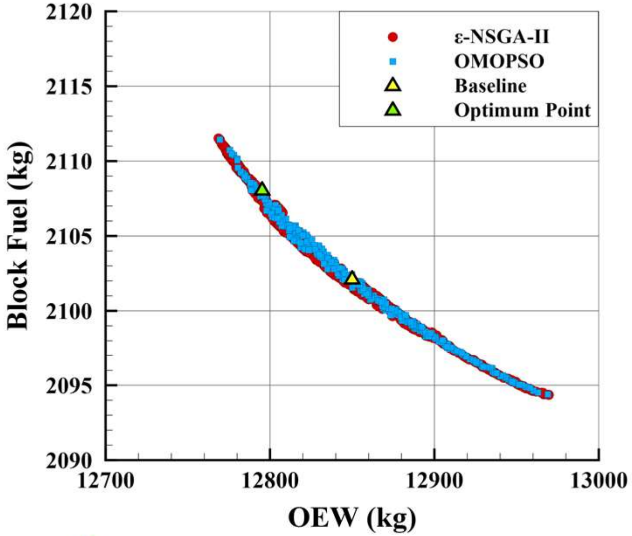


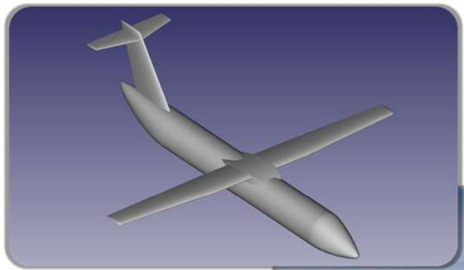
JPAD case study : ATR72 Optimization Results

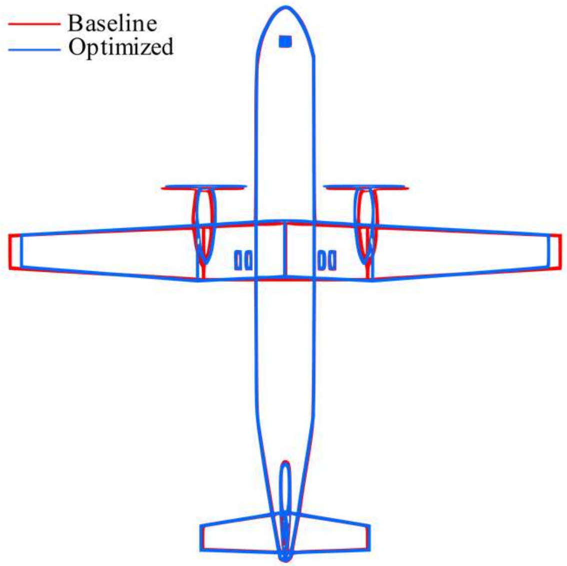
DOE with 12500 wing configurations (Xle, AR, t/c, shape)





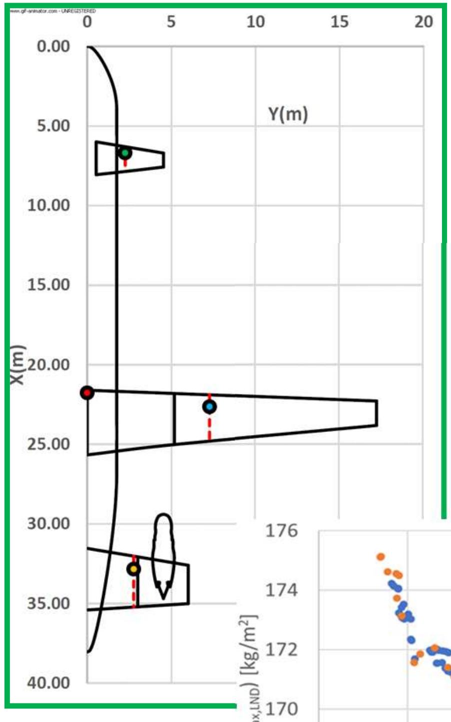


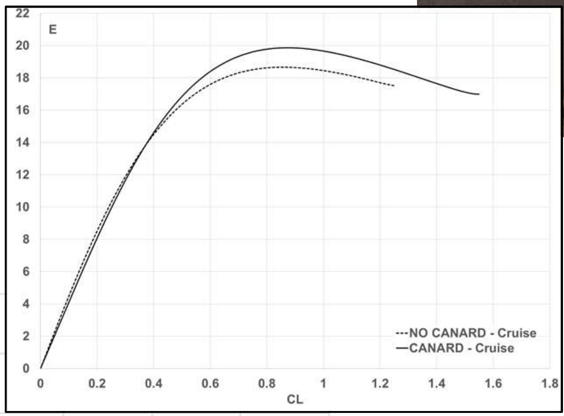


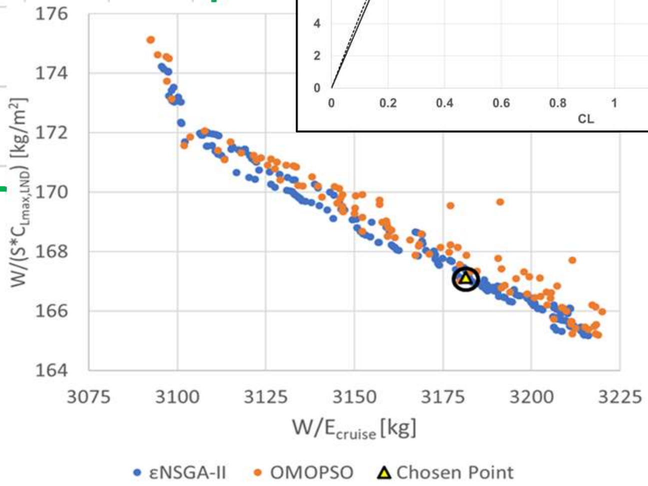


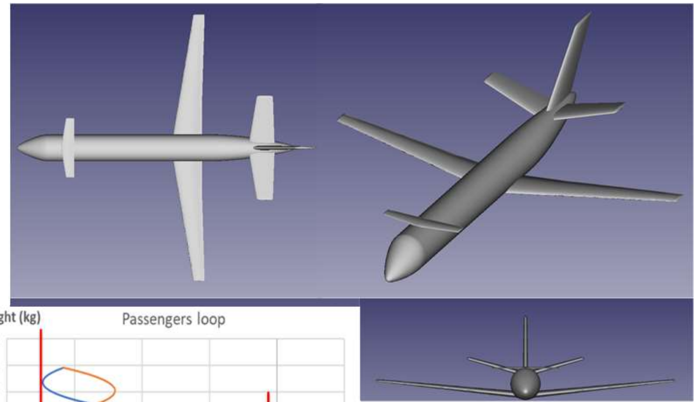
IRON Project – CS2 REG

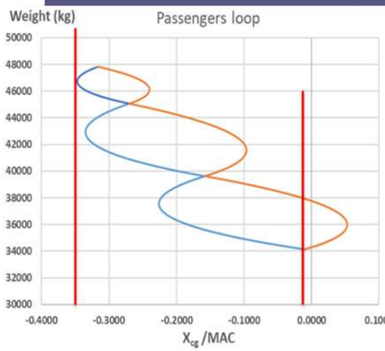
IRON Project – 130 pax Regional Tprop
With rear engine installation











Il PROGETTO PROSIB (PON finanziato dal MIUR) 2018-2021

Progetto di Ricerca PROSIB ARS01_00297
PROpulsione e Sistemi IBridi per velivoli ad ala fissa e rotante

Total cost 6.3 M€

- Il progetto di ricerca PROSIB (coordinato da Leonardo) si propone di realizzare un'esplorazione quantitativa dei vantaggi competitivi e delle criticità che scaturiscono dalla adozione della propulsione elettrico/ibrida su velivoli da trasporto regionale & commuter (ala fissa) e configurazioni VTOL (ala rotante)

COME ?

⇒ studi configurazionali con analisi di **trend delle principali tecnologie abilitanti**
⇒ dimostrazione a TRL 3 di alcuni enabler tecnologici :
configurativo (prove in galleria del vento per DEP e configurazioni innovative)
elettrico (dimostratore tecnologico di un sistema scalato dell'energy management)

RISULTATI ATTESI

- Roadmap elettrificazione velivolo classe ATR-42 con identificazione degli enabler tecnologici critici
- **Esplorazione configurazioni innovative ibride** per "classe ATR-42" e Comuter (19 pax)
- Sviluppo di configurazioni VTOL ad ala rotante
- Ambiente integrato di simulation & modeling per l'analisi multidisciplinare di configurazioni ibride ***(SVILUPPO FRAMEWORK per MDO Velivoli Ibridi)***

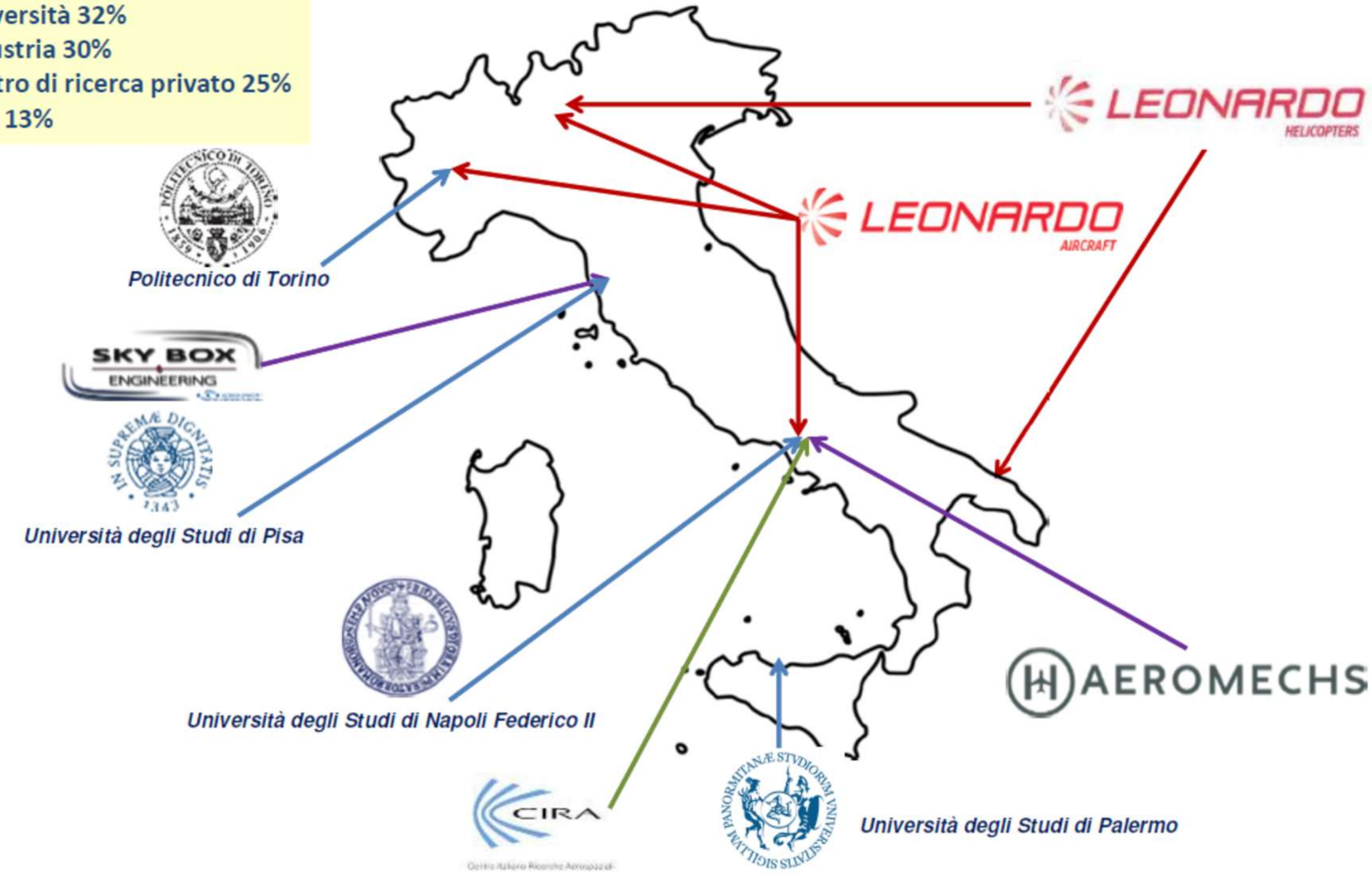
Il PROGETTO PROSIB (PON finanziato dal MIUR) 2018-2021

