La Propulsione nei futuri sistemi di trasporto aerospaziale

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Aeronautics and Space

Different propulsion systems

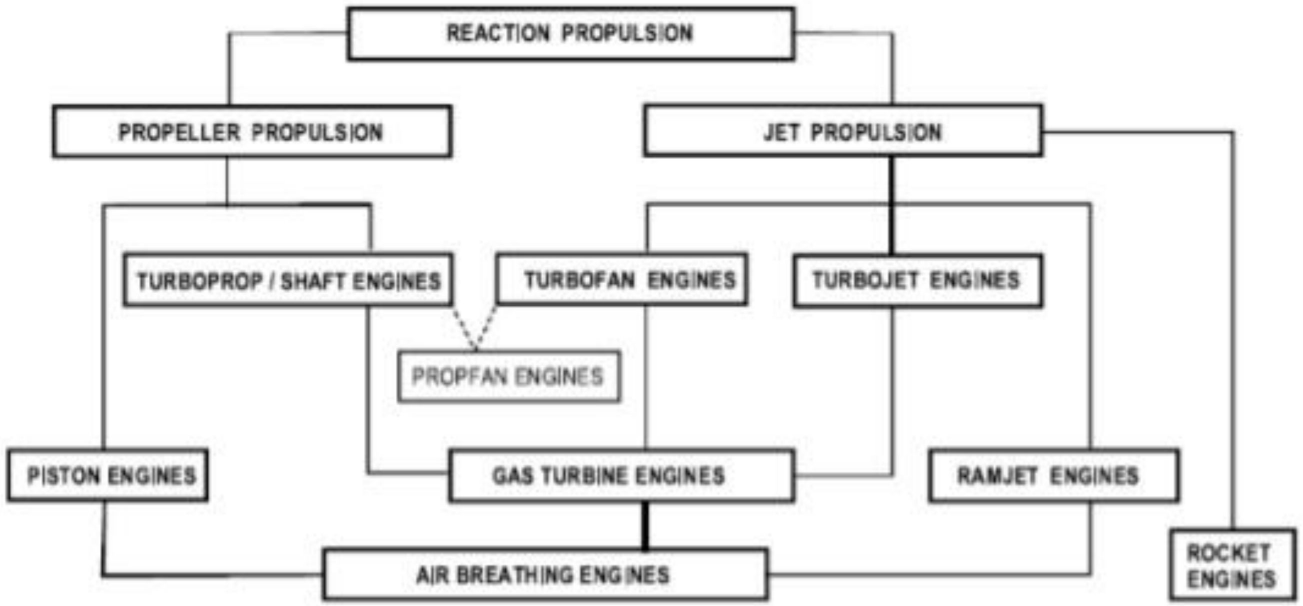
Airbreathing: atmospheric air is captured, whereas the fuels is in the vehicle:

Piston engines (light aircrafts
Turboprop (regiional transport
Turbojet (military aircrafts)
Turbofan (long distance or business aircrafts)

Non airbreathing: propellants are stored in the vehicle: rocket propulsion

Aircraft Propulsion Systems

Classifications: 1) Thrust generation; 2) propellants; 3) power source, ….



Classification of Engine Concepts , mostly used in Aviation

NASA Maxwell X-57

1) Thrust generator: propeller
2) propellant: air
3) power source: electrical

X-57- Tecnam P2006T twin-engine light aircraft modified with specially designed wing and 14 electric motors. NASA Aeronautics researchers will use the Maxwell to demonstrate that electric propulsion can make planes quieter, more efficient and more environmentally friendly

Advancements in propulsion systems

- New technologies and innovation in conventional airbreathing engines (e.g. jet engines with simplified architecture, 3D additive layer manufacturing, compact design, advanced lighter materials, lower maintenance cost, lower specific fuel consumption, low noise and emissions)
- Advanced hypersonic propulsion technology (combined cycle turbo-ramjet, augmented chemical rockets)
- Space (rocket) propulsion
- Electric/hybrid propulsion

Innovation in conventional airbreathing engines

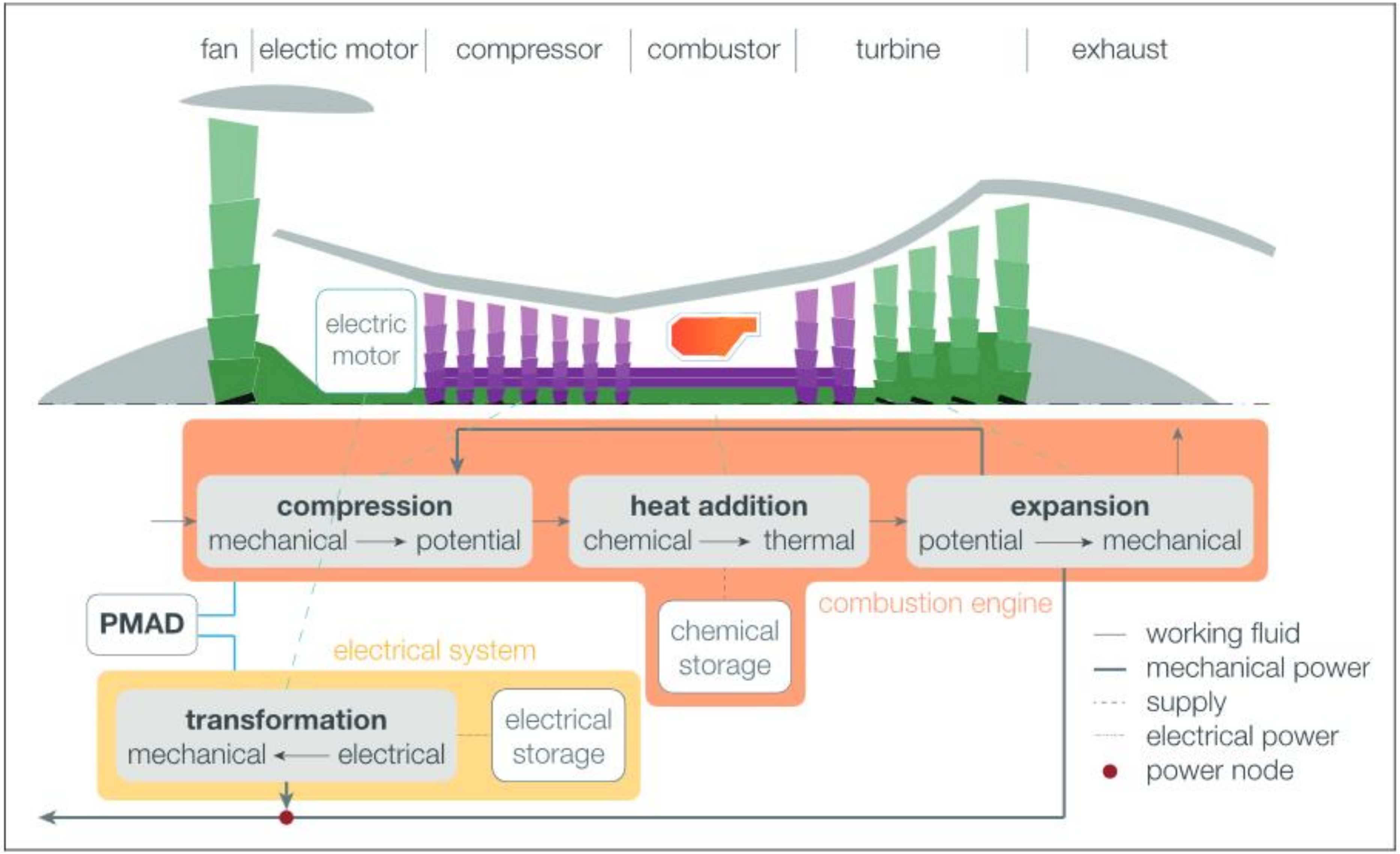
Rising overall efficiency requires improvements in thermal and propulsive (including transmission) efficiency

The most practical option is to increase the engine bypass ratio, which means enlarging the diameter. Ducted propellants with bypass ratios up to about 15 have been demonstrated, but they incur drag and installation penalties. Bypass ratios above about 10 generally require the addition of a gearbox to the power train.

In the Geared Turbofan Engine a state-of-the-art gear system allows the engine's fan to operate independent of the low-pressure compressor and turbine, resulting in greater fuel efficiency and a slower fan speed for less noise.

