

AIRCRAFT ENGINES



FUTURE OF AIRCRAFT PROPULSION

ISABE 2017
Manchester, UK

Dr Jerome BONINI
VP Research & Technologies



Safran – An international high-tech group



AEROSPACE

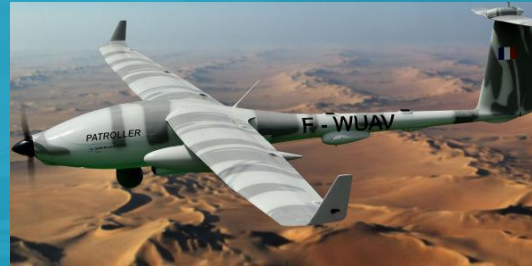
- Safran Nacelles
- Safran Ceramics
- Safran Aero Boosters
- Safran Electrical & Power
- Safran Transmission Systems
- Safran Aircraft Engines**
- Safran Landing Systems
- Safran Helicopter Engines
- ArianeGroup*

* ArianeGroup is a 50/50 joint company between Safran and Airbus Group



DEFENSE

Safran Electronics & Defense



€15.8 bn
Sales in 2016



Near **58,000**
Employees



30 countries
Global presence

Safran Aircraft Engines – Military and commercial aircraft propulsion



Alpha Jet
Larzac®
14kN



Mirage F1
Atar
49kN



Rafale
M88
75kN



Mirage 2000
M53
95kN



A400M
TP400 (3)
11 000 shp



€8.1 bn
Sales in 2016



15,000+
Employees



Falcon 5X
Silvercrest®
9 500 to
12 000 lb



SSJ100
SaM146(1)
15 400 to
17 800 lb



737
CFM56-7B(2)
19 500 to
27 300 lb



A320neo
LEAP-1A(2)
21 500 to
33 000 lb



737MAX
LEAP-1B(2)
21 500 to
28 000 lb



A320neo
LEAP-1A(2)
21 500 to
33 000 lb



A320neo
LEAP-1A(2)
21 500 to
33 000 lb



C919
LEAP-1C(2)
21 500 to
30 000 lb



A340
CFM56-5C(2)
31 200 to
34 000 lb



747
CF6(4)
52 500 to
72 000 lb



A380
GP7200(4)
70 000 to
85 100 lb



777
GE90(4)
93 700 to
115 300 lb



777X
GE9X(4)
~ 100 000 lb

(1) PowerJet (50/50 Safran Aircraft Engines-NPO Saturn)

(2) CFM International (50/50 Safran Aircraft Engines – GE)

(3) EPI (ITP, MTU, Rolls-Royce, Snecma)

(4) In cooperation with GE



35
facilities
Global presence

CFM56[®] – The world's best selling commercial engine

800
MILLION
FLIGHT HOURS

 AIRBUS

A320ceo



 BOEING

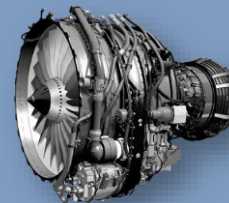
737 NG



CFM56-5B



CFM56-7B





CFM56

More than **31,000**
CFM56 engines
delivered worldwide



Every **2 sec.**
a CFM56-powered
aircraft takes off
somewhere in the world



3 million
travelers use CFM56-
powered aircraft daily

LEAP® – Combining the best technologies from Safran Aircraft Engines and GE

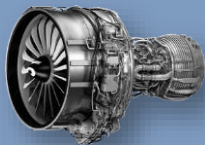
 AIRBUS

A320neo



EASA
Certified
FAA

LEAP-1A
Entry into service
August 2016



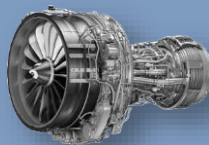
 BOEING

737 MAX



EASA
Certified
FAA

LEAP-1B
Entry into service
May 2017



 COMAC

C919



EASA
Certified
FAA

LEAP-1C
Entry into service
2018



LEAP

More than **14,000**
engines ordered to date



-15% lower fuel
consumption*



-15% reduction
in CO₂ emissions*

* Compared with previous-generation engines

LEAP[®] – Combining the best technologies from Safran Aircraft Engines and GE

Direct-drive
High bypass ratio

Composites
Fan blades & case

Debris rejection system
Airfoils protection against erosion

High-pressure compressor
10 stages
22:1 compression ratio

Low-pressure turbine
4th gen 3-D aero

Titanium-Alumin TiAl lightweight LPT Blades

High-pressure turbine
4th gen 3-D aero
Advanced cooling
CMC materials
Active clearance control