LEONARDO

Regioni meridionali 80,4%
Regioni settentrionali 19,6%

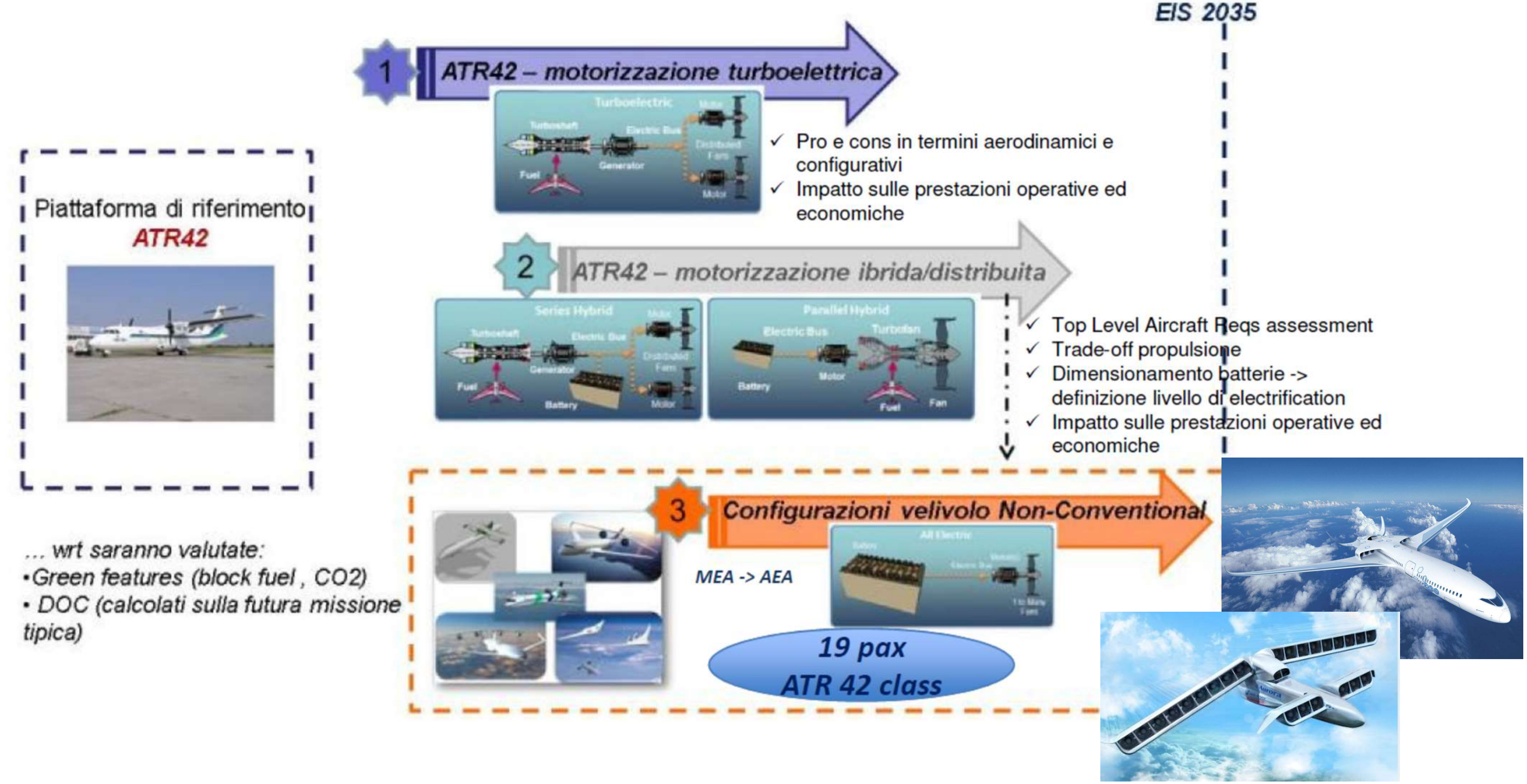
Università 32%
Industria 30%
Centro di ricerca privato 25%
PMI 13%

Definizione del consorzio



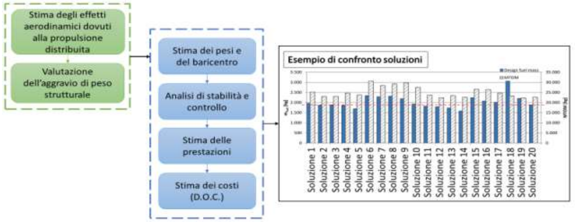
Il PROGETTO PROSIB (PON finanziato dal MIUR) 2018-2021

Partendo dalla configurazione di riferimento "ATR42 class" ed arrivando a configurazioni velivolo non convenzionali saranno valutati i pro e i cons in termini aerodinamici, configurativi, prestazionali ed economici (DOC) dell'utilizzo di una motorizzazione ibrida distribuita.



PROSIB, ATTIVITA' UNINA

Gruppo Prof. Del Pizzo DIETI



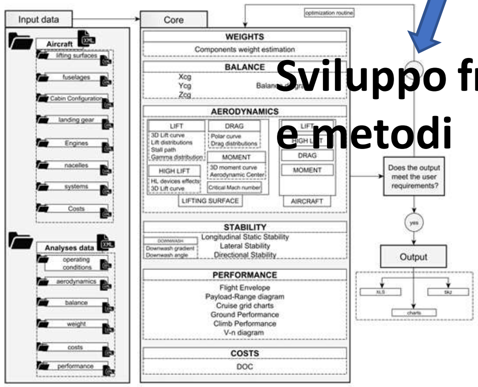
PROSIB
Leonardo Velivoli

Management
Leonardo Velivoli

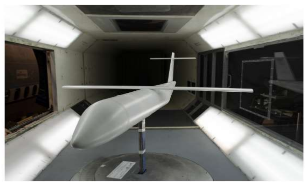
- OR1: Requisiti e vision — Leonardo Velivoli
  - OR1.1 Vision ala fissa
  - OR 1.2 Vision ala rotante
  - OR1.3 Vision tecnologie abilitanti
- OR2: Configurazioni velivoli — CIRA
  - OR2.1 Ala fissa
  - OR2.2 Ala rotante
  - OR2.3 Configurazioni avanzate
- OR3: Metodi di progetto e scenari — Leonardo Velivoli
  - OR3.1 Metodi di progetto per ala fissa
  - OR 3.2 Metodi di progetto per ala rotante
  - OR3.3 Metodi di analisi di scenario
- OR4: Tecnologie abilitanti — UNINA
  - OR4.1 Sistemi accumulo energia elettrica
  - OR4.2 Macchine elettriche
  - OR4.3 Elettronica di potenza e strategie di energy management
  - OR4.4 Analisi architetture (Ala fissa)
  - OR4.5 Definizione dei Sistemi (Ala Rotante)
- OR5: Prove e Integrazione — Leonardo Velivoli
  - OR5.1 Prova dimostratore di rete
  - OR5.2 Prove in galleria del vento
  - OR5.3 Valutazione velivoli negli scenari
  - OR5.4 Integrazione risultati