NASA ULTRA HIGH BYPASS RATIO (GTF) ENGINE (PW1700G/1900G); Noise -20dB; Emissions -50%

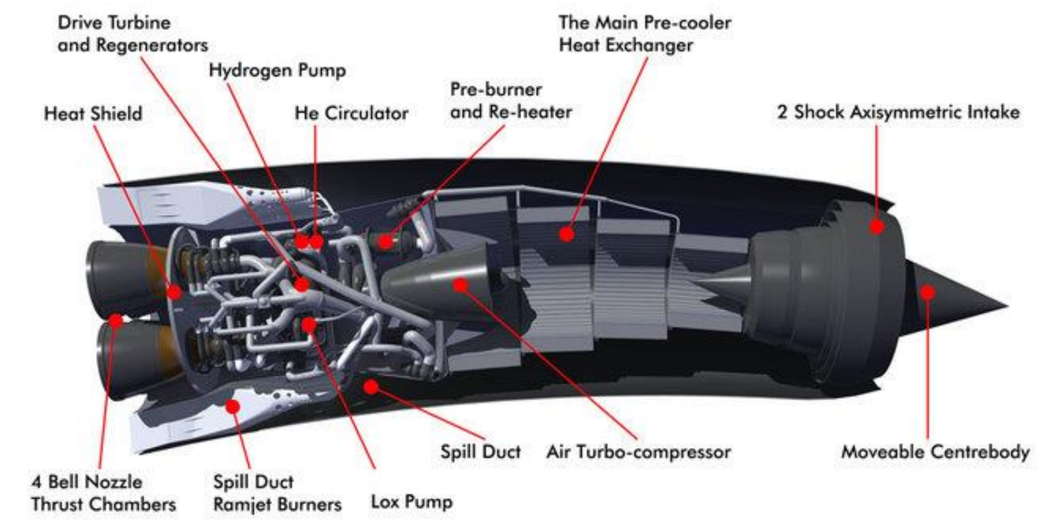
Electrically assisted airbreathing engine



Advanced hypersonic propulsion

REACTION ENGINES SABRE

Hypersonic Precooled Hybrid Airbreathing Rocket engine (Mach 5)



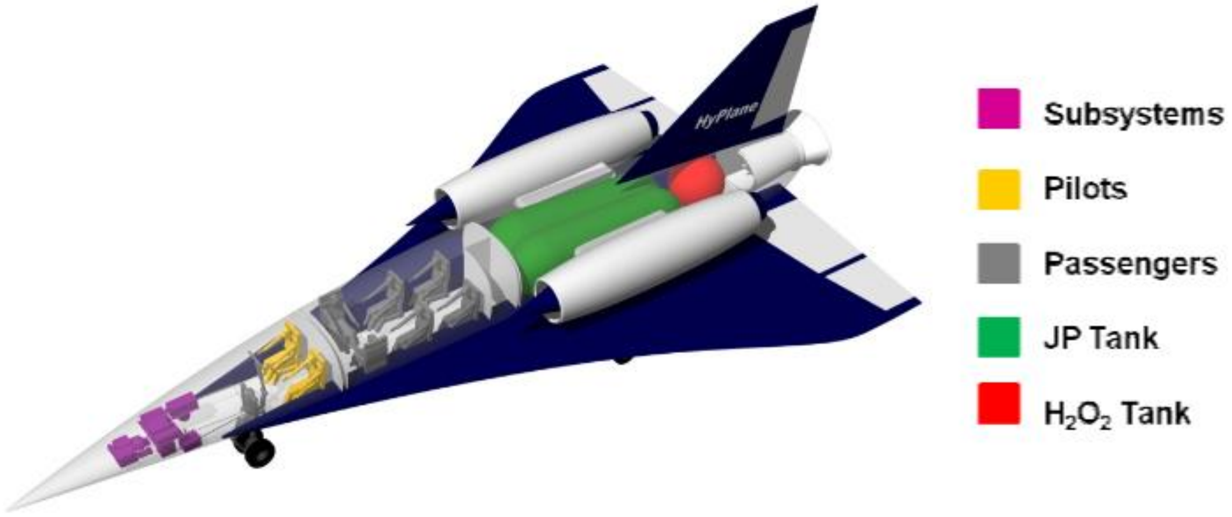
NASA ULTRA HIGH BYPASS RATIO ENGINE

New generation engines with simplified architecture, reduced parts (3D additive layer manufacturing), compact design, advanced lighter materials, lower maintenance cost, lower specific fuel consumption, low noise and emissions.

Hypersonic flight/Space Tourism

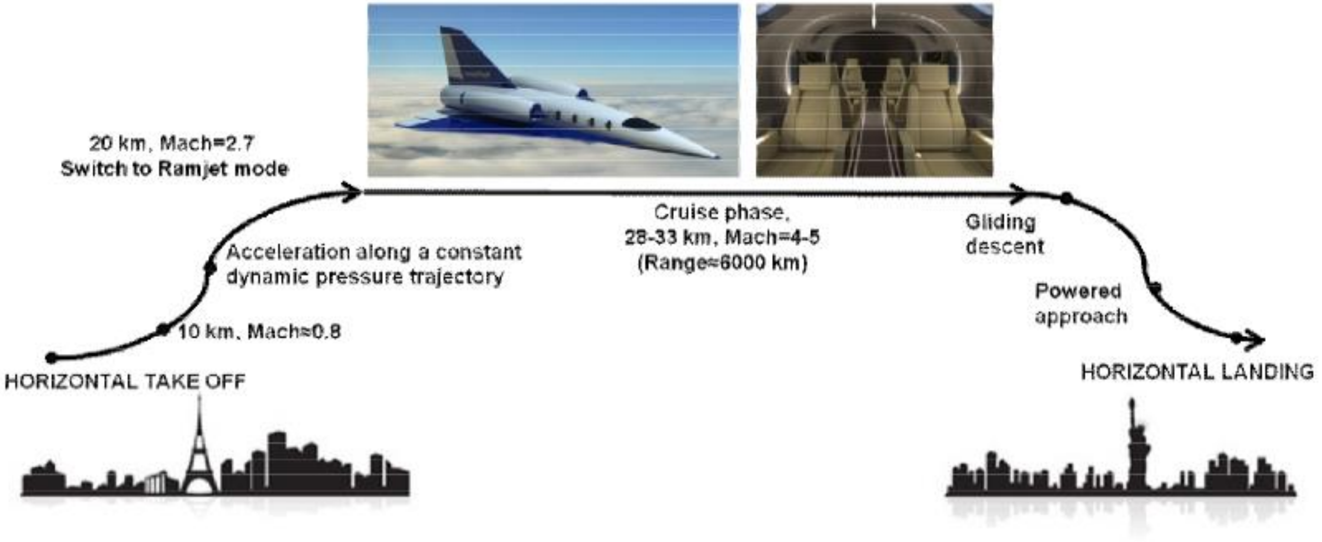
A Multi-Purpose Small Hypersonic Aerospaceplane

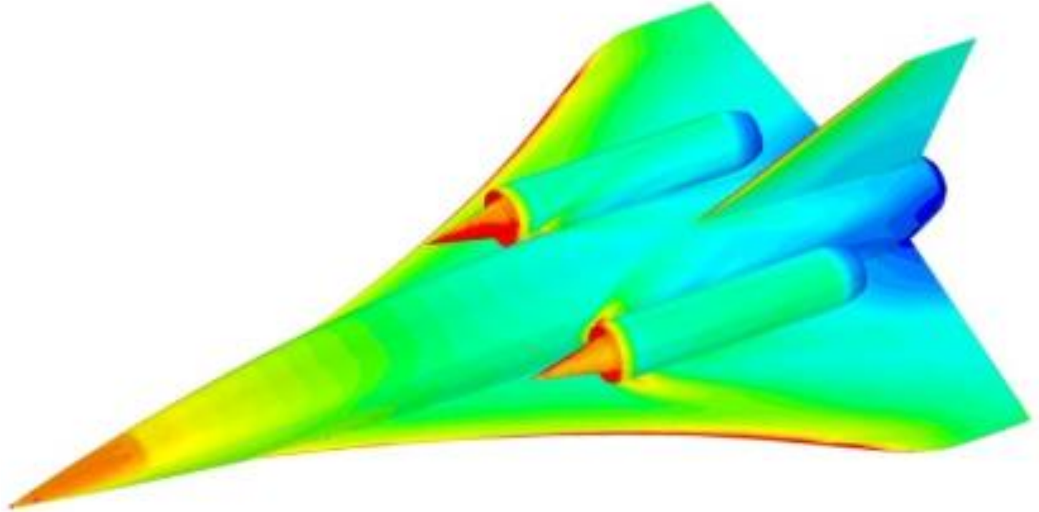
- Fully reusable single stage
- GTOW = 27 t ; 24 m long ; 16 m span
- Mission capabilities:
  - 30 km altitude flight, Mach 4.5-5, **stratospheric flight**
  - **Sub-orbital** "jumps" up to 100 km (Karman Line)