Combustor
Lean-burn and low emissions

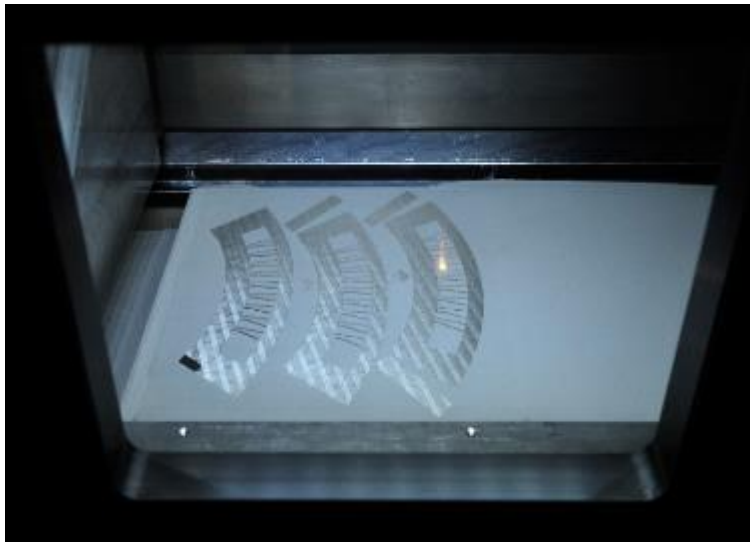
3D Woven Resin Transfer Molding (RTM) technology
→ 500 kg of mass reduction
→ Improved reliability to shocks
30 years of experience

Accessory gearbox (AGB) on fan module

TAPS 2
Twin Annular Premixing Swirler
→ Reduce particles and NOX emission with 50% margin to OACI CAEO/6 regulation

GE

The factory of the future is transforming the way manufacturing is done



Additive manufacturing

2008 : Rapid Prototyping Tool

2013 : Components for Development and Production Engines

2025 : 20% Reduction in Engine Parts Count

Set up of a specific organization relying on:

- Close to business Integrated Design and Production Unit
- Generic skills and materials



**Advanced
assembly
lines**



**Robotized
inspection
methods**



**Augmented
and Virtual
Reality Tools**

What's next ?



Say hello to the future

The LEAP engine has 19 fuel nozzles. While they may look deceptively simple from the outside, this revolutionary design, grown using additive manufacturing, is keeping harmful NOx emissions in line. We're re-shaping the future from the inside, out.

Another first. CFM gives you more to believe in.

Go to cfmaeroengines.com

PERFORMANCE | EXECUTION | TECHNOLOGY **LEAP** MORE TO BELIEVE IN

Can we go further ?

NOx the socks off emissions

Not only does our LEAP engine reduce NOx emissions by 50%, but also delivers a 50% margin to CAEP/6 regulations. Innovation with an eye to the future.

Another first. CFM gives you more to believe in.

Go to cfmaeroengines.com

CFM International Inc. (CFI) is a company whose stock is not listed on any stock exchange.

* Compared to current CFM56 engines with identical overall pressure ratio.

PERFORMANCE | EXECUTION | TECHNOLOGY **LEAP** MORE TO BELIEVE IN

Can we extract more ?

No one extracts more

The LEAP engine is naturally innovative. Fortified with advanced materials and leading-edge aerodynamics to quench your thirst for superior performance and a very healthy bottom line. Pure CFM. It's a great way to start your day.