Studio ATR42 Ibrido

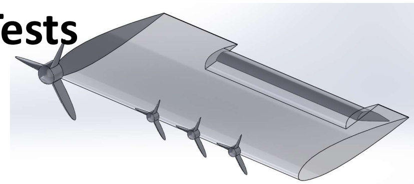
Config Innovative Ibride



Sviluppo framework e metodi

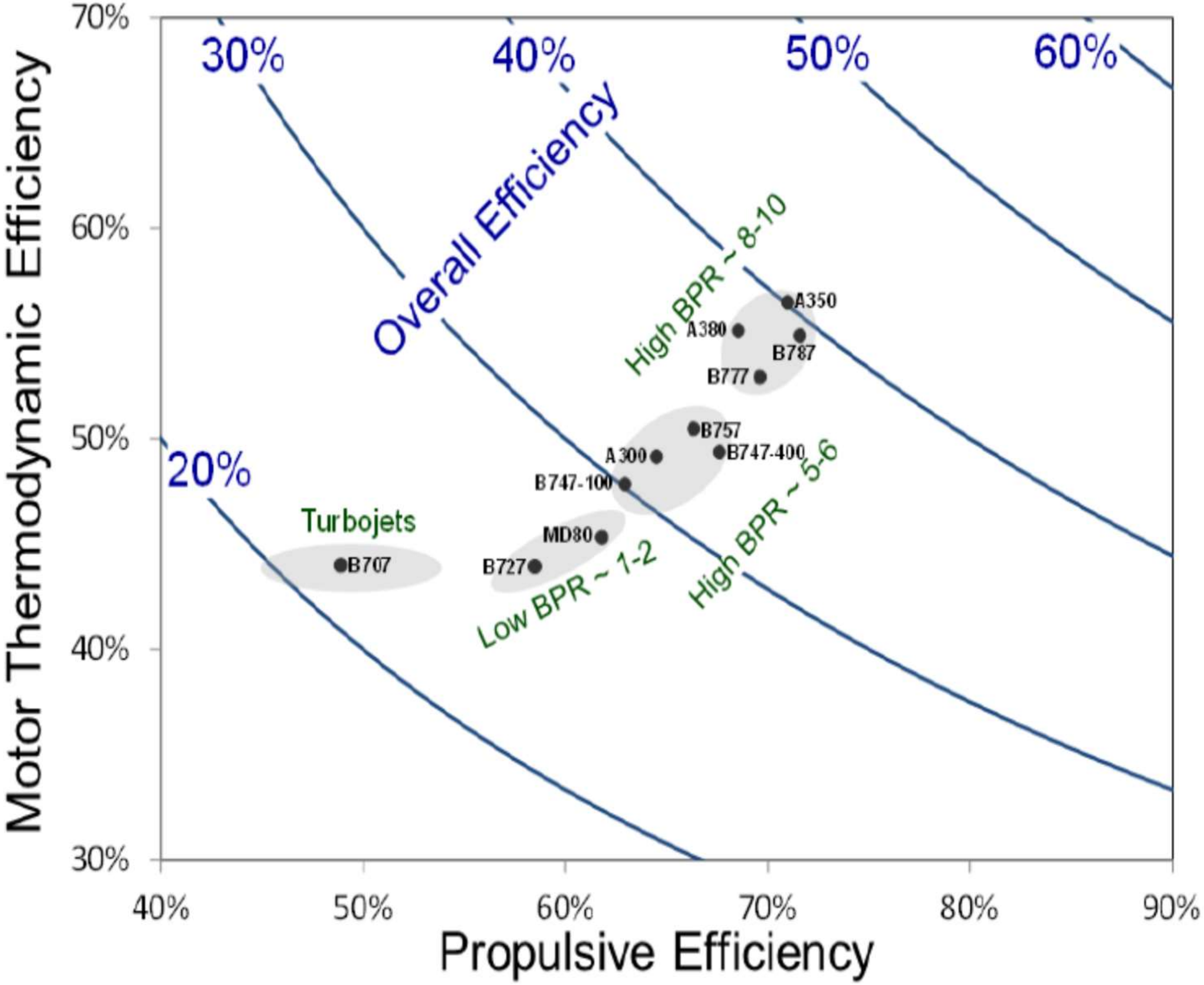


WT Tests



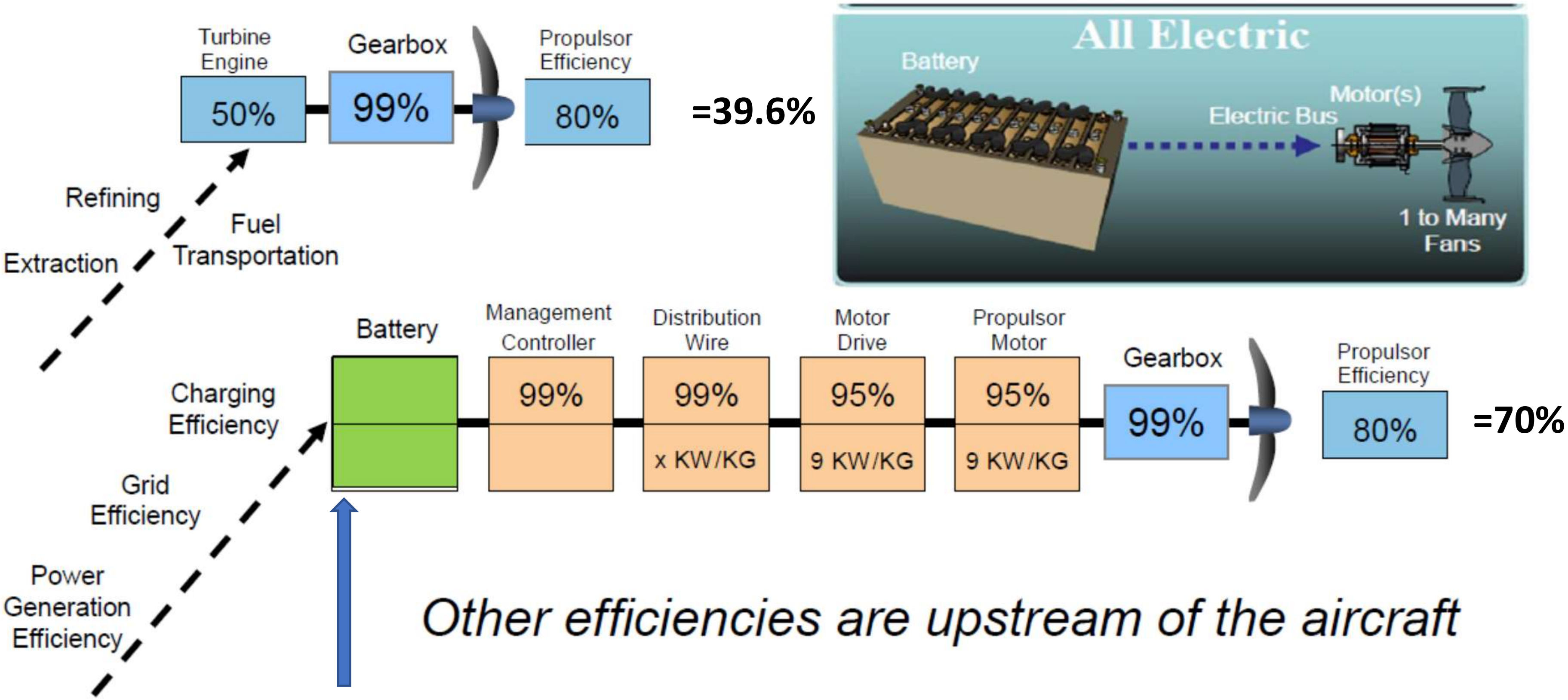
ELECTRIC/HYBRID AIRPLANES

Jet engines Propulsive Efficiency



ELECTRIC/HYBRID AIRPLANES

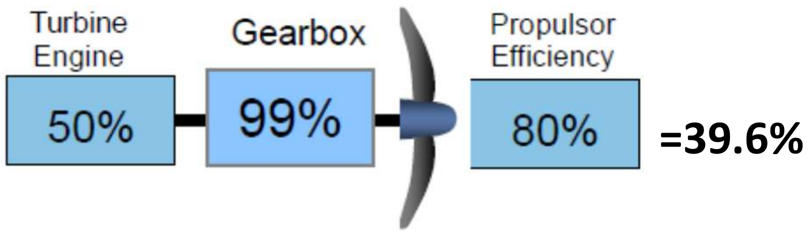
Prop aircraft : Propulsive Efficiency

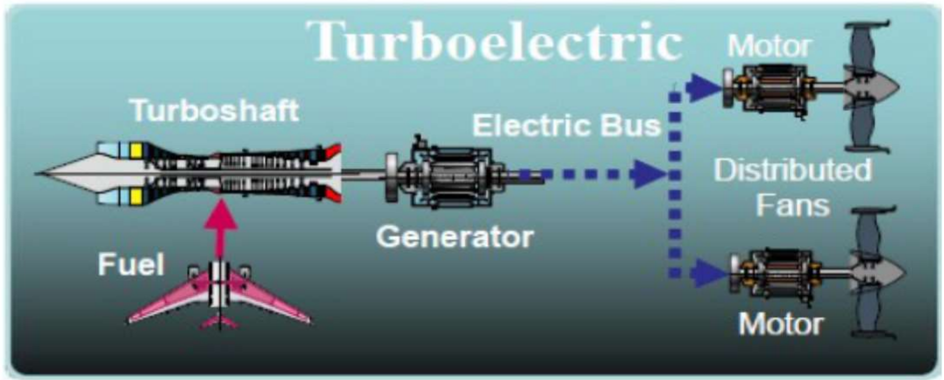


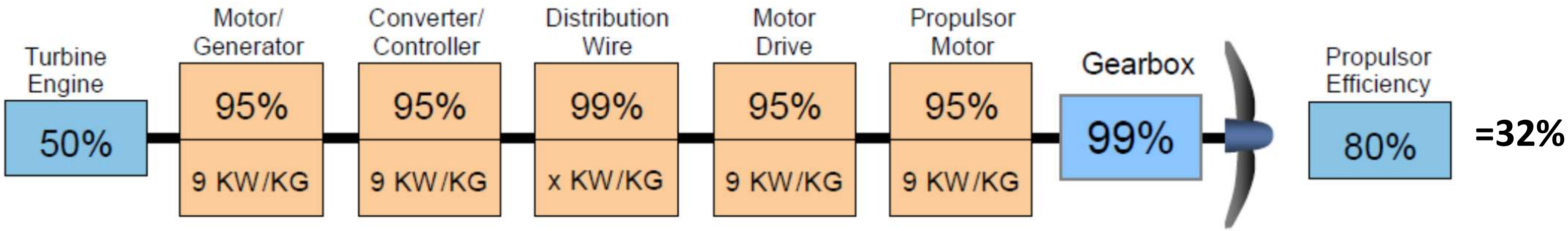
BATTERY WEIGHT ??

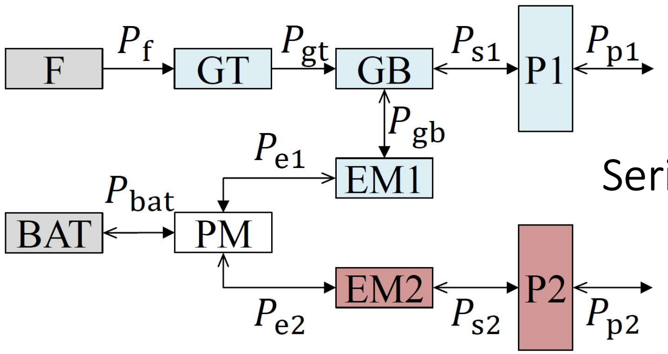
ELECTRIC/HYBRID AIRPLANES

Propulsive Efficiency







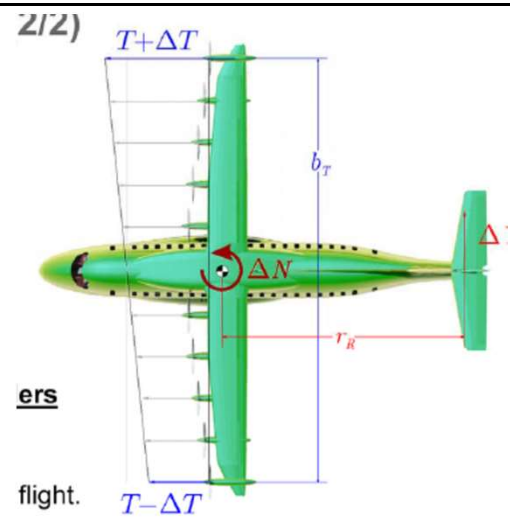


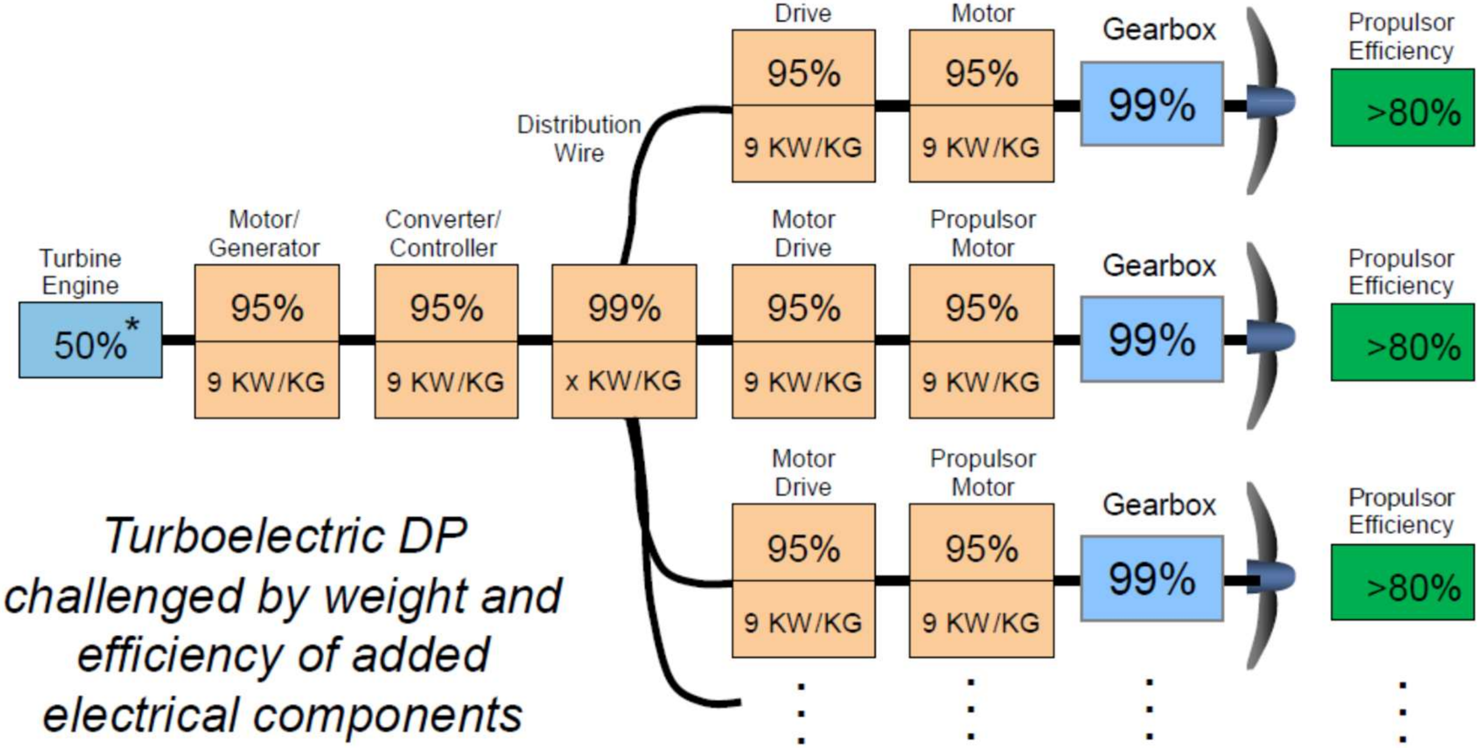
Serial/parallel partial hybrid (SPPH)

ELECTRIC/HYBRID AIRPLANES

Distributed Propulsion (DEP) :

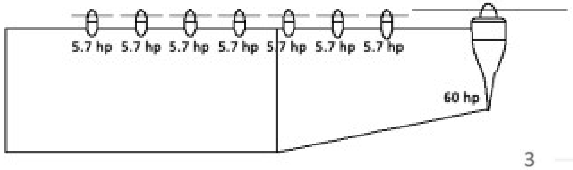
- Aerodynamic gain (dCL)
- Higher safety
- Dir control



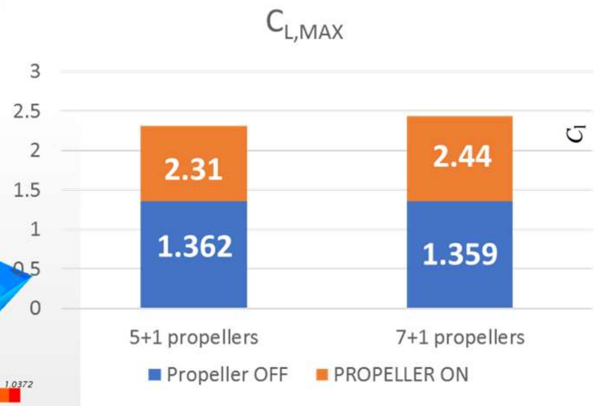


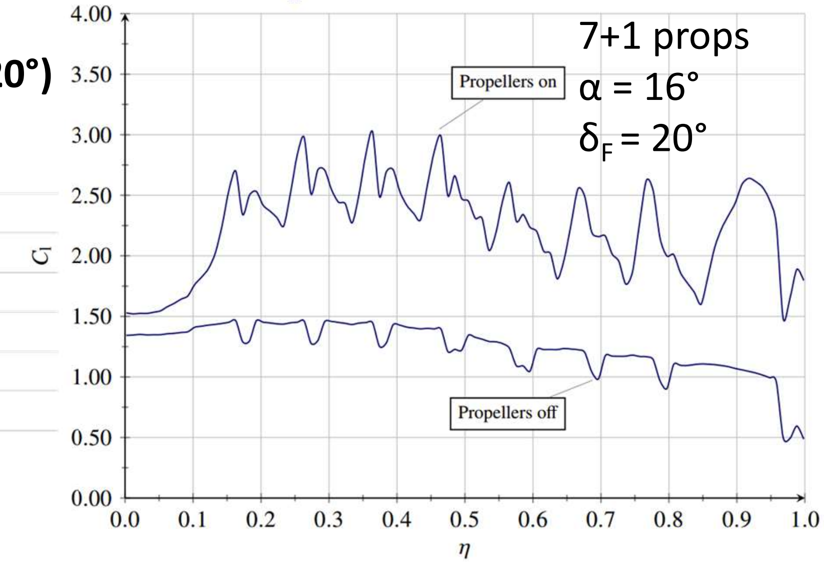
Turboelectric DP challenged by weight and efficiency of added electrical components

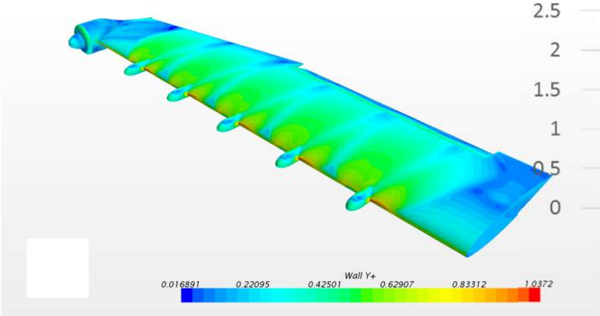
Analysis and modelling of Distributed Electric Propulsion

