SAFRAN ELECTRICAL & POWER

Considerations for High Power Aerospace Applications

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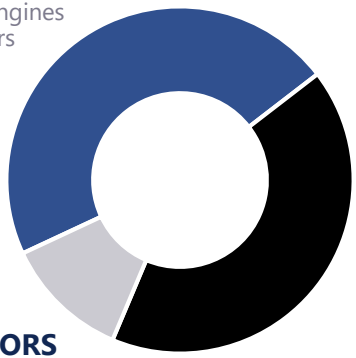
SAFRAN

Safran Electrical & Power part of Safran Group

AN INTERNATIONAL HIGH-TECHNOLOGY GROUP

46,5%
AEROSPACE PROPULSION

- Safran Aircraft Engines
- Safran Helicopter Engines
- Safran Aero Boosters



41,8%
AIRCRAFT EQUIPMENT, DEFENSE, AEROSYSTEMS

- Safran Landing Systems
- Safran Nacelles
- Safran Electrical & Power
- Safran Transmission Systems
- Safran Electronics & Defense
- Safran Aerosytems

11,7%
AIRCRAFT INTERIORS

- Safran Cabin
- Safran Seats
- Safran Passenger Solutions

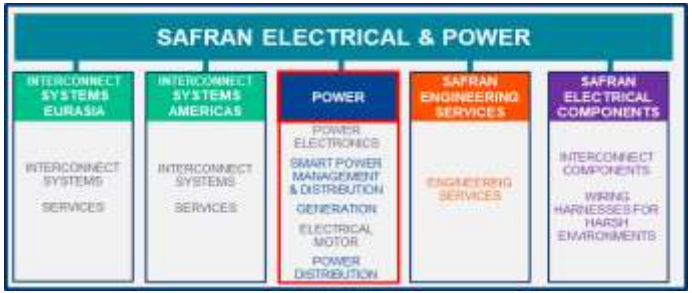
€19,0
Billion in revenue

~83,000
Employees

27
Countries

Safran Electrical & Power

Stéphane CUEILLE
CEO



Power sources

Engine

Apu

Fuel Cell

ELECTRICAL POWER MANAGEMENT SYSTEMS

RAT

Interconnect System For Power And Data

Electrical Components

Electrical Smart Motors

Generator

Primary & Secondary Distibution

Smart Power Management

Battery

A key building block to Safran portfolio

Other Electric Loads

Flight Controls

Nacelle

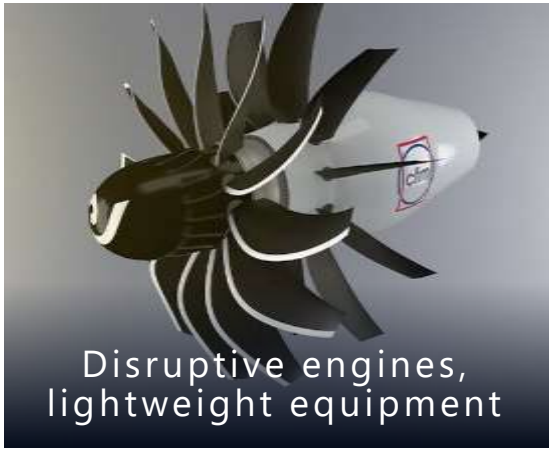
Landing Gear

SAFRAN

Decarbonizing aviation, our strategic priority

Innovative technologies

to contribute to a “zero emission” aviation by 2050



TRENDS IN AEROSPACE ELECTRICAL SYSTEMS

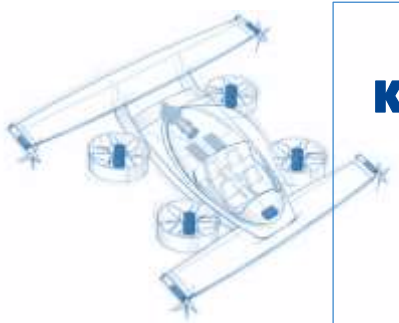
- ✓ Increasing adoption of inverter-fed brushless (particularly PM) machine technology
- ✓ Increasing system voltages and : 115VAC➔230VAC / 28VDC ➔ 270VDC ➔ 540VDC ➔ HVDC
- ✓ Drive towards E-propulsion, beyond traditional ATA 24. Acceleration of HVDC up to 800VDC
- ✓ Diversification and distribution of energy sources (Generators, Fuel Cells, Batteries)

ePOWER solutions

FOR HYBRID-ELECTRIC AND FULL ELECTRIC PROPULSION

ePower

- A brand new range of products preparing the future of hybrid / electric propulsion.
- Scalable technology bricks enabling application from non propulsive to propulsive
- Tested on several new mobility platforms to validate concepts