Go to cfmaeroengines.com

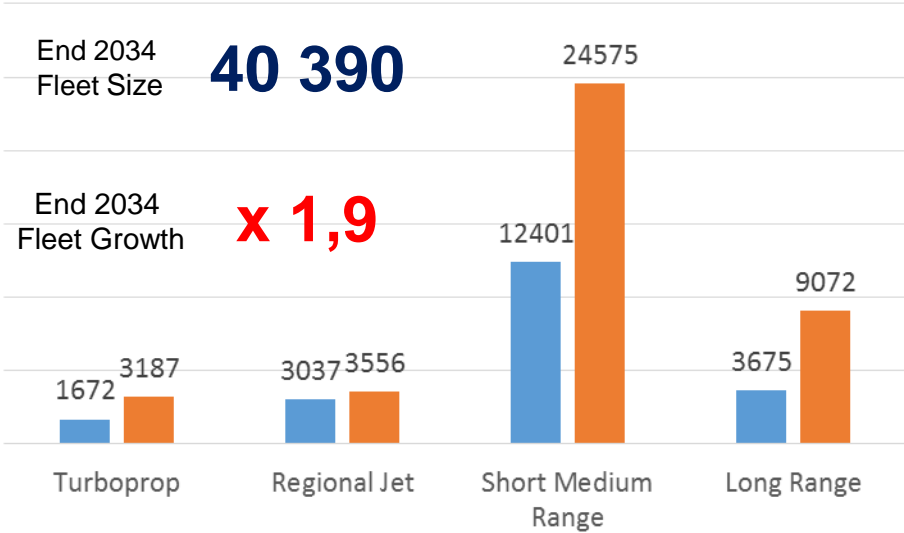
➤ See the LEAP engine come to life. Get the CFMLEAP app NOW.

CFM International Inc. (CFI) is a company whose stock is not listed on any stock exchange.

Superior performance | Lower cost of ownership | Greater reliability **LEAP** MORE TO BELIEVE IN

Ensure sustainable growth of air traffic

End 2034 Fleet Evolution by Aircraft Type (36+ pax)



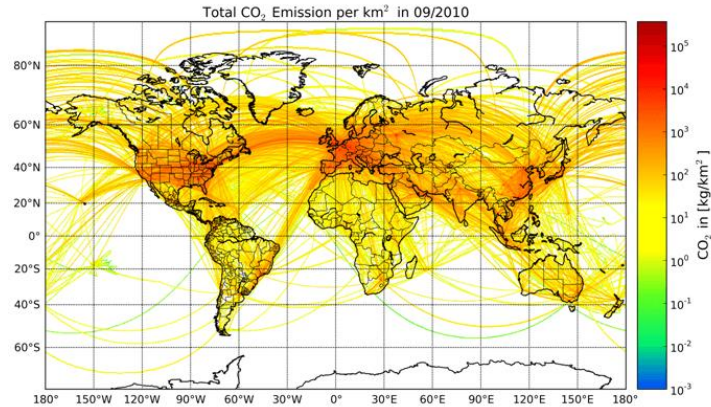
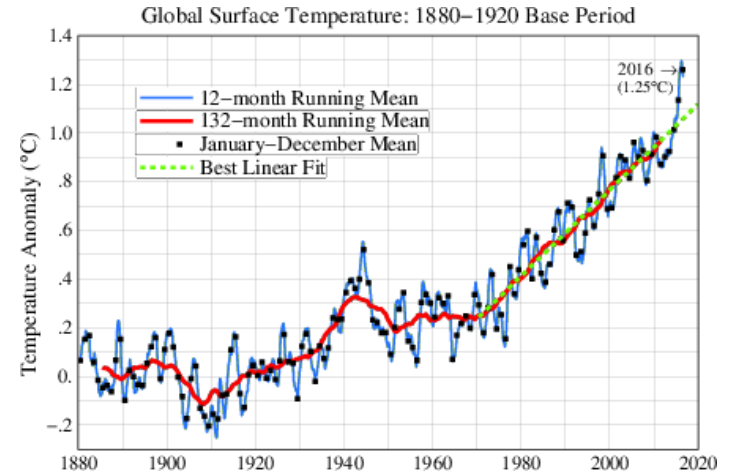
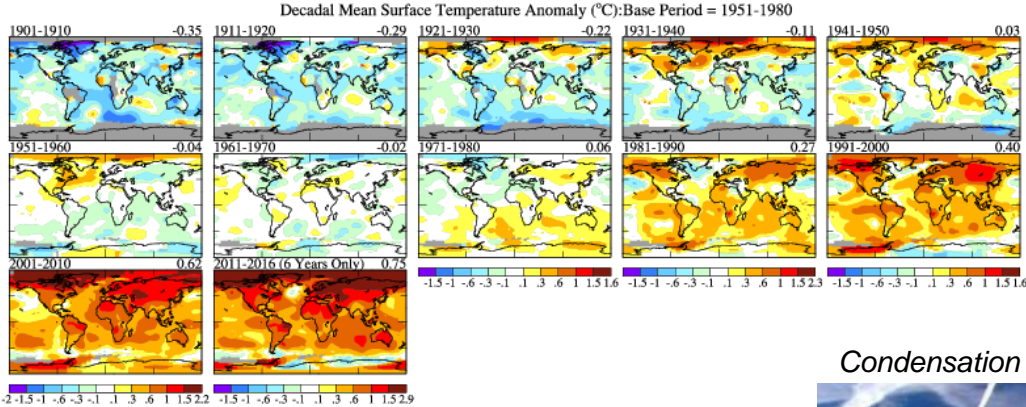
World fleet to double by 2034
 more than 40 000 new aircraft
 54% in SMR category