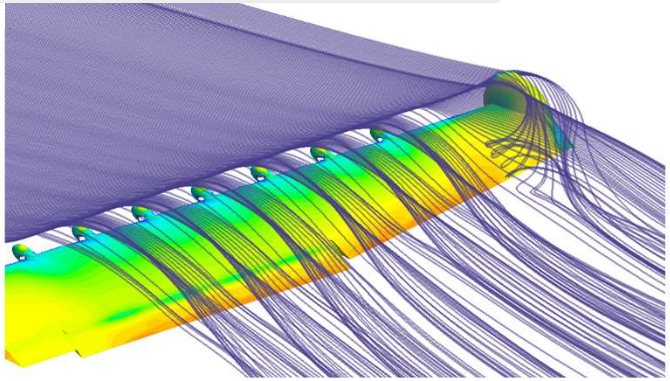


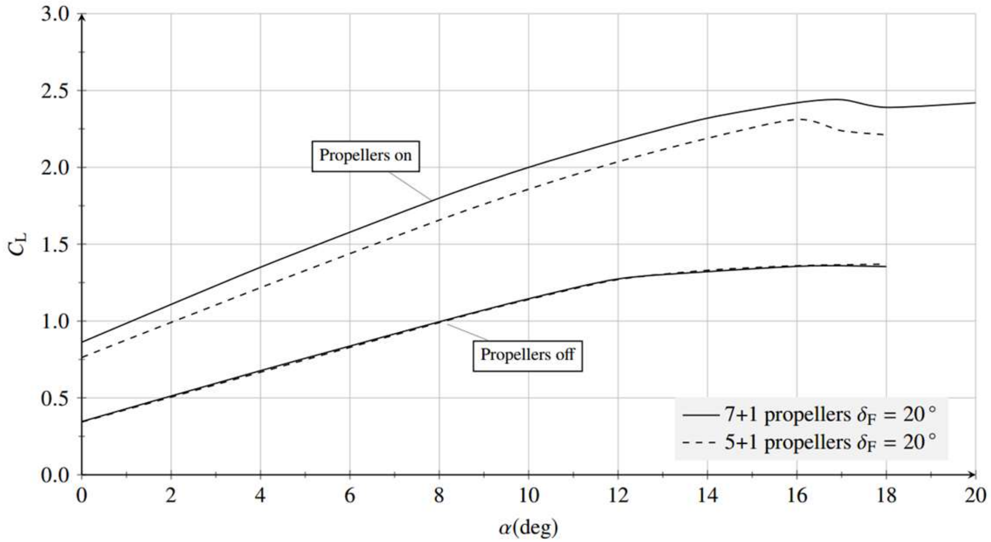
Take-off condition (flap 20°)











$$C_L = C_{L_{airframe}} + \Delta C_L \qquad \eta_{p_{eff}} = \eta_p + \Delta\eta_p$$

$$C_D = C_{D_0} + \Delta C_{D_0} + \frac{C^2_{L_{airframe}}}{\pi A R e} + \Delta C_{D_i}$$

ELECTRIC/HYBRID AIRPLANES CHALLANGE

With more than 40,000 flights over America each day — most by jet aircraft — air transport accounts for roughly **3 percent** of annual carbon emissions in the U.S., as well as a big proportion of air pollutants like sulfur oxides and hydrocarbons.

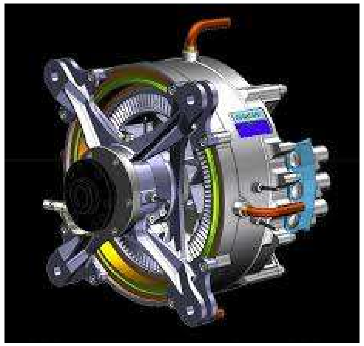
Advantages of Electric propulsion

- Electric/Hybrid propulsion lead to lower emission
- Much lower cost (€ / kWh) of electrical energy w.r.t. aviation fuel
- Possibility to apply distributed propulsion (electrical engine scalability)
- Lower cost for electrical engines
- Lower engine maintenance
- Lower noise

CRITICAL ISSUES

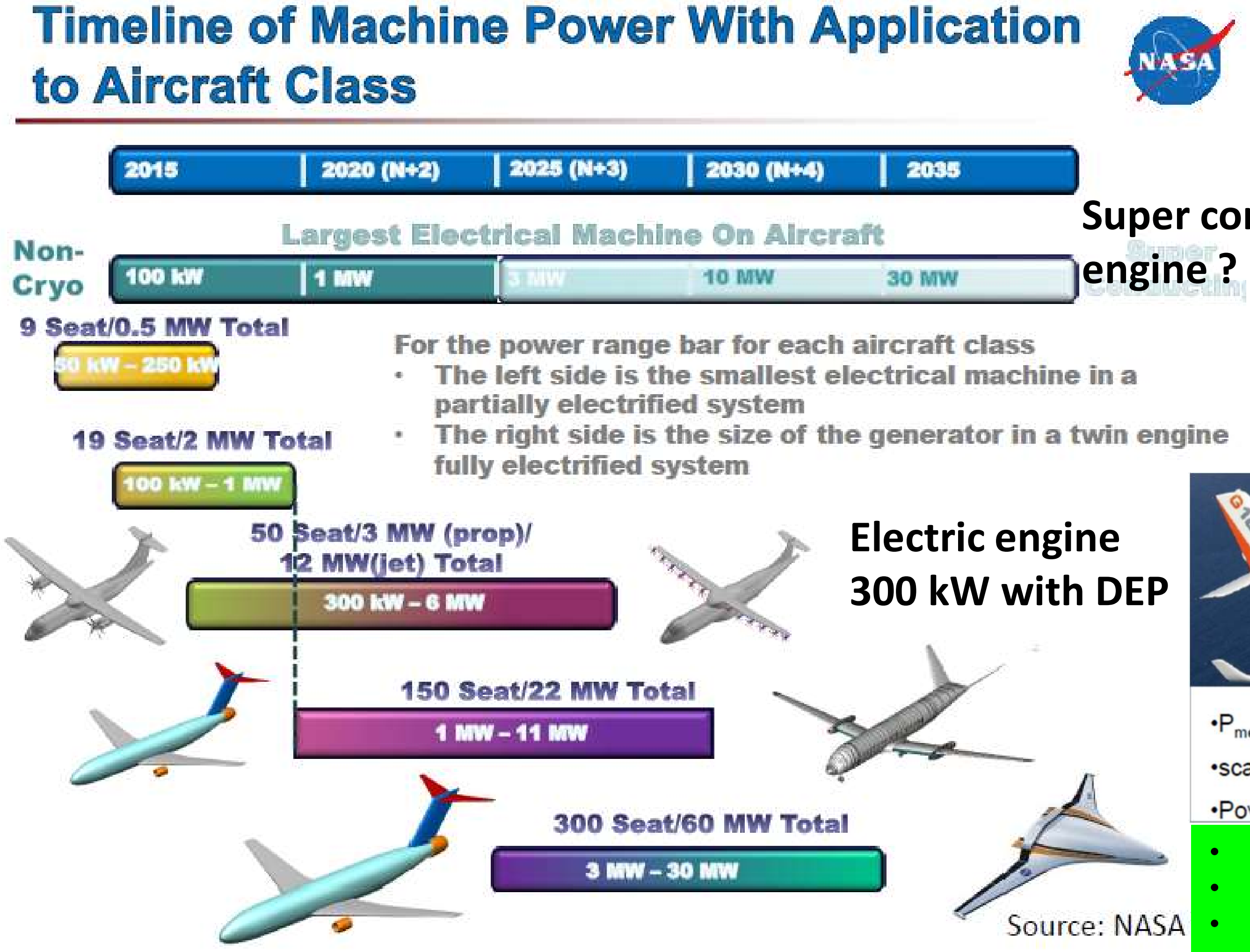
- **Weight, Volume**
- **Systems**
- **Safety**

ENGINES ?



BATTERIES ?

ELECTRIC ENGINES for AVIATION



Super conducting engine ?

Electric engine 300 kW with DEP

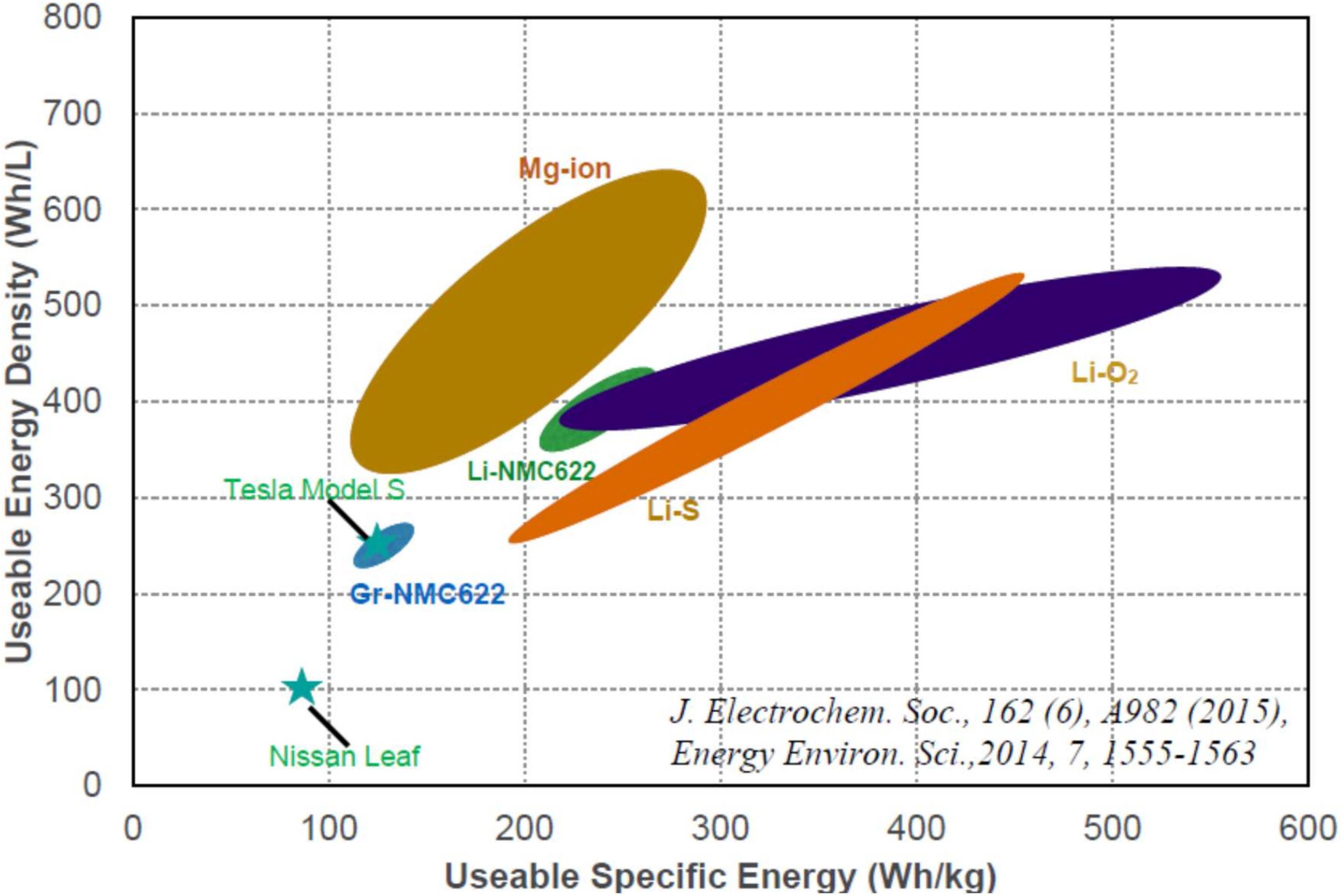
SIEMENS

P_{cont} = 261 kW
N_{max} = 2500 rpm
M_{cont} = 1000 Nm
η_{260kW} = 95 %

- **High electric freq for high torque density**
- **Smart magnetic circle**
- **Optimized structural design (light)**
- **Optimized cooling**