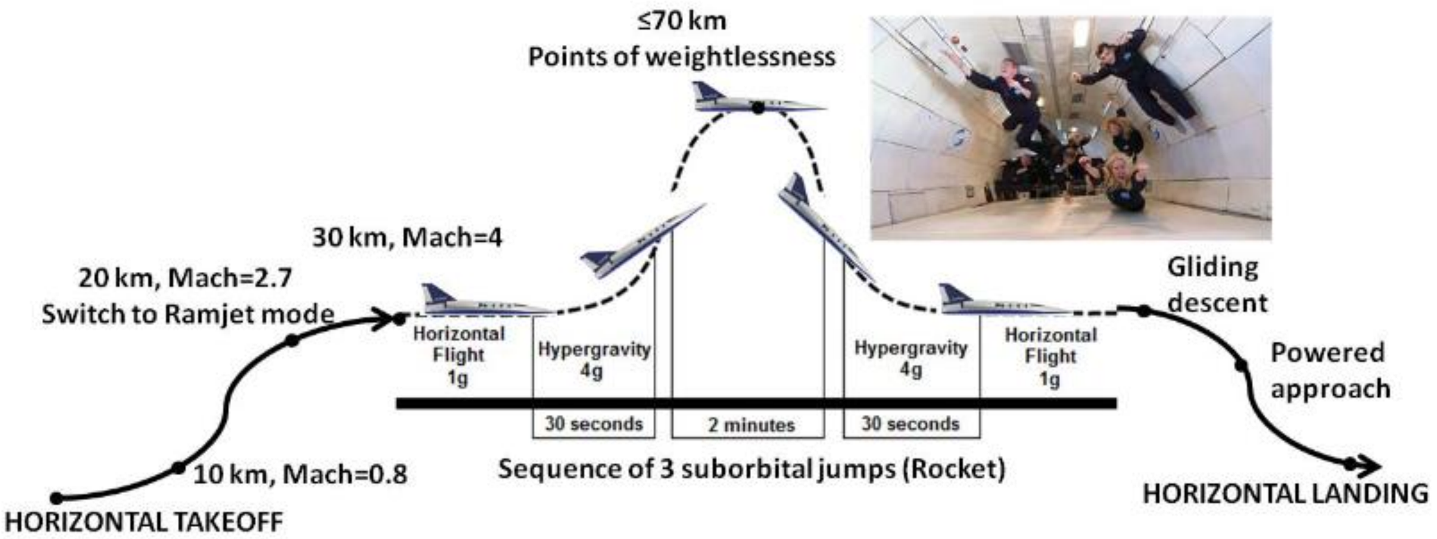


- 6-8 seats small Mach 4-4.5 spaceplane
- HTHL within the present rules governing common airports
- Urgent Travel market segment
- Space tourism