Today and 2030 air traffic



Environmental impact



Condensation trails



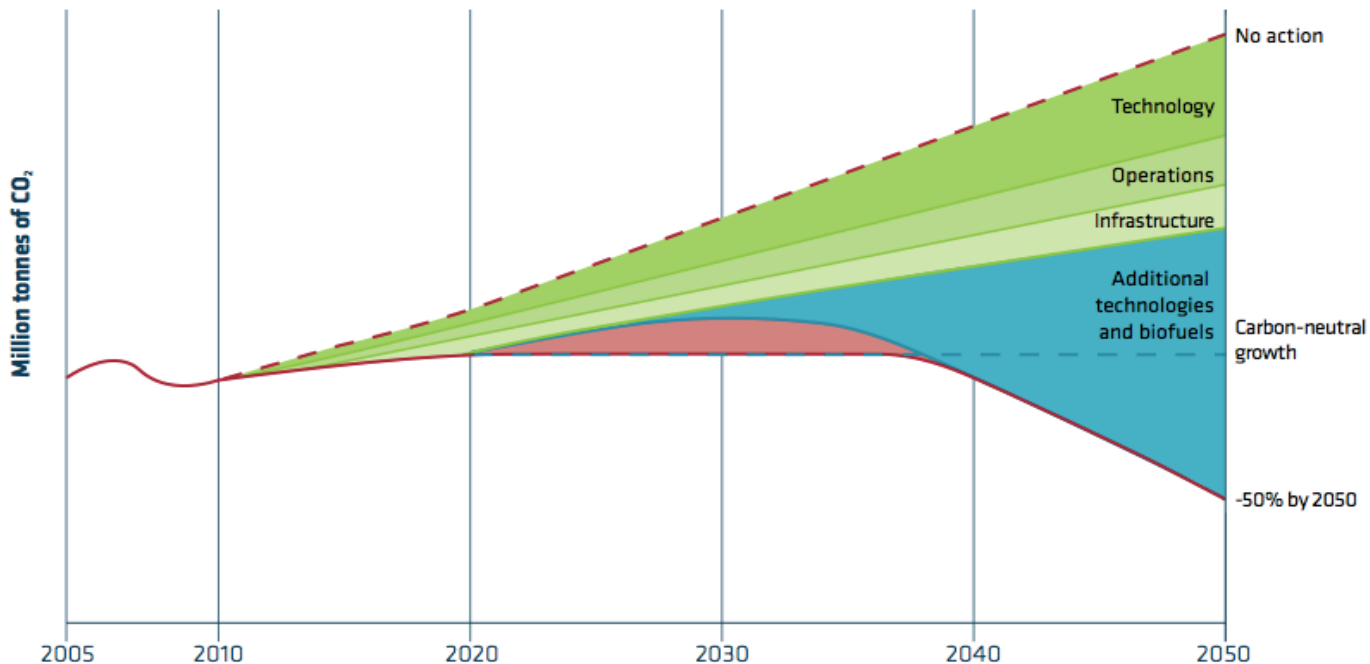
Environmental engagement



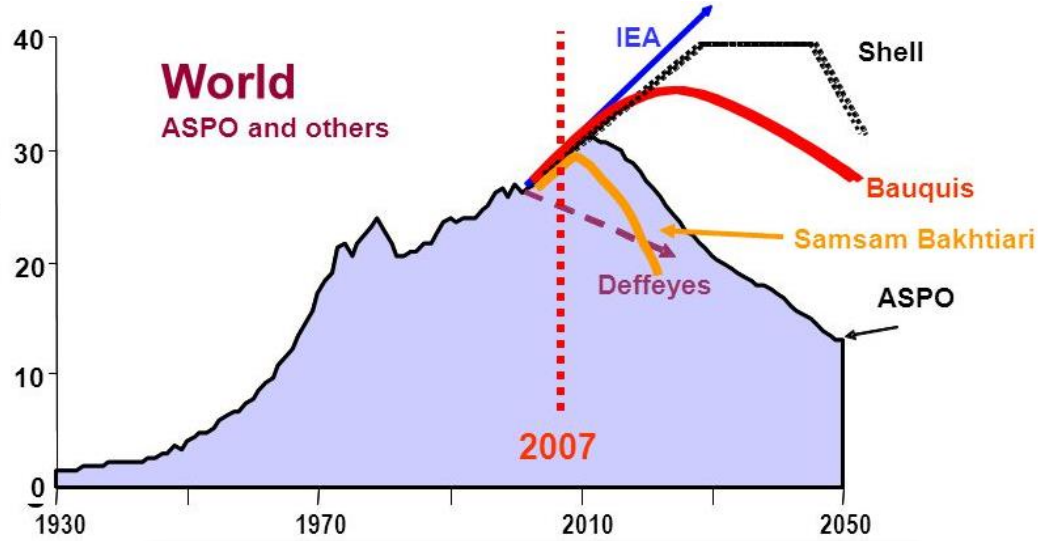