POWER DENSITY 5 kW/kg

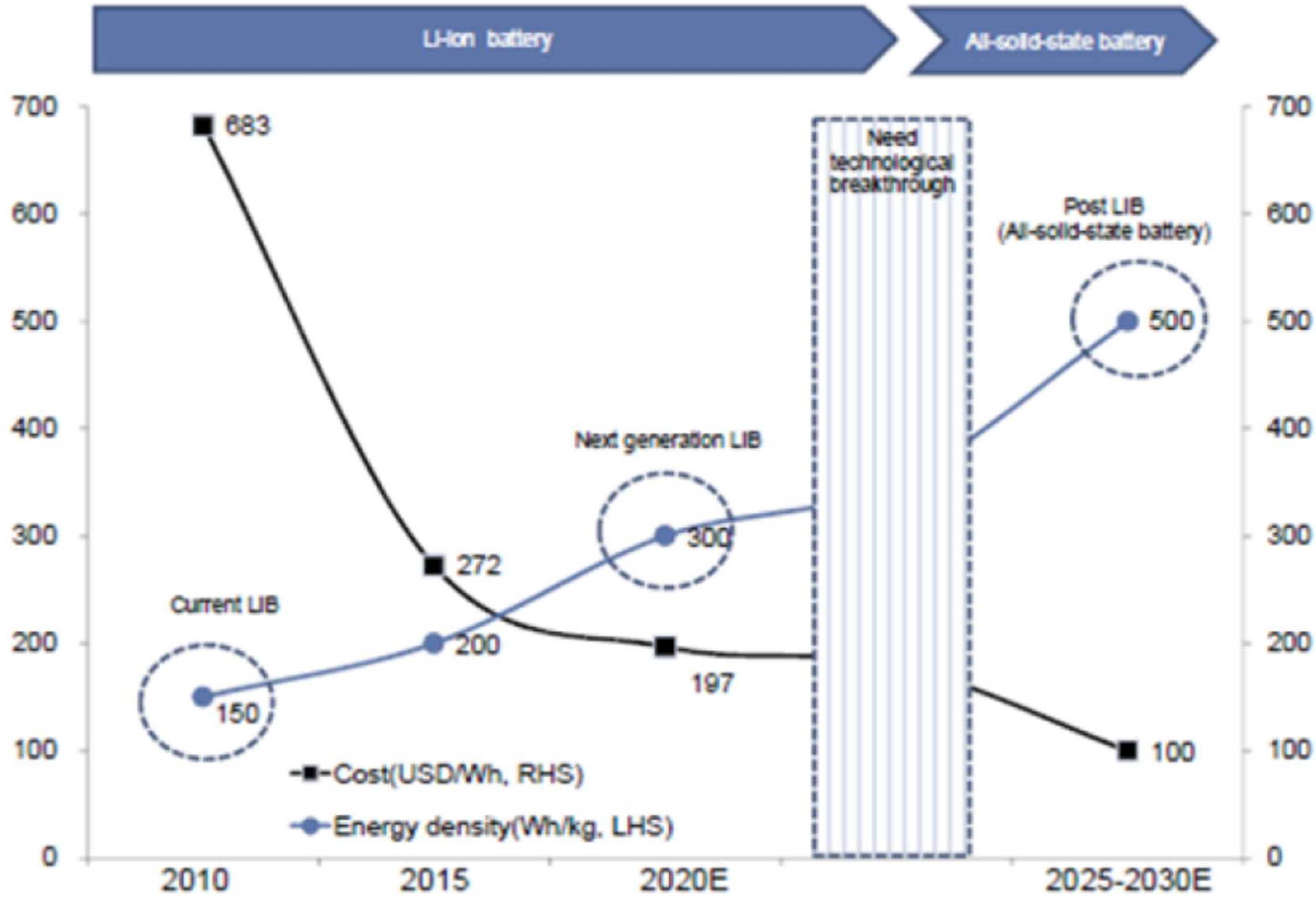
BATTERIES…


Useable Energy Density (Wh/L)
Useable Specific Energy (Wh/kg)
0
100
200
300
400
500
600
700
800
Mg-ion
Li-O2
Li-NMC622
Li-S
Tesla Model S
Gr-NMC622
Nissan Leaf
J. Electrochem. Soc., 162 (6), A982 (2015),
Energy Environ. Sci.,2014, 7, 1555-1563

BATTERIES…

BATTERIES : Energy Density and Cost evolution

Ioni di Litio **Stato solido**



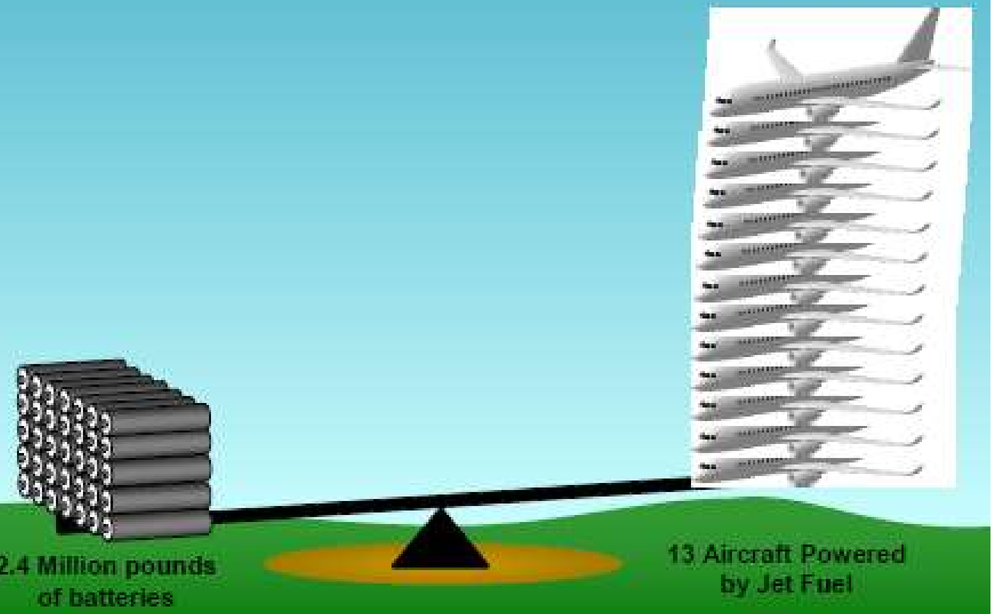
BATTERY WEIGHT…

Lithium-ion **batteries** are getting cheaper, but they aren't getting much lighter and smaller, and inventing better batteries is a key area of research for electric aircraft developers !

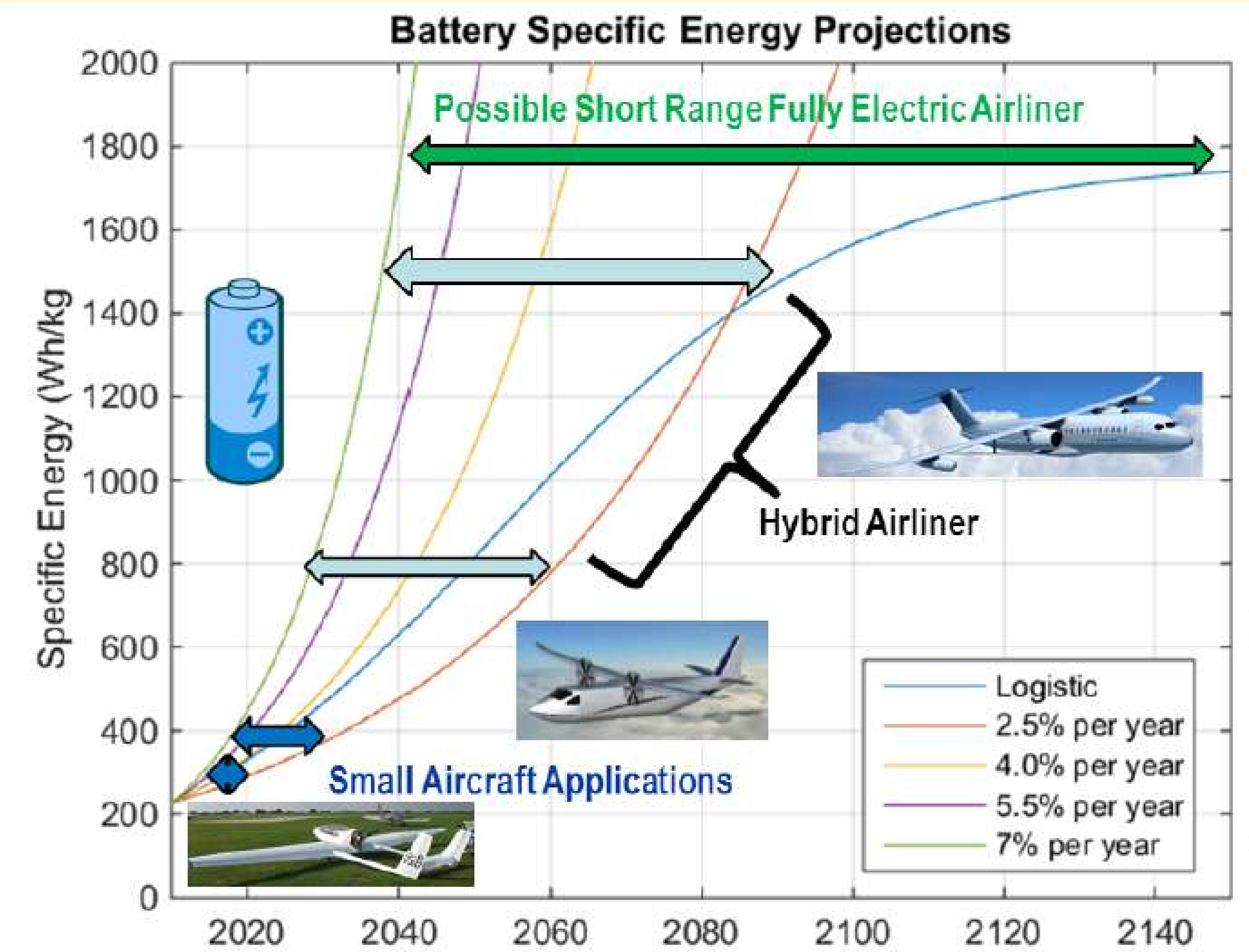
SUGAR Free (737-like)
154 Passengers, 3500 NM
Takeoff Weight: 184,800 lbs
Jet-A Fuel: 60,200 lbs

- Jet-A has lots of energy/weight: ~**11,900 Watt Hours / kg**
- 60,200 lbs of Jet-A has **325,000,000 Watt Hours** of Energy
- It the battery (Lithium Ion) module is developed to: **300 Watt Hours / kg**

It takes **2.4 Million** pounds of batteries to reach the same energy as **60,200** lbs of Jet-A!