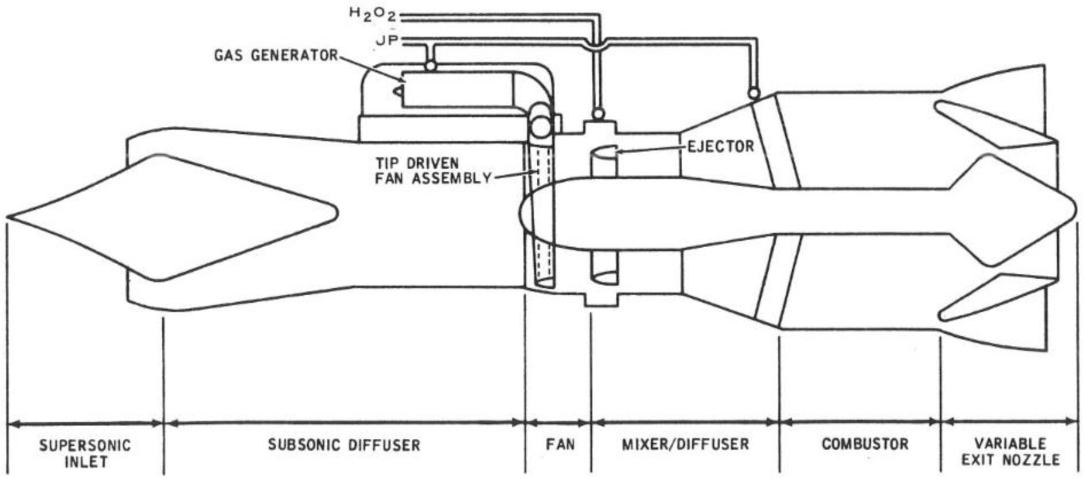
Hypersonic flight/Space Tourism

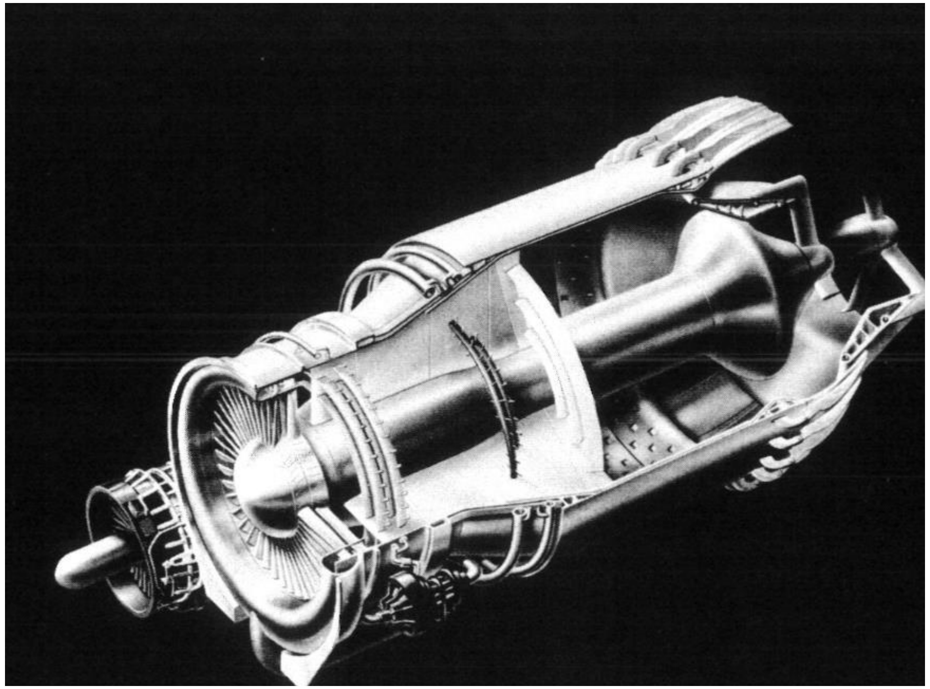


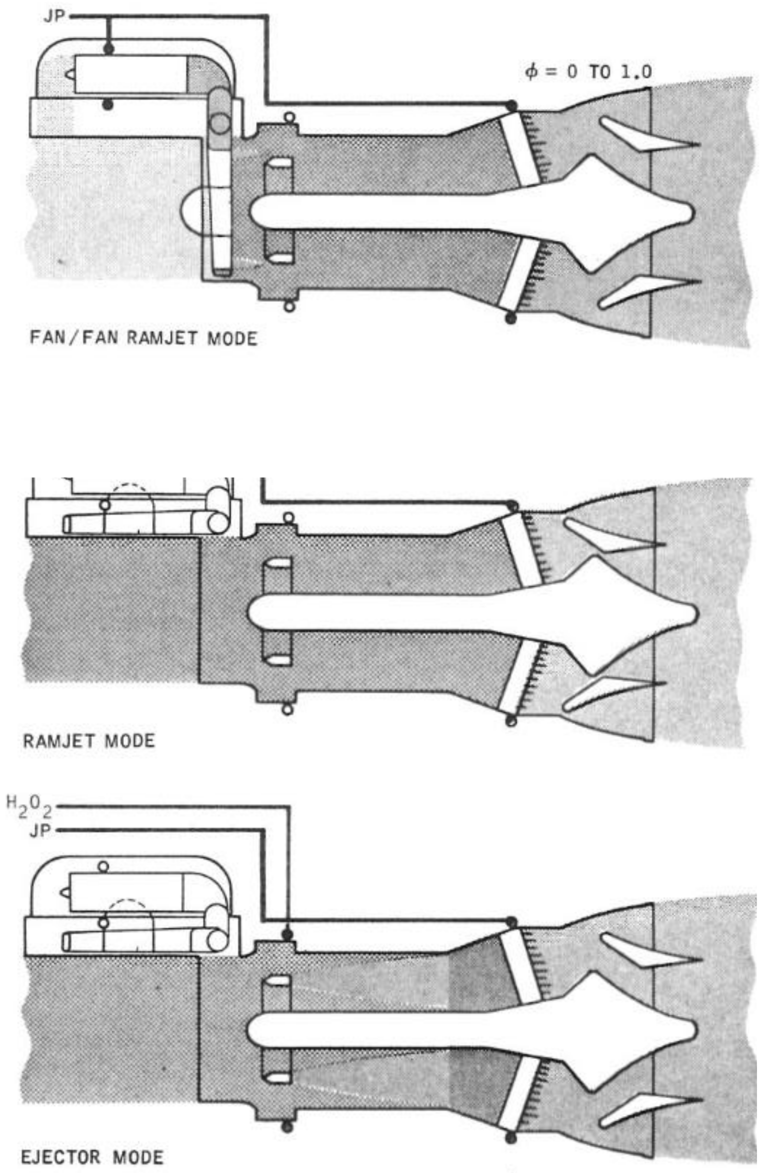




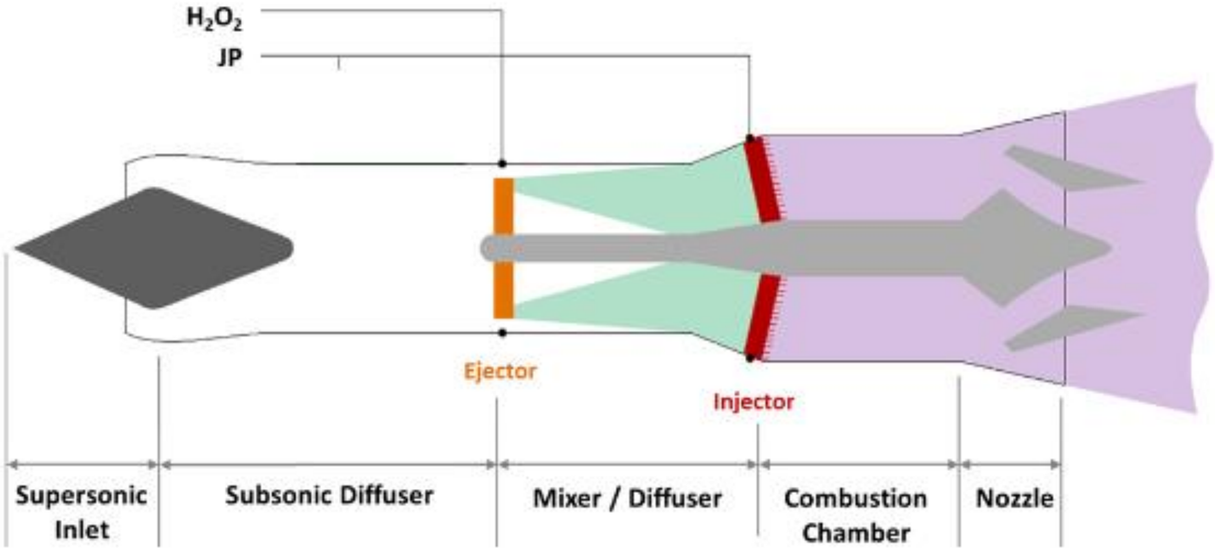
Supercharged ejector-ramjet





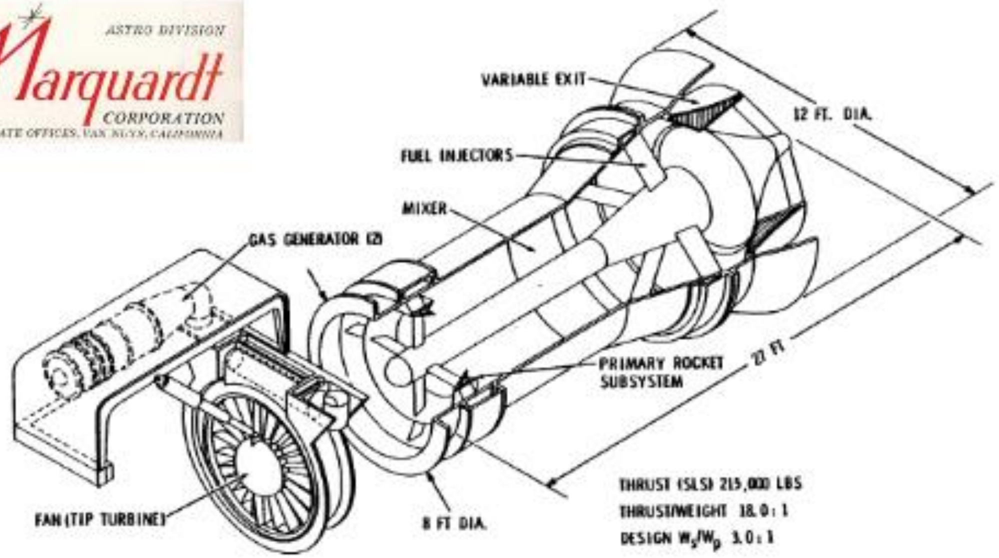


Supercharged Ejector Ramjet (SERJ)

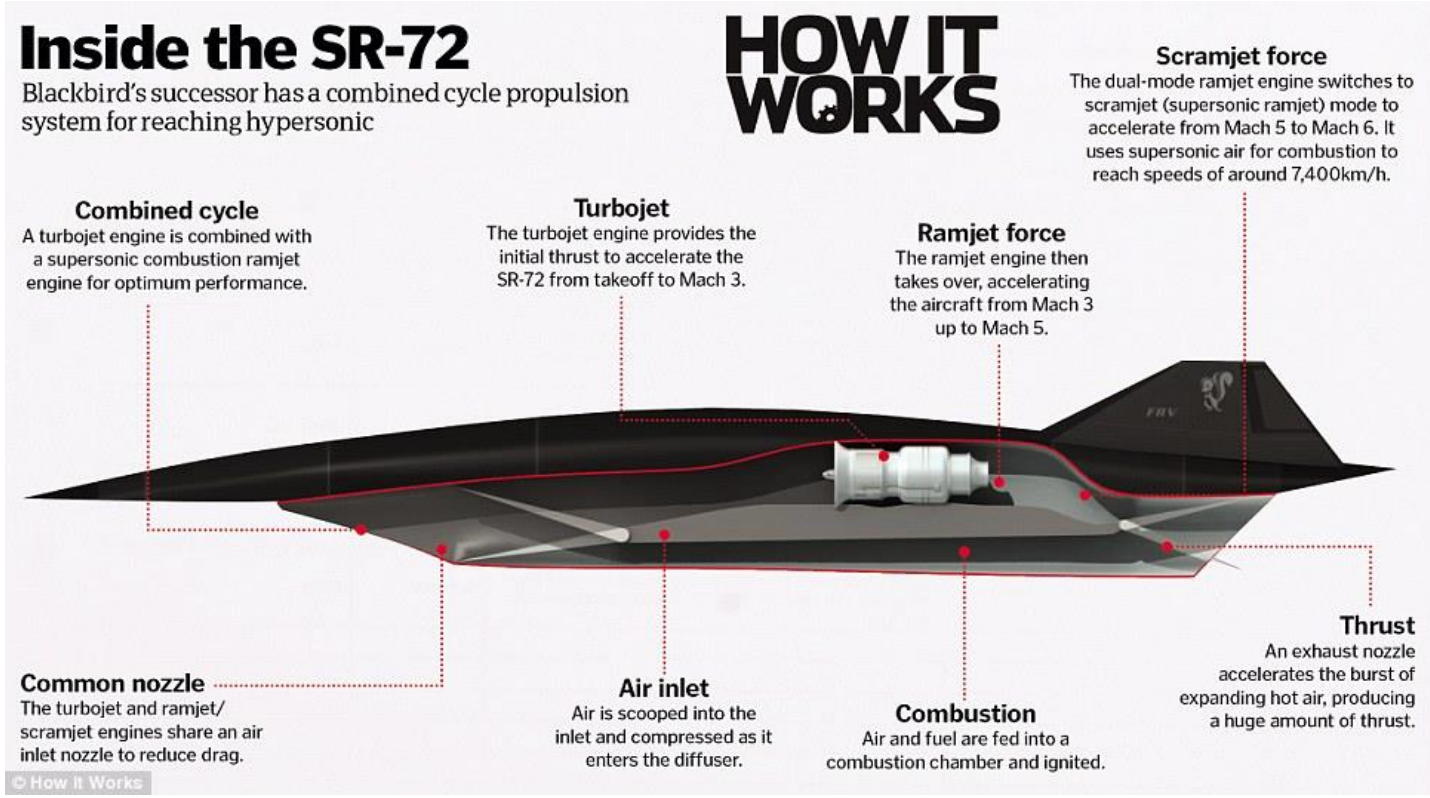


PHASES	CONFIGURATIONS
Takeoff and subsonic climb	Fan + Afterburner
Transonic climb	Fan + Afterburner
Supersonic climb 1	Fan + Afterburner
Supersonic climb 2	Ramjet
Parabolic flight	Ejector
Supersonic cruise	Ramjet
Gliding descent	Fan + Afterburner
Subsonic loiter	Fan