KEY SUCCESS FACTORS

1. INNOVATION
2. CERTIFICATION
3. PRODUCTION SYSTEM

GENeUS

HIGH VOLTAGE DC MOTORS & GENERATOR

ENGINeUS

INTEGRATED MOTOR DRIVE ENGINE

GENeUSGRID

POWER MANAGEMENT UNIT

GENeUSPACK

ENERGY STORAGE

Recent public announcements supporting global strategy

Safran Signs Agreement with Electra to Develop Turbogenerator for the Propulsion of its Hybrid-Electric Aircraft

ELECTRA.AERO

Diamond AIRCRAFT

HYUNDAI SAFRAN

Hyundai Motor Group and Safran signed a Memorandum of Understanding for Advanced Air Mobility development cooperation

ELECTRIC POWER SYSTEMS

AURA AERO

Safran - Equipment

Très investi sur le marché des nouvelles mobilités aériennes, Safran s'adapte à des clients d'un nouveau genre et leur propose son expertise et ses technologies de pointe pour co-construire les avions de demain.

See translation

VOLTAERO

BELL

Volocopter and Safran to Collaborate on Next-Gen Electric Powertrain

VOLOCOPTER

CAE launches Electric Aircraft Modification Program with Piper Aircraft Inc.

Safran on board the Chinese E20 eVTOL from TCab Tech!

BYE AEROSPACE

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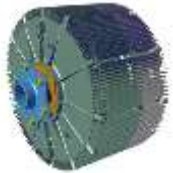
SAFRAN SMART PROPULSION MOTOR ROAD MAP

ENGINeUS 500

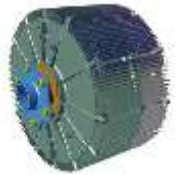
Turboprop replacement

New TC A/C
or
STC on existing A/C



Piston engine replacement

ENGINeUS 100



ENGINeUS 100

- Low speed, high torque density
- Integrated motor controller

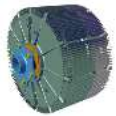
} 30% weight reduction, easier vehicle integration

- Up to 800VDC
- Direct replacement of existing CS23 heat engines
- Targeting Direct Drive (1.5-3krpm) or small-reduction-ratio gearing can be integrated into motor where lower propeller speed (<1krpm) is required
- Demonstrated tandem operation capability, supporting modular scalability.
- Optimised cooling: Direct Oil - motor torque density breakthrough ➔ 35-40A/mm^2; Improved thermally conductive resin systems for optimized Air Cooling. Common machine & electronics cooling system.

Scalable technologies

Air cooled — Liquid cooled

ENGINeUS 50



ENGINeUS 100

ENGINeUS 500

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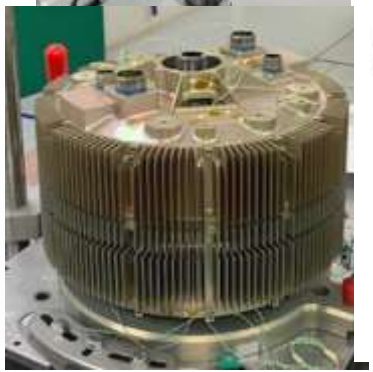
ENGINeUS™ Family scrapbook