BATTERIES…

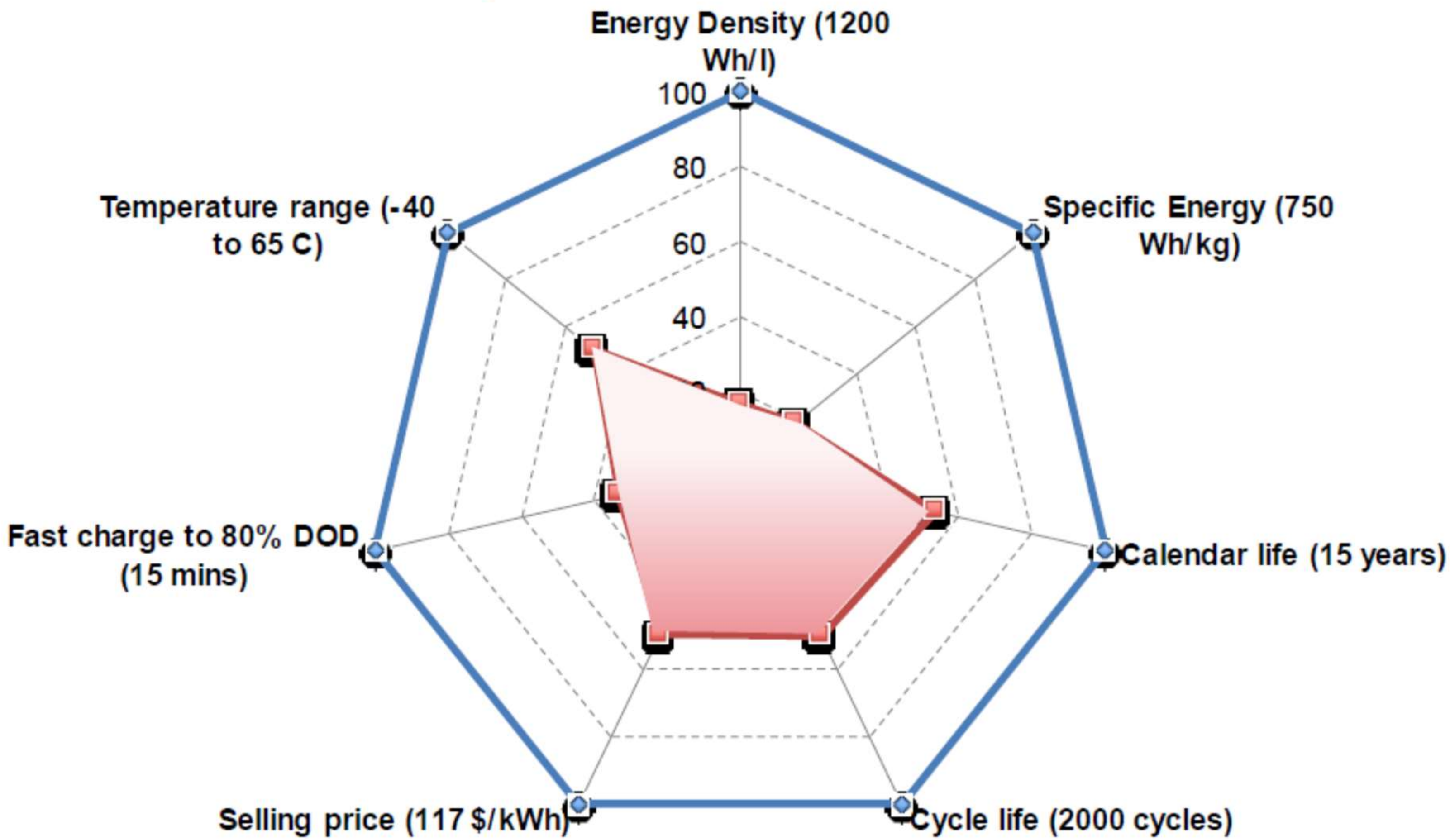


NEAR Term Application
⇒ Small Aircraft

LONG Term Application
⇒ Transport Aircraft

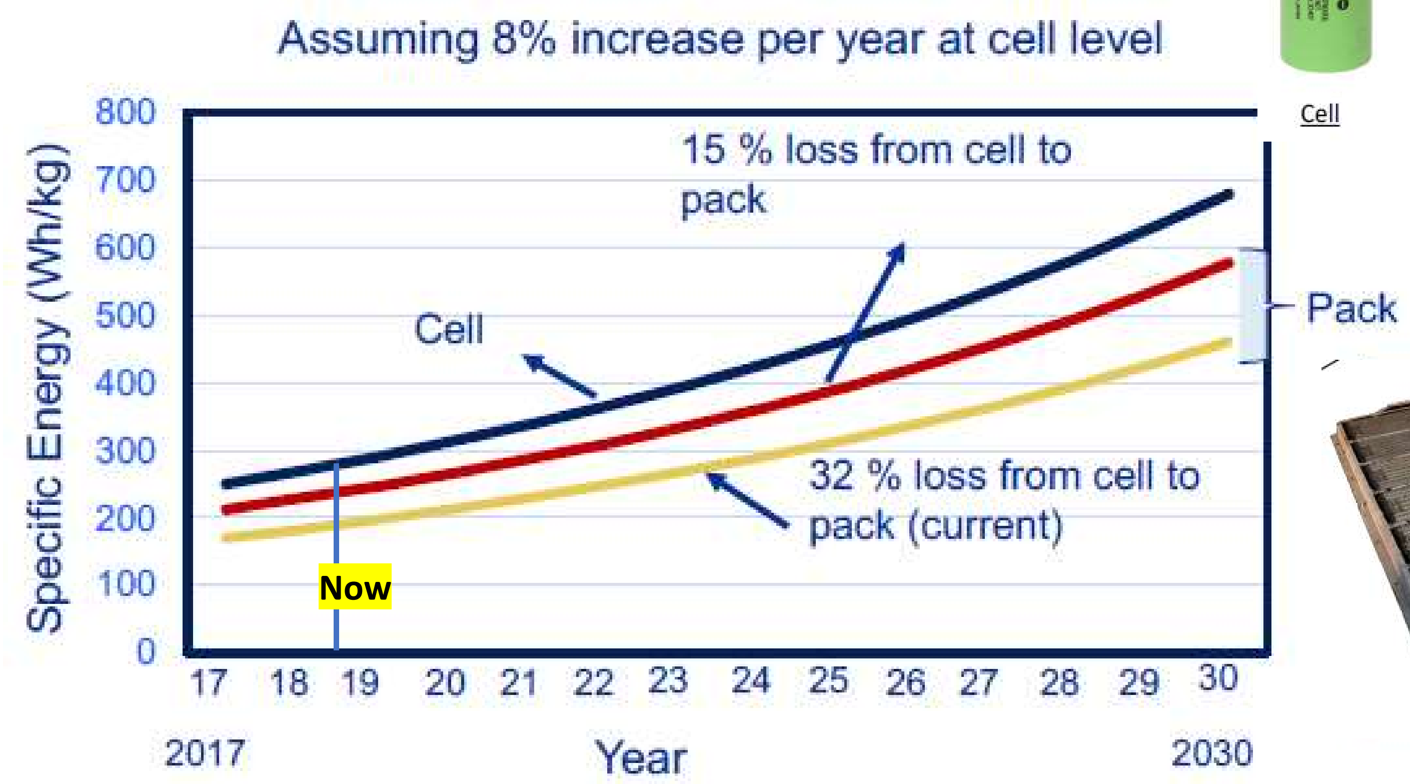
BATTERIES…

Where are we ? Status vs Aviation Needs

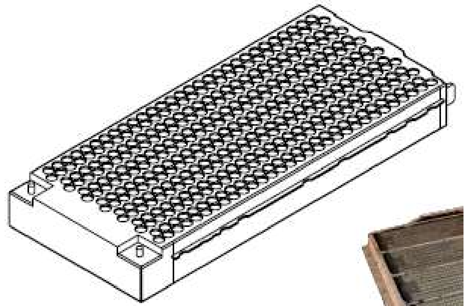


BATTERIES…

From Cell to Pack….



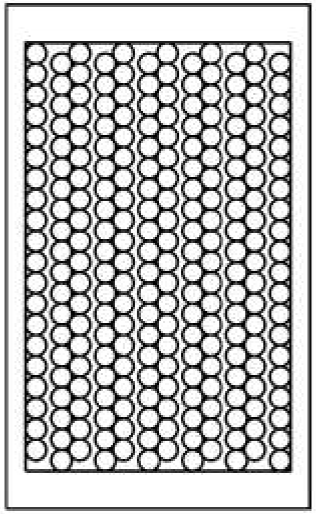
Cell



Module

Cells, Current collection, Fusing, Integral Cooling, Structure

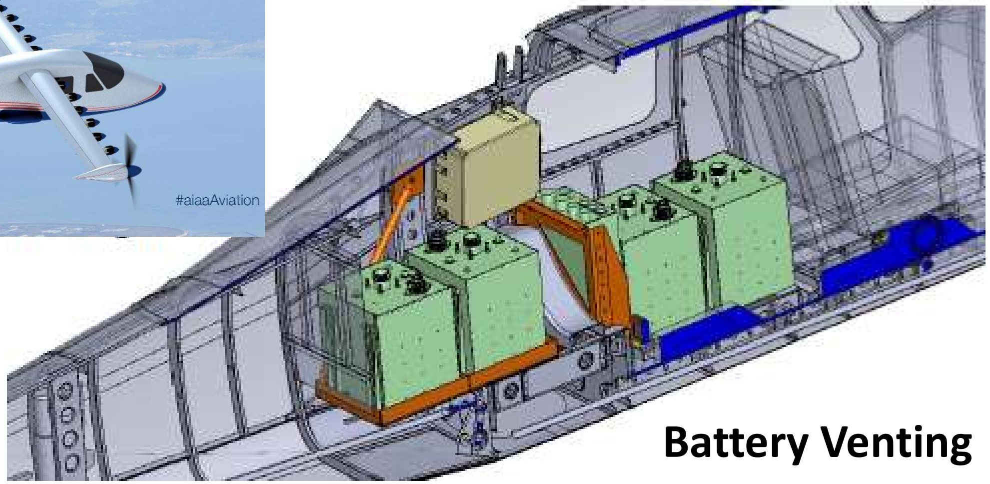
BATTERIES… Volumetric efficiency….

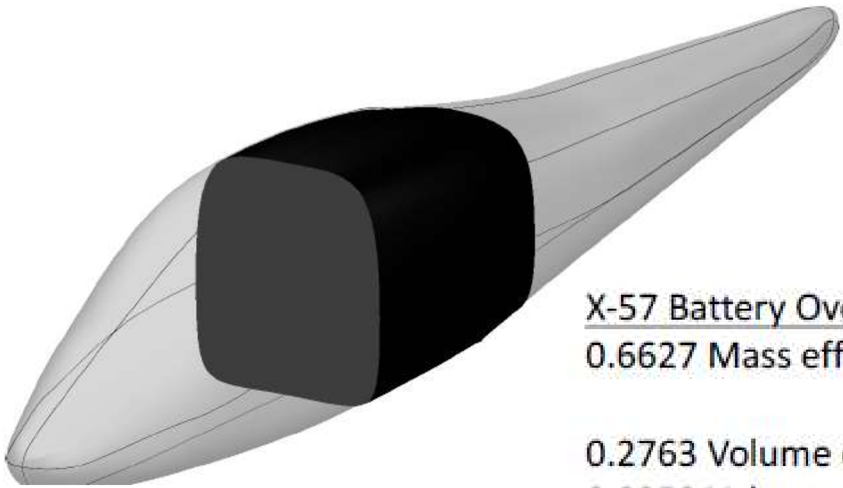


12 Columns
20 Rows

$\eta \approx 0.2798$

NASA X57-Maxwell

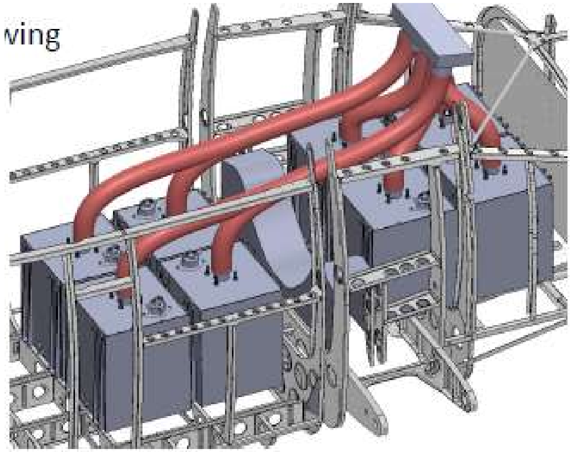




X-57 Battery Overhead
0.6627 Mass efficiency to module

0.2763 Volume efficiency to module
0.0353 Volume efficiency to fuselage bay

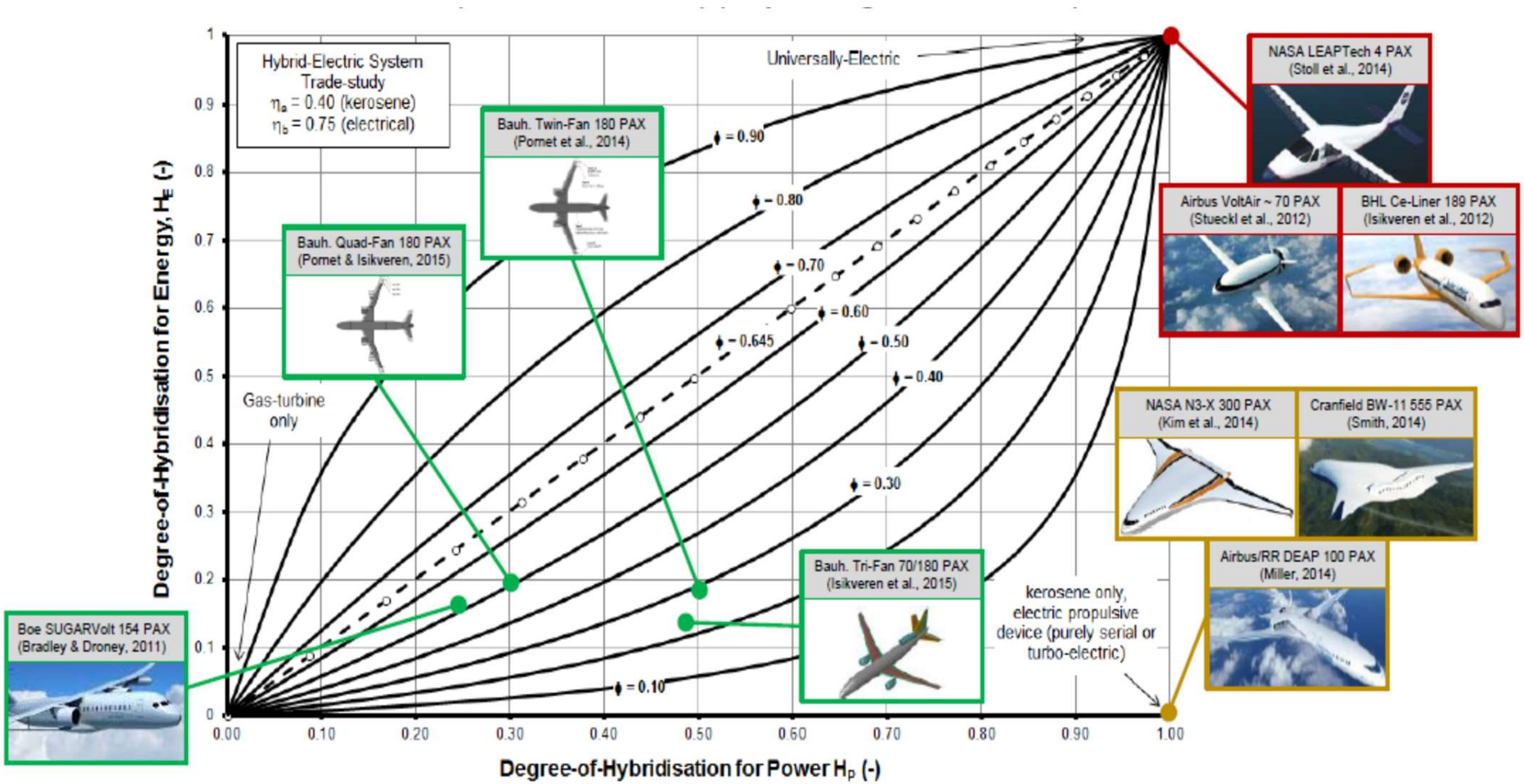
Battery Venting



Tecnam P2006T was not designed as an electric aircraft !