THE Marquardt CORPORATION ASTRO DIVISION
CORPORATE OFFICES, VAN NUYS, CALIFORNIA



Scramjet propulsion



KEY FOR HYPERSONIC FLIGHT

Main research programs in USA, Australia, Russia, China, India

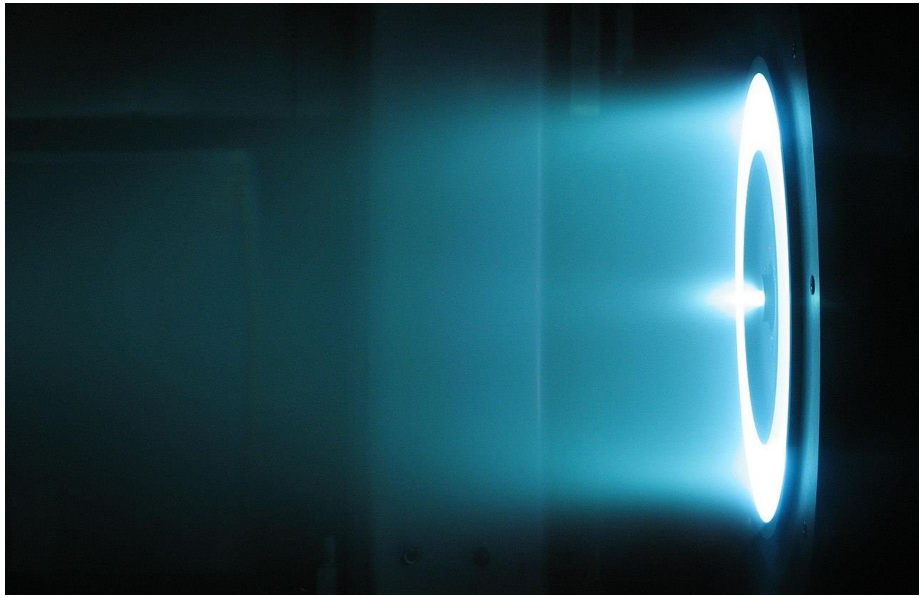
HyCAUSE Australian Mach 10 scramjet-based missile test

Innovation in rocket propulsion

Green chemical space propulsion

Monopropellants, Hybrid Rockets for launch systems, vehicles, satellites or other spacecraft, advanced design, green, inherent safety, throttling capability, reignition, high performance

Non conventional (non chemical) rockets



Electrostatic, Electrothermal, Electromagnetic thrusters operating at higher specific impuse for interplanetary missions or for future small satellites

Innovation in rockets with unconventional features

Design-for-Environment, or Eco-design"(non toxic, safe green propellants e.g, LOX/Hydrocarbon, Nitrous Oxide/Hydrocarbon)

Engine architecture driven by the lay-out of the vehicle

Economic target driven by cost of passenger ticket (100-200 Keuro)

Optimum performances (Isp level and thrust magnitude) as well so that the spaceplane rocket is neither "booster stage" nor "upper stage" standards driven.

"aircraft-like" because the vehicle is expected to be operated weekly (need for high-reusability of the rocket engine)

"launcher upper stage-like", as it is planned to ignite after aeronautic phases including take-off and climbing to altitude

"launcher first stage-like" like as ignition happens when atmosphere density is not yet zero.

Electrical and hybrid aircraft propulsion

Hybrid Electric Propulsion is an exciting area with much promise for improving the fuel efficiency, emissions, and noise levels in commercial transport aircraft

Research in this area includes airplane concepts, electrical power systems, component materials, and test facilities, how batteries might be used to boost power during takeoff, and how to reduce drag by strategic placement of electrically-driven fans.

NASA Subsonic Ultra Green Aircraft (SUGAR)

NASA N3-X Eco friendly electric airplane (wing-body with turbo-electric propulsion)

Electrical and hybrid propulsion for aircraft

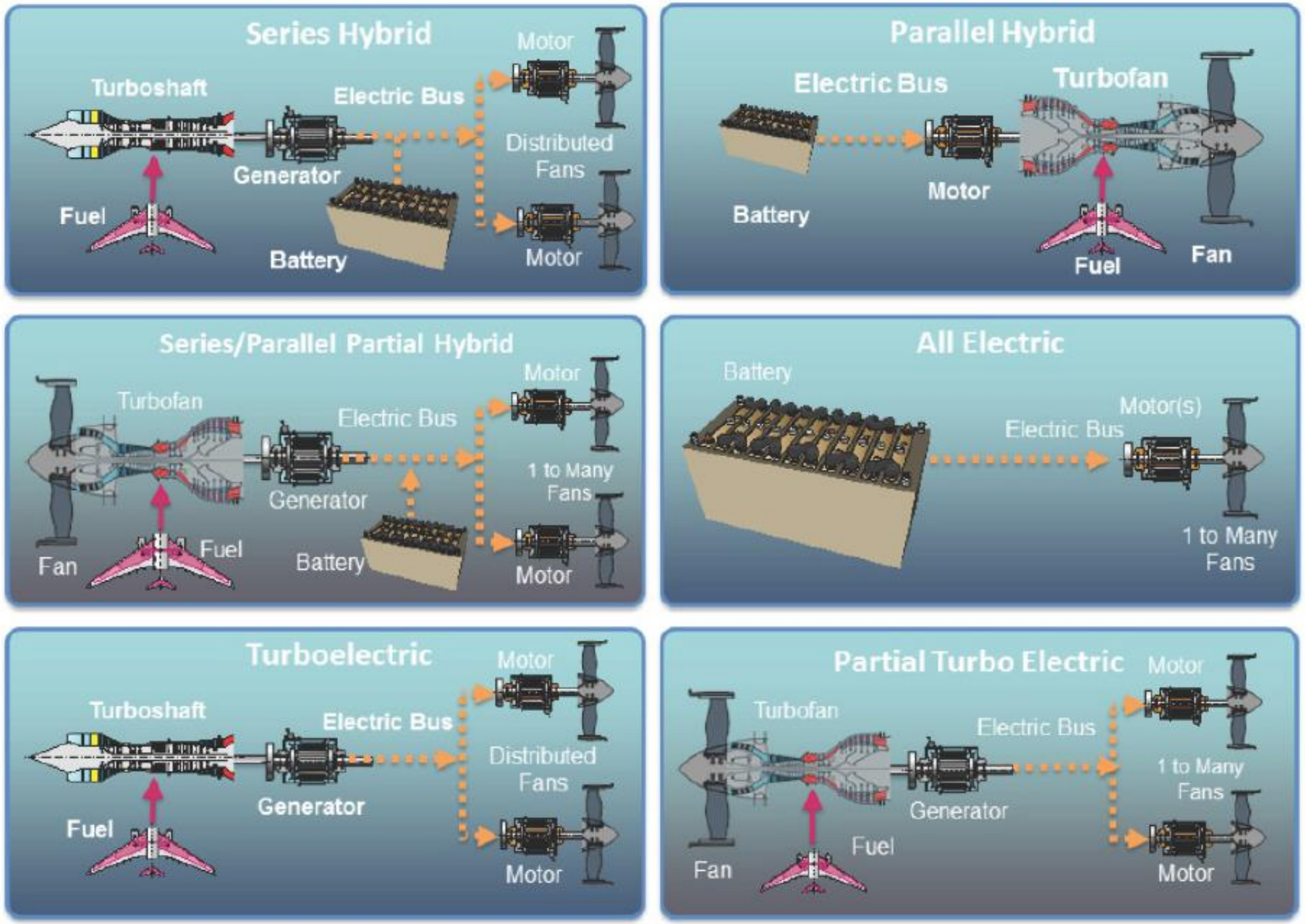
- Series hybrid: where electric motors drive propellers and thermal engines provide energy to batteries;

- Parallel hybrid: where both electric motors and thermal engines are mechanically connected to propellers;

- Series/parallel hybrid: as for parallel case, but thermal engines are also connected to a generator to provide energy to batteries;

- Partial hybrid: combinations that may vary case by case.