ENGINeUS™ 500

UK visit September 2021

VOLTAERO

'Tour de France' achieved in July 2021

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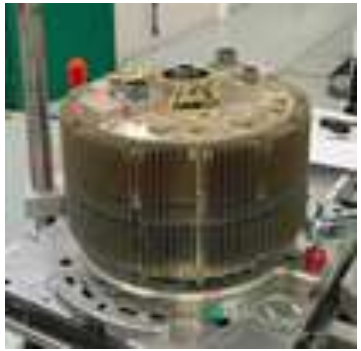
OVERVIEW - ENGINeUS™ FAMILY

- ✓ **ENGINeUS 100 is a family of products covering Max Take Off Power (MTOP) from 110kW up to 150kW**
- ✓ **Air cooling : relying on natural external flow. Easier vehicle integration. Water-glycol cooling jacket option.**



- ✓ **Integrated control & power converter. Common cooling system**
- ✓ **Can operate at up to 800VDC at altitude**

- ➢ **Power-to-active weight ratio : >6 kW/kg**
- ➢ **Torque-to-active weight ratio : >22 Nm/kg**

OVERVIEW - GENeUS™ 300 FEATURES

Preliminary configuration

- Multi-phase PMG
- 600-800VDC output
- 3 independent channels, as an available option
- 34-36,000rpm operating range
- Oil Cooled
- Integrated rectifier/inverter
- Motor or generator mode
- power density > 10 kW/kg
- 95% efficiency

GENeUS™ 300

Motor/Generator with integrated Power Electronics

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Aircraft propulsive power requirements

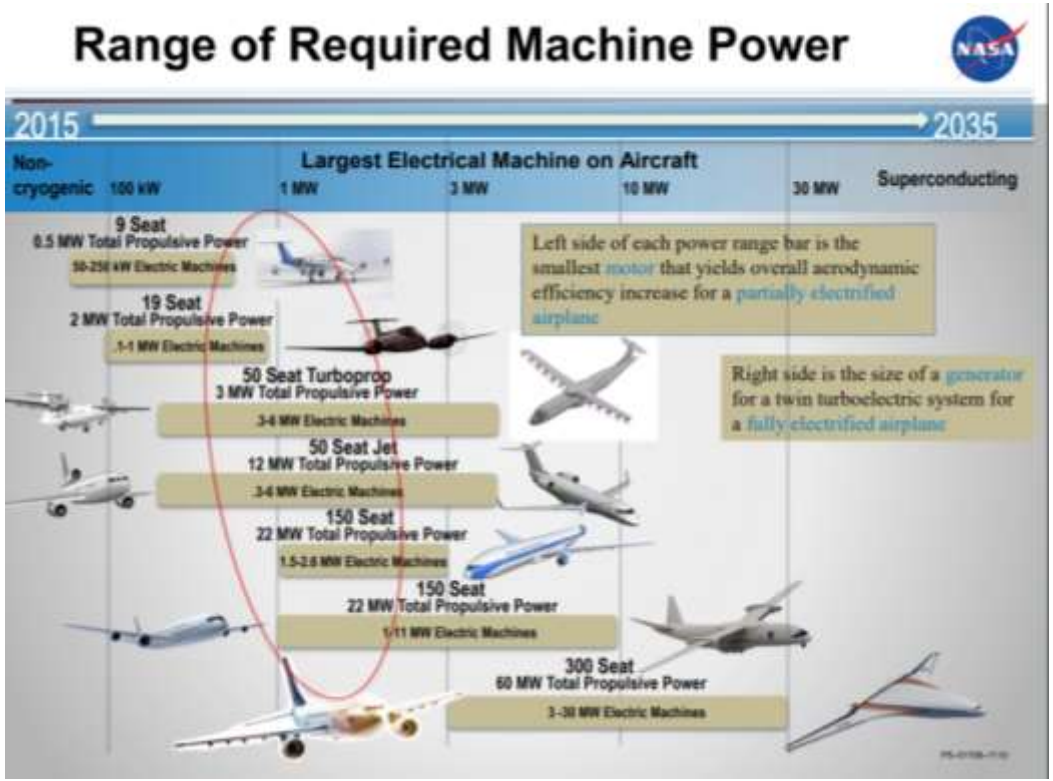

Figure 2. retrieved from Sizing Power Components of an Electrically Driven Tail Cone Thruster and a Range Extender. Ralph H. Jansen1, Cheryl Bowman2 and Amy Jankovsky3 . NASA Glenn Research Center