ELECTRIC/HYBRID AIRPLANES

Studi in corso con diversi livelli di "Ibridizzazione"



ELECTRIC/HYBRID AIRPLANES

NEED FOR Reliable and Efficient Multi-Disciplinary Framework and Tools for Hybrid/Electric Aircraft Design

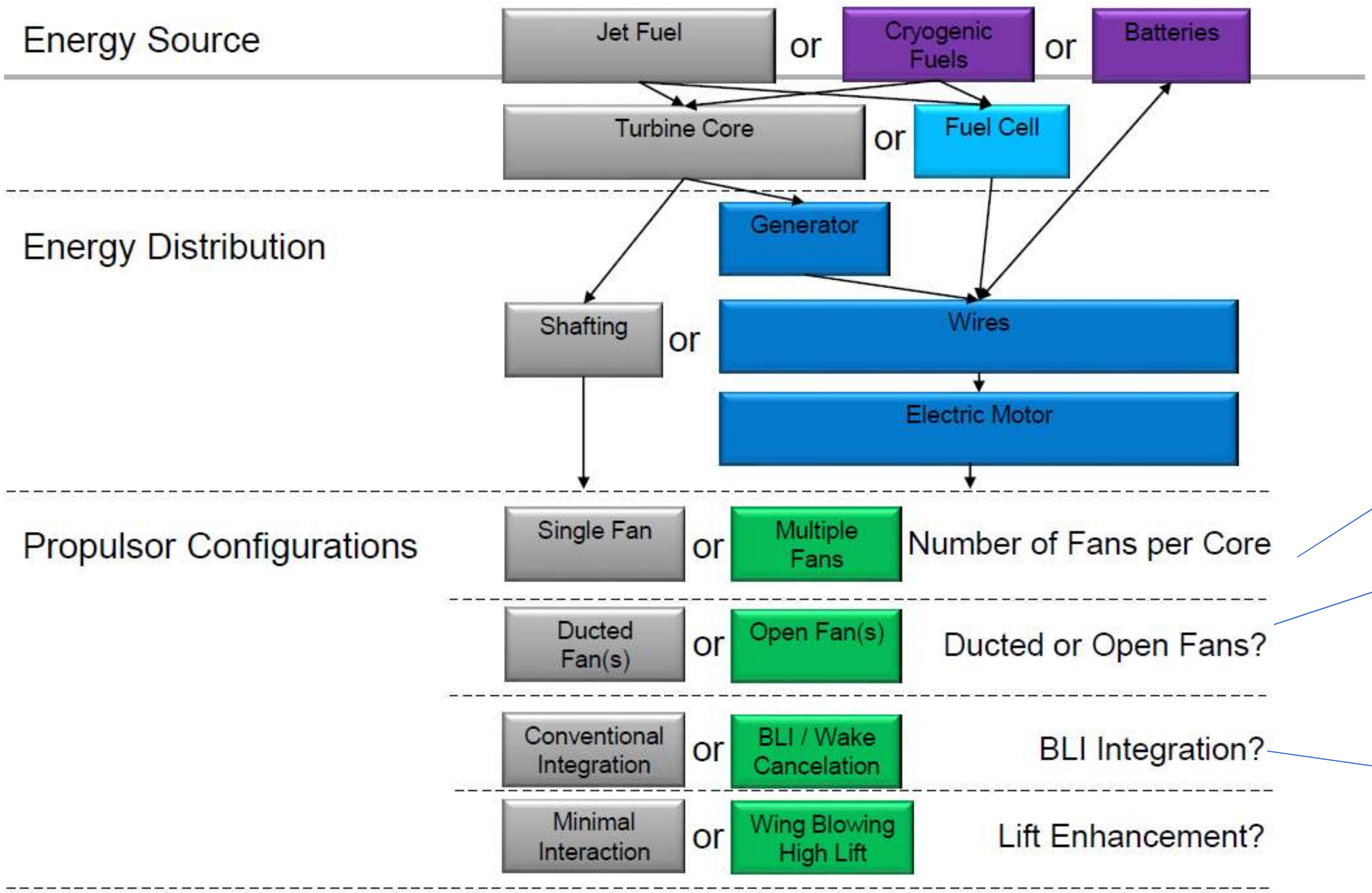
- Need for an **Highly-integrated** framework for A/C Design
- Reliable model for the electric part of the propulsive chain
- Battery characteristics and battery model
- Propulsive characteristics highly integrated in the sizing (strong coupling between propulsion and aerodynamics) (DEP, BLI, etc)
- **Different A/C configuration and powertrain configuration**
- Mission can be part of sizing and optimization process (usually an input)


NASA X-57

STARC-ABL Mach 0.70

ELECTRIC/HYBRID AIRPLANES

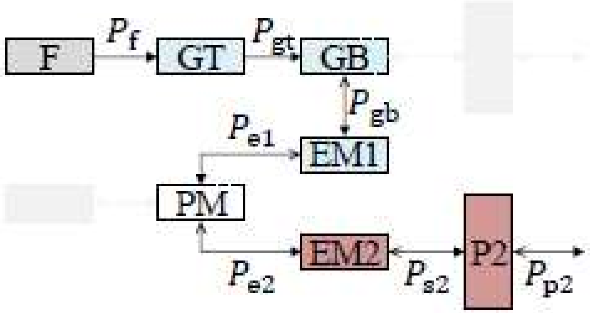
Propulsive Architecture Options



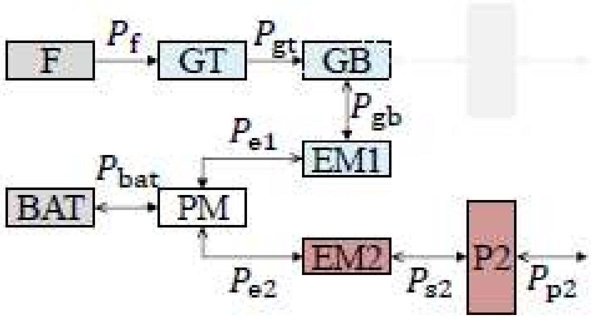
Combinations are also possible (i.e. fuel cell + batteries, shafting + wires, etc.)

Powertrain configuration, many options !

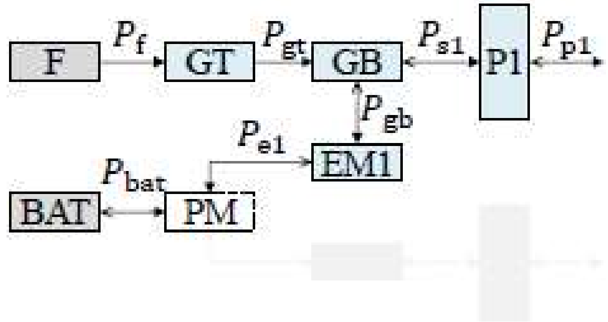
2. Turboelectric



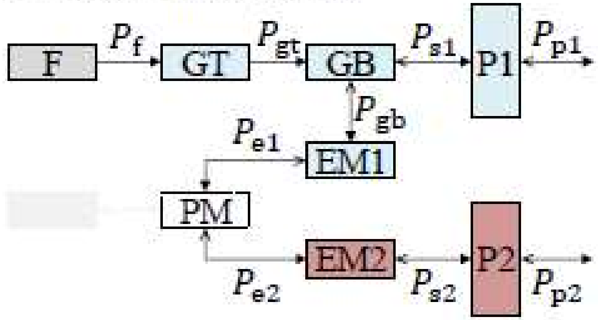
3. Serial



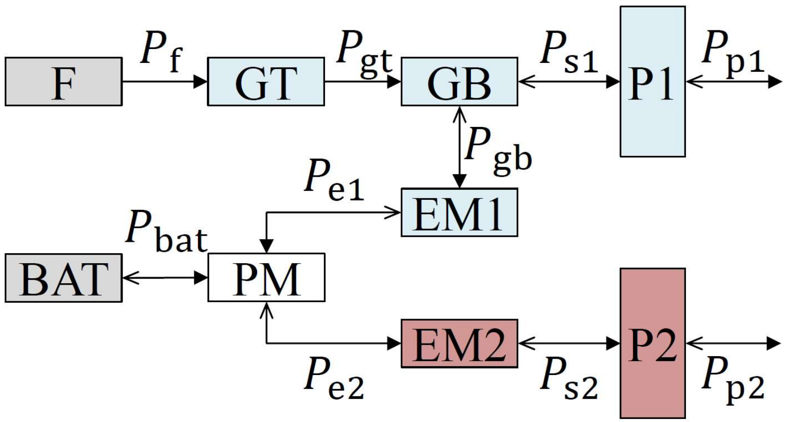
4. Parallel



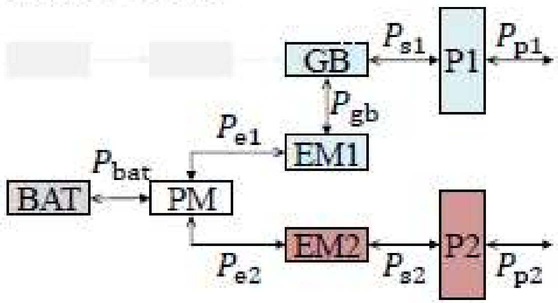
5. Partial turboelectric



Serial/parallel partial hybrid (SPPH)



9. Dual-electric



ELECTRIC/HYBRID AIRPLANES

Range Equation and Impact of variable mass on range

Batteries are dead weight !

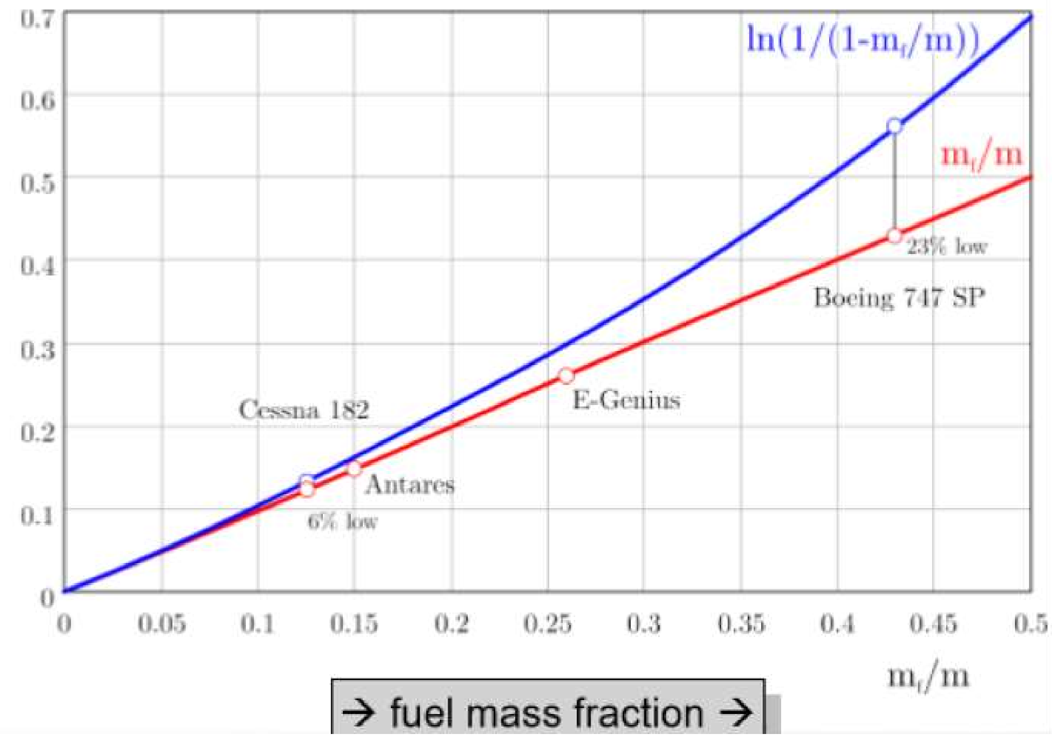
Once you've depleted the charge, you still sit with exactly the same mass as for a full battery, that means your plane never becomes more lighter and more fuel efficient as you cruise.

Normal aircraft bank on the fact that it gets lighter as you burn off fuel.
Both for range/endurance and to prevent you from landing overweight.

An electric large airplane like B747 will have about **-25% Range** with the same battery mass fraction.

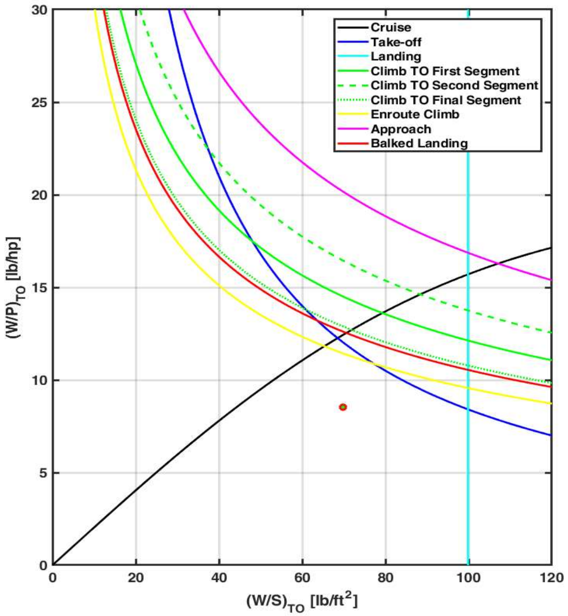
$$R = E^{*} \cdot \eta_{total} \cdot \frac{1}{g} \cdot \frac{L}{D} \cdot \ln\left(\frac{1}{1-\frac{m_{fuel}}{m}}\right)$$

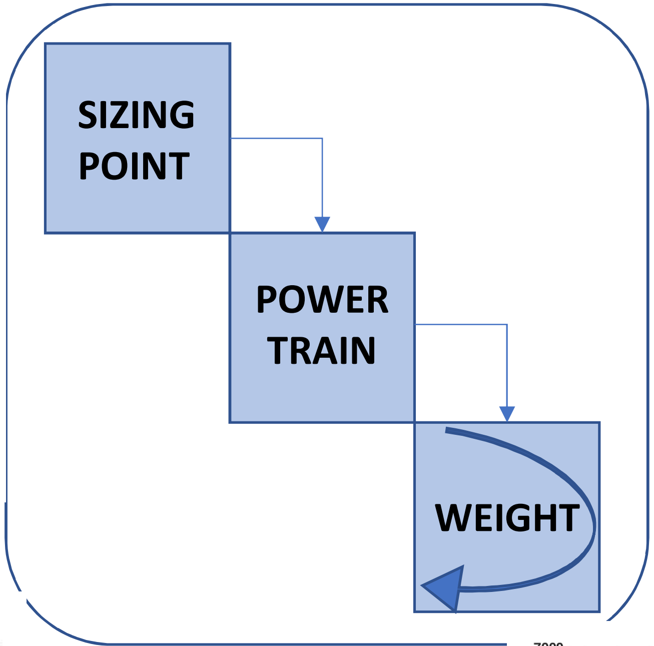
$$R = E^{*} \cdot \eta_{total} \cdot \frac{1}{g} \cdot \frac{L}{D} \cdot \frac{m_{battery}}{m}$$