Electrical and hybrid propulsion for aircraft



Electrical and hybrid propulsion for aircraft

Energy degree of hybridization, HE, measuring the extent of electrical energy on the overall stored one (electrical and fuel)

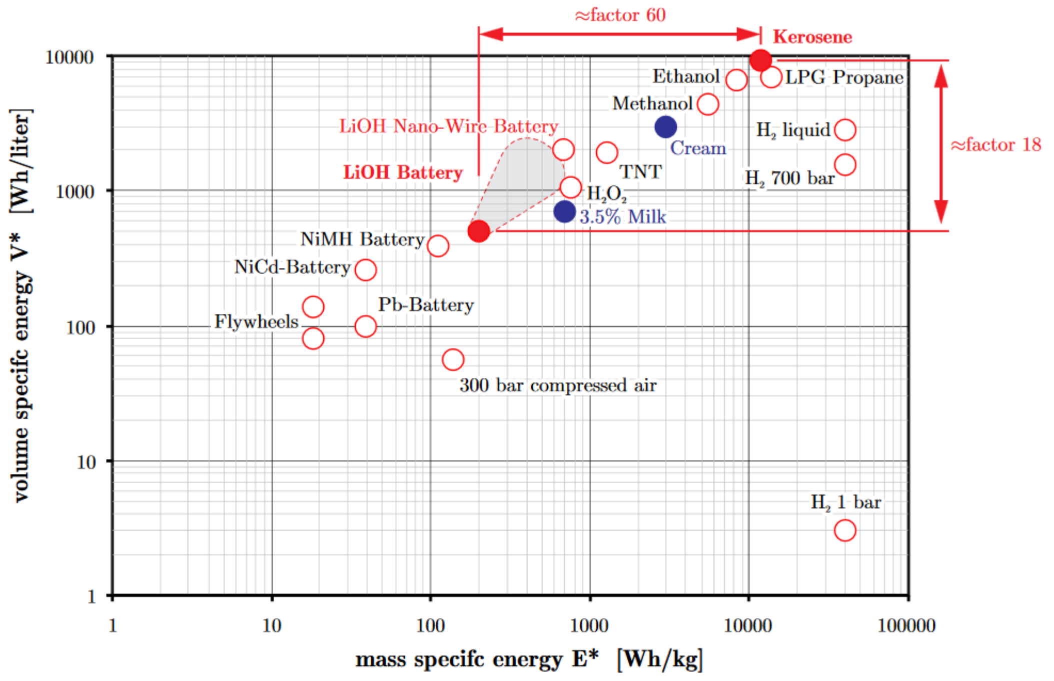
Power degree of hybridization, HP , measuring the amount of power provided by electric motors on the overall installed one (electrical and fuel)

Conventional aircraft; with 100% thermal engines fed by fuel tanks, degrees of hybridization will be zero, thus: HE = 0 and HP = 0

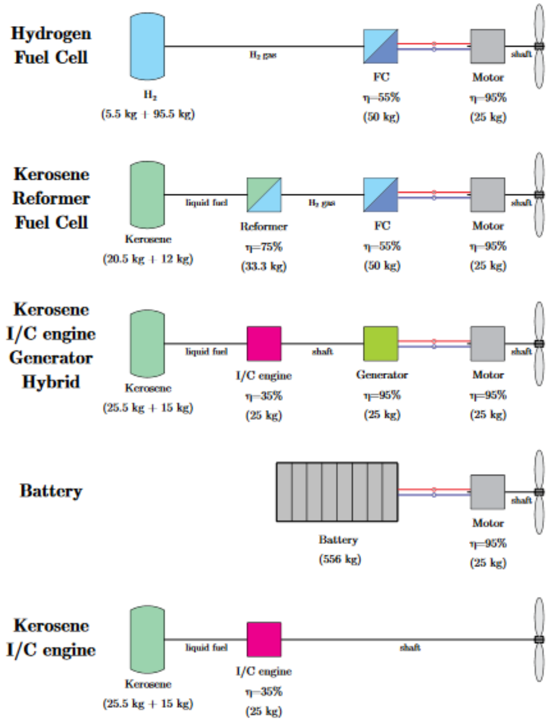
Full Turbo-Electric aircraft; all power is provided by electric motors fed by fuel based generators: HE = 0 and HP = 1

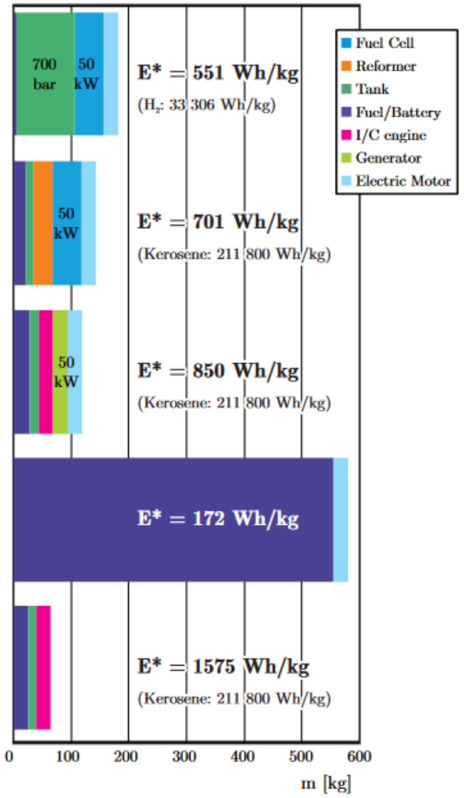
All-Electric aircraft; all power is provided by electric motors and all energy is provided by batteries: HE = 1 and HP = 1

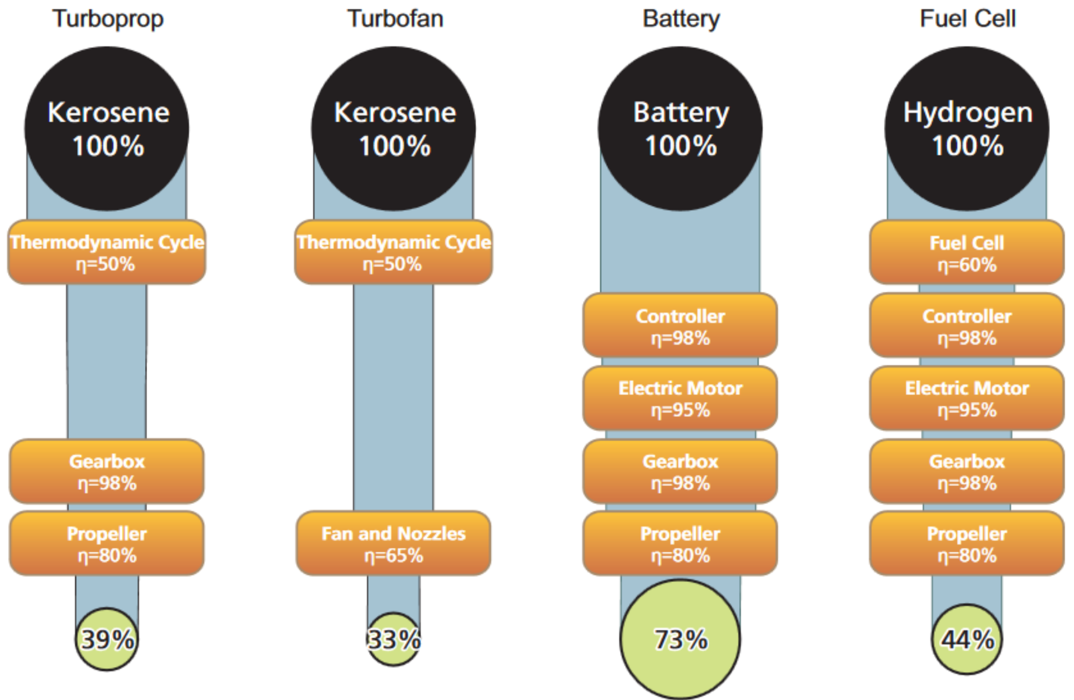
Electrical propulsion Potential and limitations



shaft power of 50 kW for 2 hours







Electric Propulsion Evolution Strategy

- Can electric propulsion impact aviation over the next decade, or is battery specific energy too constraining?
- What value does electric propulsion offer aviation in the near-term in terms of carbon emissions?
- What is the likely evolutionary technology path?