Electrification benchmark: the energy storage problem

- All-electric: “Most contemporary electric cars are 20 to 30 percent heavier than petrol cars of comparable size and power output.”
  - Nissan Leaf Battery: 303kg (1580kg vehicle weight)
  - Tesla “S” Battery: 544kg (2069kg vehicle weight)
  - Tesla “Y” Battery: 530kg (2003kg vehicle weight)

Single aisle (150pax): 22MW propulsive power requirement

- Jet engine: 54MW thermal requirement (41% efficient)
  - 5.5 tonnes engine weight (power density: 9.9 kW/kg)
  - 2 hours: 9t fuel consumption (Jet fuel: 43 MJ/kg) cf. 18.8t A320 fuel capacity
- Electric engine: 24.4MWe required (90% efficient)
  - 7 tonnes engine weight (power density 3.5kW/kg)
  - 201 tonnes of batteries required (Li-ion: 0.875 MJ/kg)

A320 MTOW 83t including airframe, systems, payload

Trade studies to be “won”

- **Hybrid concepts: maintain turbine power sources, with “augmentation” using electromechanical power conversion. The objectives are:**
  - improvement of platform efficiency by tuning the operating point(s) of the turbine(s), and
  - reduction of turbine size by levelling the power demand using the electromechanical power system.
  - reduction of CO2 emissions, with Sustainable Aviation Fuels, or elimination through use of Hydrogen
- **Electric concepts: batteries and/or fuel cells power electrical propulsors. The objectives are:**
  - elimination of turbines and associated accessories
  - elimination of emissions
- **Viability: technologies needs to be demonstrated to show that the benefits of the improvements are more significant than the impact of installing the necessary power conversion equipment and energy storage devices.**

Safety, Weight, Purchase and Operating Costs, Reliability, Maintainability are all key factors for Aircraft Operators

The route to convergence

- **Primary SYSTEM LEVEL objectives for electromechanical conversion:**
  - Maximum power and/or torque density
  - Appropriate levels of redundancy and/or fault tolerance
  - Flexible control to allow additional functionality
- **System: From the voltage source to the propeller**
  - Efficiency and thermal management are key
  - Each part of the system impacts all other parts, e.g. motor frequency drives filter and power electronics design
- **System components:**
  - Interconnects
  - Protective devices
  - Power Electronics
  - Control system
  - Motor (with gearbox if necessary)

System optimisation is a key enabler to future viable electrified aircraft platforms

Degrees of freedom

- **Integrated vs separate:**
  - Integrated PE offers reduced filtering requirement at the cost of (typ.) a harsher environment
  - Separate PE allows a more favourable environment, although this will normally still be challenging.
- **Converter topology:**
  - Two-level conversion is sufficient for 800V, but requires increased filtering. Multi-level conversion facilitates increased voltage capability, reduced filtering, greater flexibility at the cost of greater complexity. However, reliability is reduced, requiring increased redundancy.
  - Soft switching may be an option to reduce peak system voltages, but this needs to be balanced against complexity.
- **Component technology:**
  - Si / SiC / GaN / ? The reduction of losses overall is very important, but needs to be balanced against filtering requirements.
  - Increased operating temperature, lower loss passives will be a significant easement
  - Supply chain Motor

Challenges – Power Electronics

- 1 Improved switching components with reduced switching and conduction losses
- 2 Optimised converter topologies and control algorithms
- 3 High-performance harsh-environment passive components, e.g. capacitors
- 4 Improved packaging for harsh environment, reduced weight and improved performance, e.g. bus bars for high altitude applications
- 5 Filters with improved architecture and performance for reduced weight
- 6 Soft-switching or similar for reduced voltage perturbation.
- 7 Novel control for optimised performance
- 8 Component topologies for high altitude operation (e.g. partial discharge-free)
- 9 Lightning protection components and methods
- 10 Quick-sizing / pre-design tools (magnetic components, converters)
- 11 Supply chain easement: more flexible, geographically distributed

Our mission

Contribute to safer and more sustainable aviation