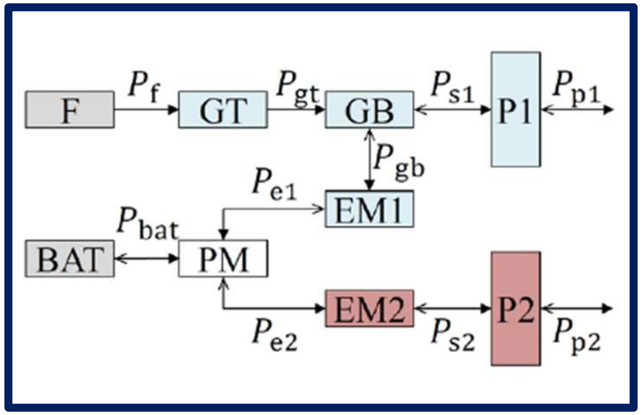


CONCEPTUAL DESIGN APPROACH

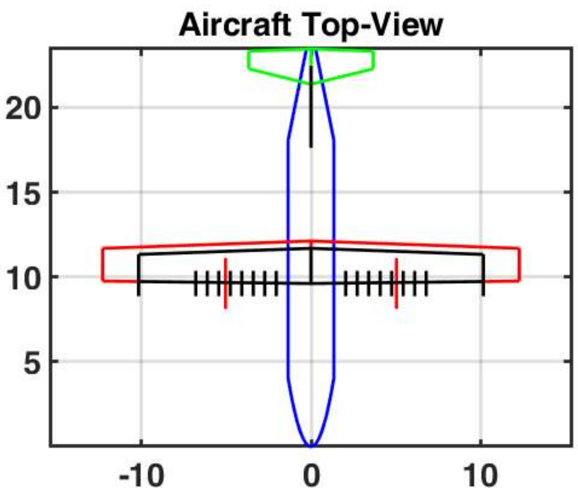
SIZING

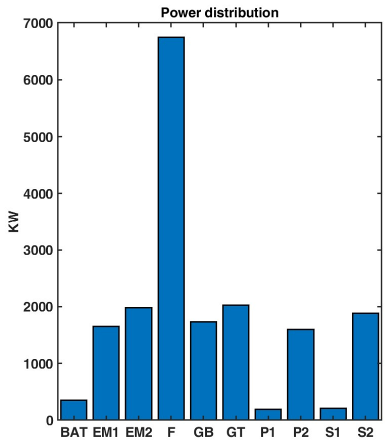


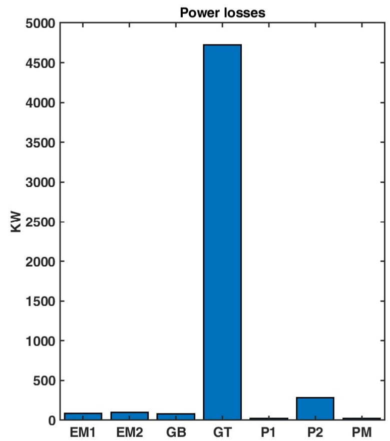




Serial/parallel partial hybrid (SPPH)

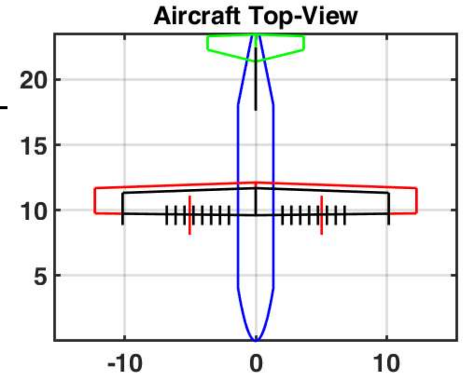




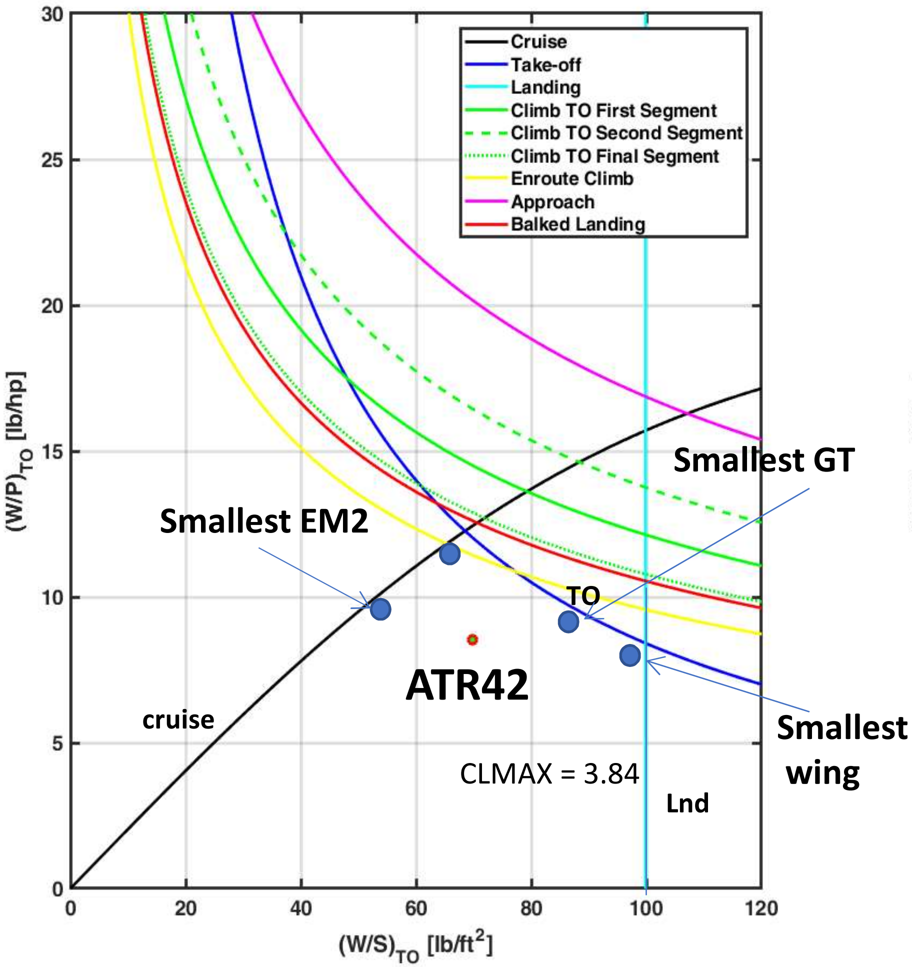


SIZING PLOT Hybrid Airplanes

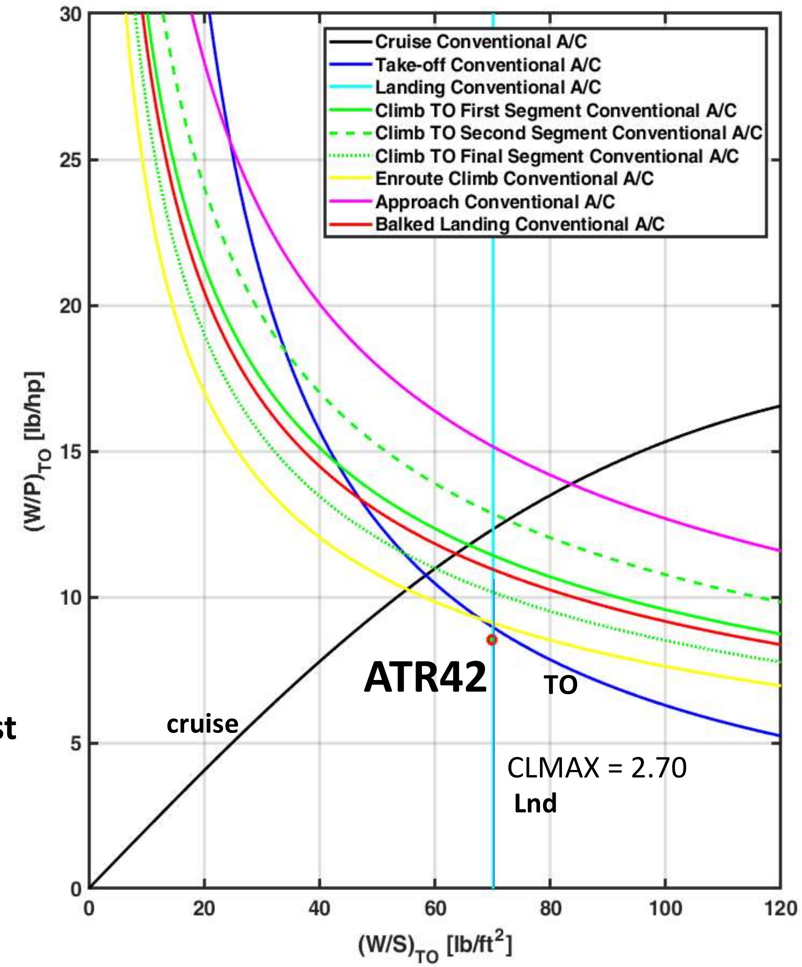
$$\phi = \frac{P_{s2}}{P_{s2} + P_{s1}} \quad \Phi = \frac{P_{bat}}{P_{bat} + P_f}$$



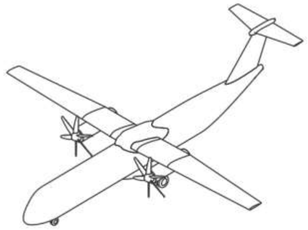
Distr. Electric Propulsion



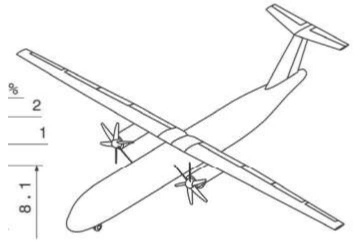
Conventional



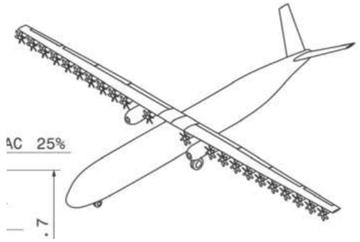
Analysis of Architecture and New Configurations



TP70

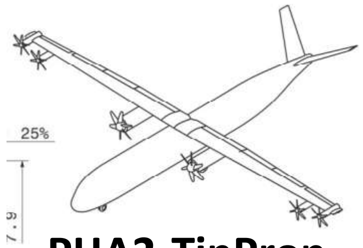


TP70-NEO+

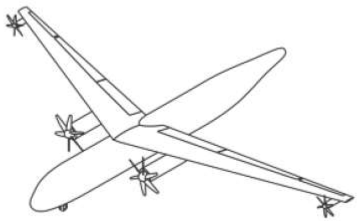


SHA2-DP

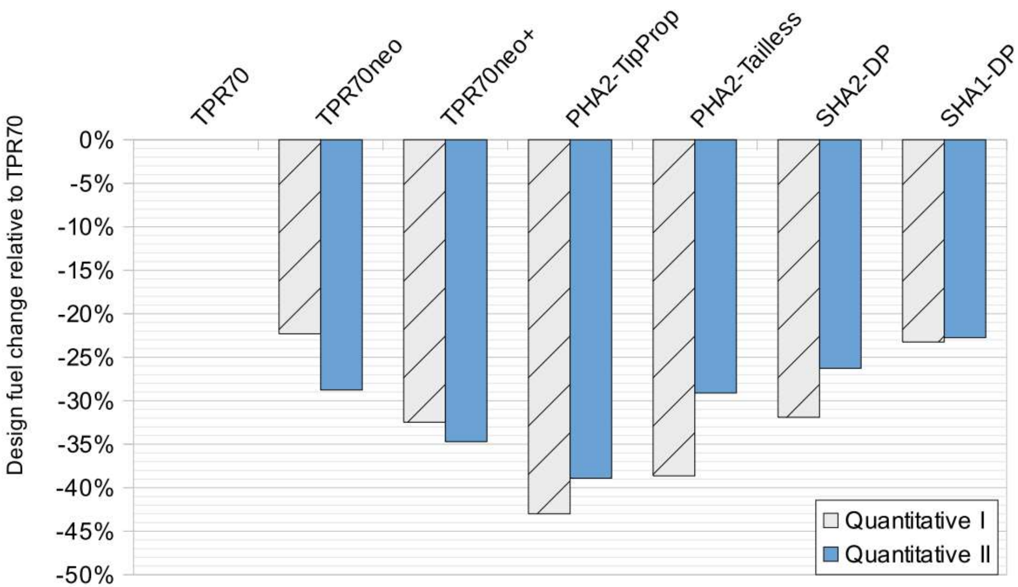
Conceptual Design Assessment of Advanced Hybrid Electric Turboprop Aircraft Configurations, Matthias Strack , Gabriel P. Chiozzotto, Michael Iwanizki, Martin Plohr and Martin Kuhn German Aerospace Center (DLR), Germany, AIAA AVIATION 2017



PHA2-TipProp



PHA2-Tailless



"La nostra immaginazione è tesa al massimo; non, come nelle storie fantastiche, per immaginare cose che in realtà non esistono, ma proprio per comprendere ciò che davvero esiste."

Richard Feynman