New trends in electrical propulsion for aircraft

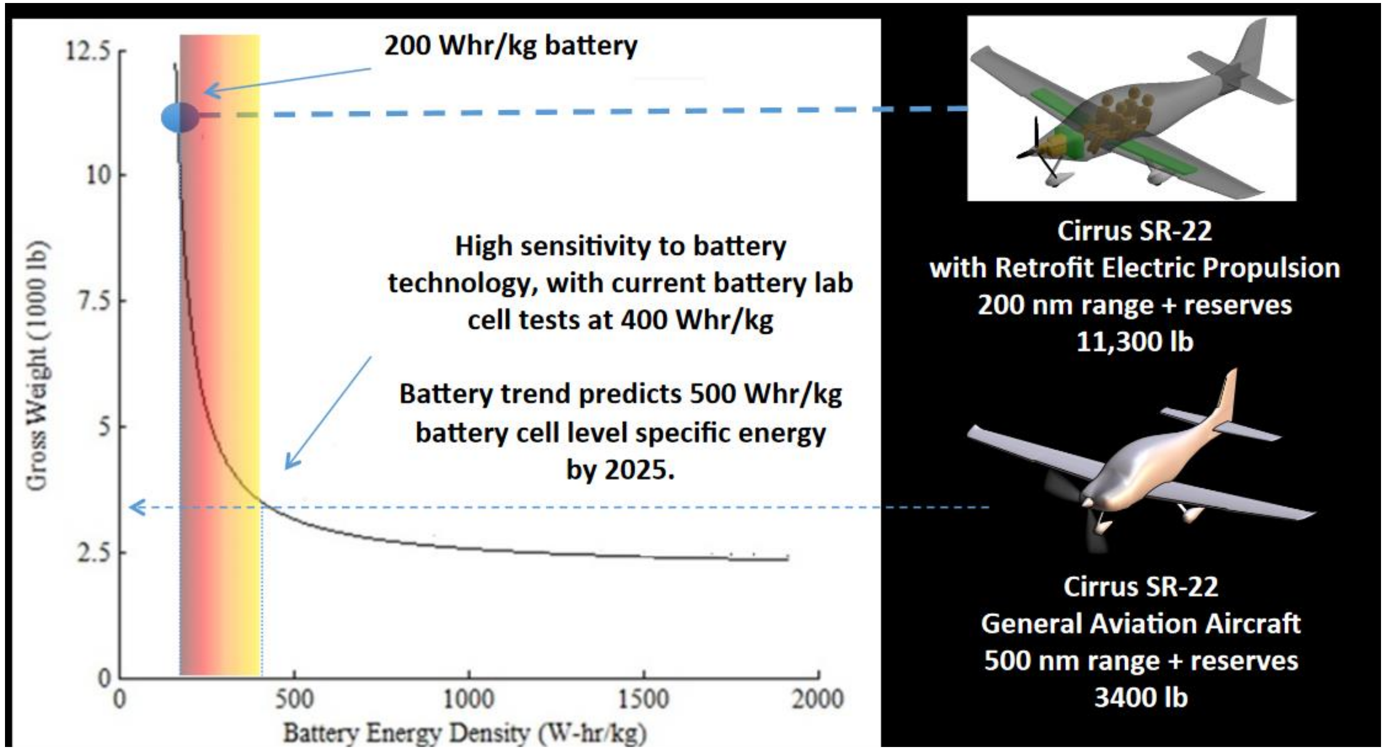
- Technological improvements exist for batteries and electric motors:

  - Batteries have achieved an average rate of improvement in energy density of ~8% per year over the past 30 years. Current available cells are ~250 Wh/kg.

  - Electric motors are currently being tested at 4-6 hp/lb specific power, with 95% to 97% efficiency.

- Penalties: Energy Storage weight, cost, Certification

- Benefits: scale-free; 1-6 x motor power to weight; 2-4 x efficiency compared to state of art engines; extremely compact; extremely quiet; zero emissions, reliable (*at any scale*)

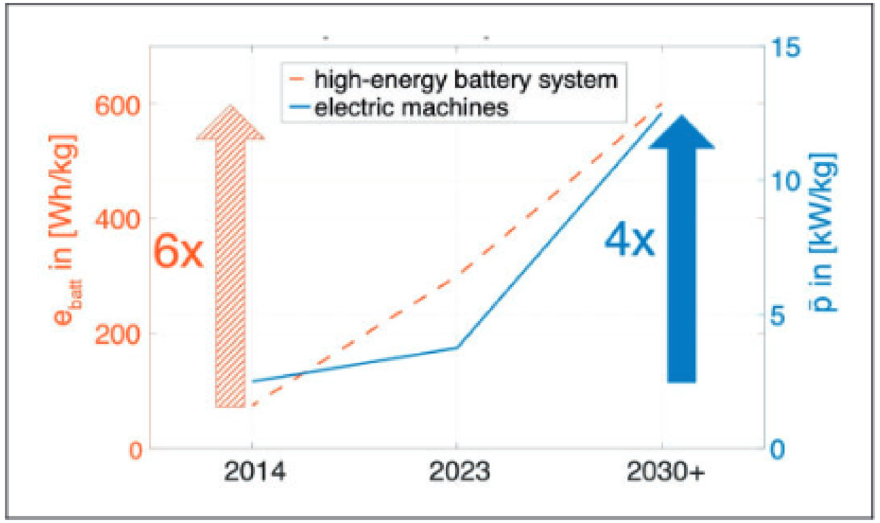


Battery energy density sensitivity for a 200 mile range Cirrus SR-22 electric retrofit concept compared to the existing conventional baseline (*the configuration is frozen*)

Efficiency of electrical components is significantly higher than thermal engines, buy the specific energy density of batteries is substantially lower than kerosene.

Battery specific energy penalty

Performance Analysis and Design of On-Demand Electric Aircraft Concepts, M.D. Paterson and B. German, AIAA Aviation 2013.



Electric Propulsion: an integration technology

- Relatively small size and low weight of electric motors and ability to scale electric motors without a significant loss of efficiency or specific power

- These characteristics provide the freedom to employ a multitude of small electric motors and propellers in strategic locations on the aircraft, resulting in a great increase in flexibility in the design of aircraft configurations

- In contrast, traditional propulsion systems typically tightly constrain aircraft designs due to scaling effects and the large size and mass of combustion engines, which normally dictate the use of no more than a small number of engines placed in a small number of practical locations

- Distributed electric propulsors that are optimized for the aerodynamic, propulsive, and acoustic requirements

Turbo-electric propulsion engines

NASA distributed turbo-electric propulsion vehicle concept using **16 distributed electric fans driven by motors** with power provided by **two wing-tip** mounted turbo-electric generators

Advantages:

1) Span-wise continuous fans give more benefits

2) low source noise levels and lower nacelle weight

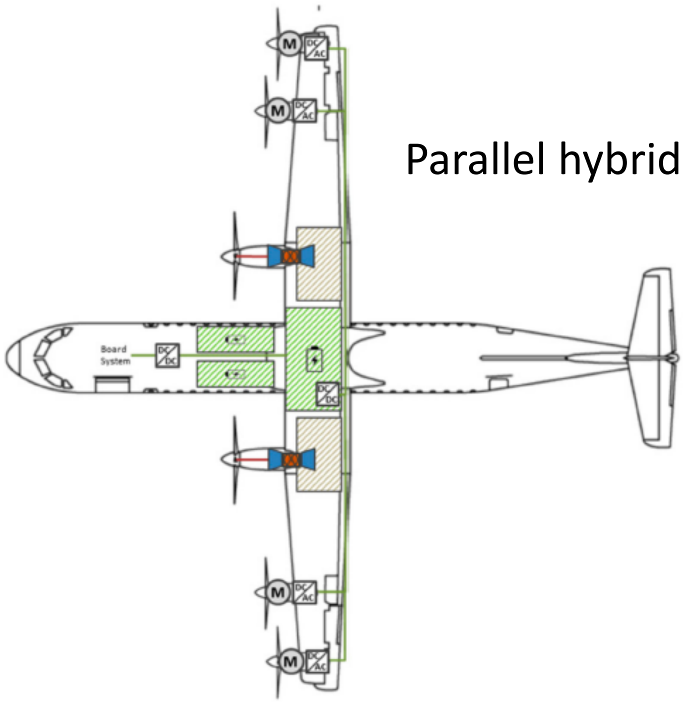
3) Increased safety because high density turbomachinery is located well away from the passenger spaces

4) Reduced lift-induced drag and wake vortex strength due to wing-tip location of the engine cores

5) The turbogenerator does not ingest boundary layer air

Aerodynamic-Propulsion integration

The hybridization of the propulsion system enables new propulsion architectures that lever additional aerodynamic improvements. An extreme example is the distributed propulsion concept with more than ten propulsors. The new arrangement of propulsors can lead to better aerodynamic lift properties of the wing



Parallel hybrid

wingtip propeller architecture for an ATR

A variation of this concept is an architecture with two electric-driven wingtip propellers and a conventionally placed turboprop on each wing

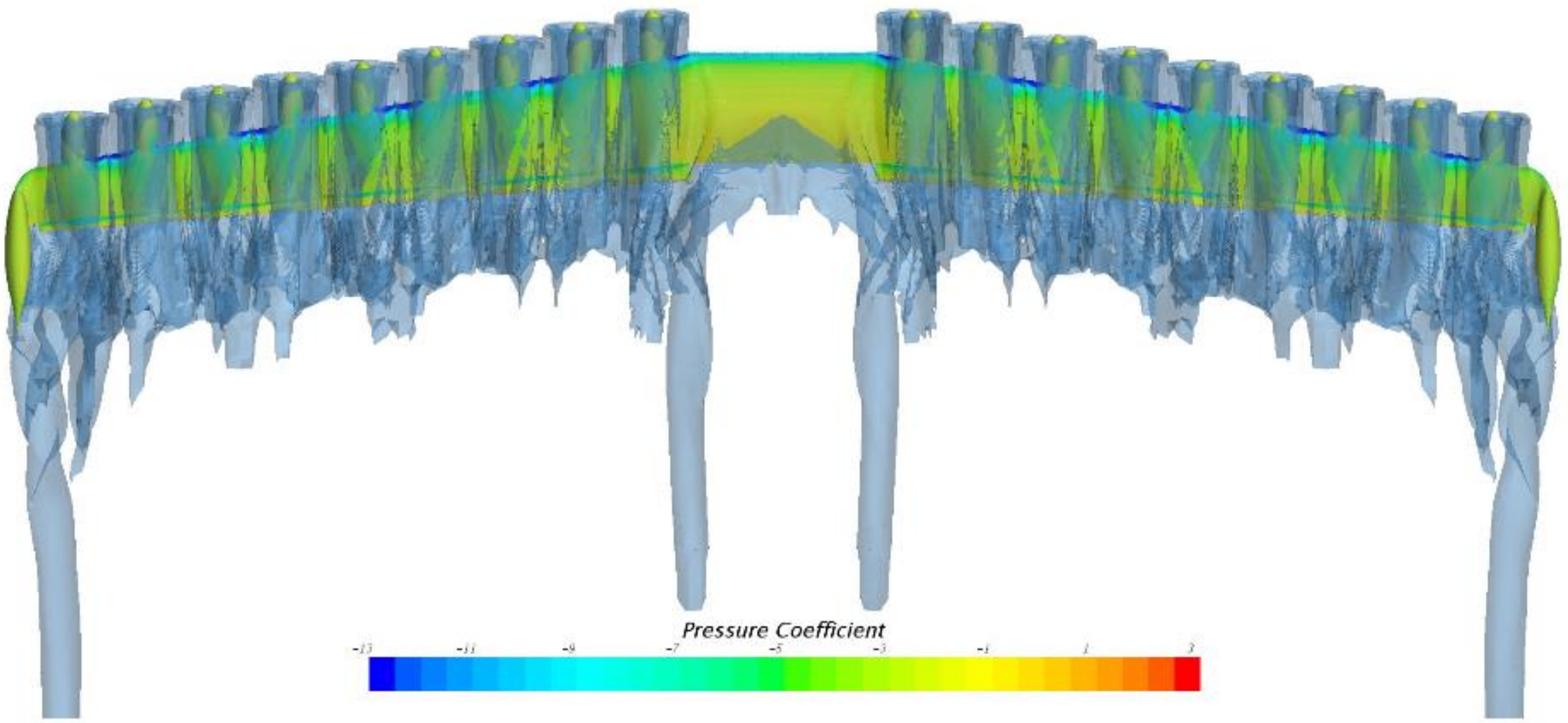
"High-lift propellers" can be placed upstream of wing such that, when the higher-velocity flow in the propellers interacts with the wing, the lift is increased

During higher-speed flight, the high-lift props are folded and stowed against the nacelles to reduce drag. The two cruise propeller at the wing tip, during higher-speed flight, not only produce thrust but reduce the induced drag

(a) Low-speed propeller configuration

(b) High-speed propeller configuration

Aero-Propulsion: CFD simulation



Tecnam P2006T Light Twin General Aviation Aircraft

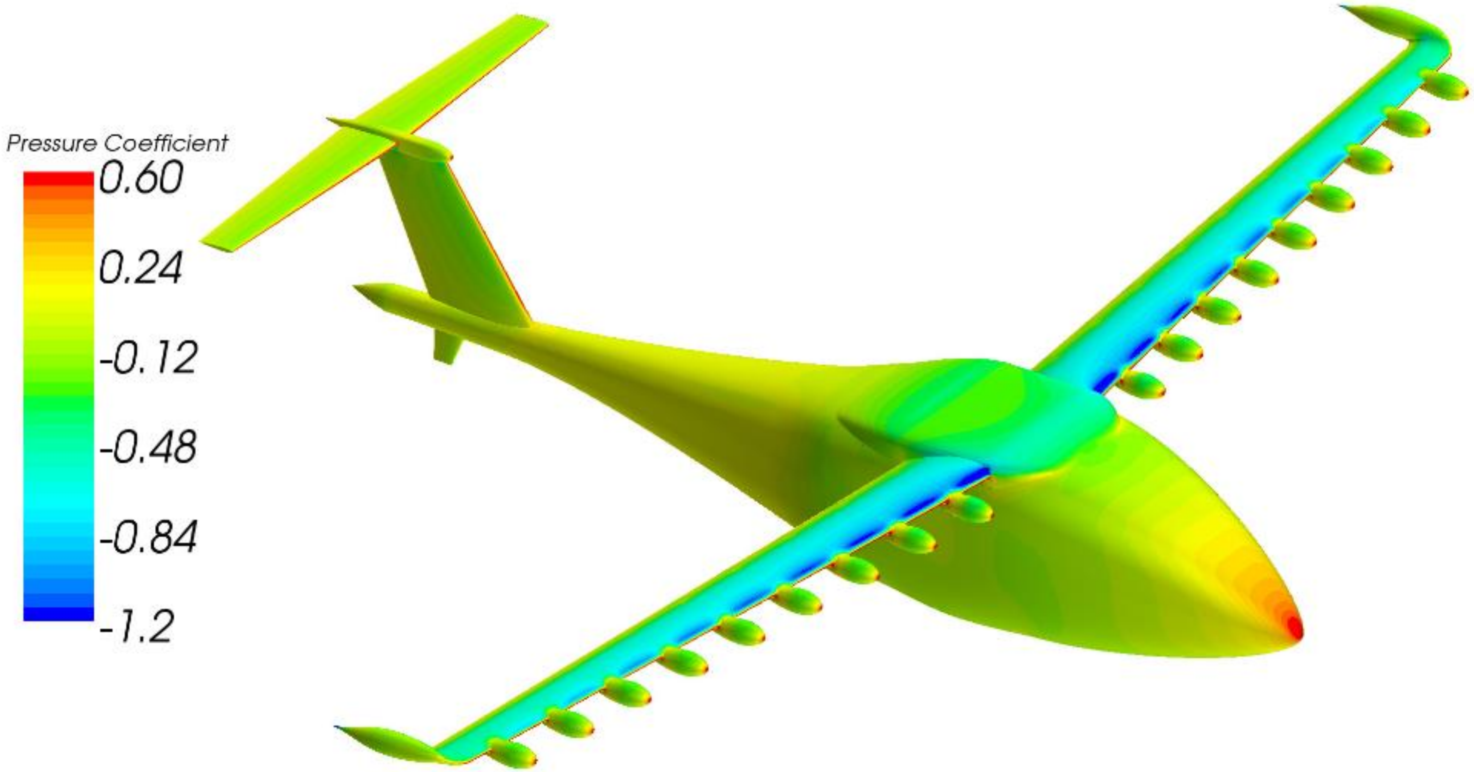
NASA Distributed Electric Propulsion (DEP) X-Plane

Scalable Convergent Electric Propulsion Technology
Operations Research (SCEPTOR)

NASA Sceptor X-plane transformational concept project

SCEPTOR focuses on how DEP technologies enables cruise efficiency at higher speeds

Flexible design: trade-off between different integration strategies



Conclusions

- Electric motors offer real advantages: unlike conventional combustion engines air is not used as power source (chemical) so that they can maintain full rated punch even at high altitudes. And unlike combustion engines with their drag-inducing requirements (for cooling air, air intakes, fuel lines, exhaust nozzles) they can be efficiently integrated in airframes
- Electric motors can be light and small and still develop considerale power (scale-free), unlike conventional engines with many moving and complex parts
- Heavy batteries are limiting factors and they energy storage capability increases only at an average of ~8% per year. However electric storage density is not the only issue (also discharging or charging time)
- **The big question is if experimental programs like NASA Sceptor can demonstrate a great benefit on the environment, on the configuration** (e.g.with take-off and landing lift augmentation) **that was not possible with conventional propulsion systems**. If the wing may be relatively smaller area and lighter than a conventional wing this is also very convenient for cruise flight (drag reduction)
- ***Operating Tecnam P2006T with DEP Nasa target is higher wing loading (2-3 x), higher aerodynamic efficiency (L/D from 11 to 18 and*** Cl_{max} ***from 2 to 5.5), propulsive efficiency from 22% to 80%, energy cost reduction, reduction of total operating cost, 1/5 total emission reduction and noise level from 85 dB to less than 70 dB***