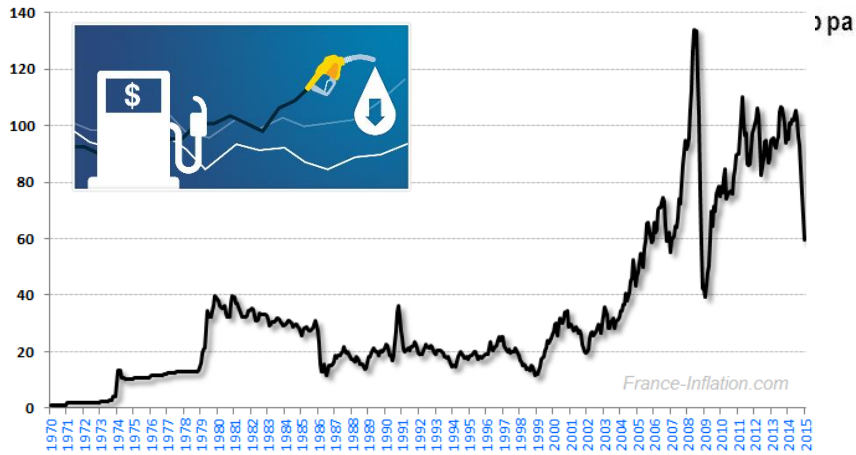
75% ↘ CO₂
90% ↘ Nox
65% ↘ Noise
0 emissions tax

2050
vs. 2000

Aeronautic is the 1st
industry engaged to reduce
impact on environment



Fuel forecast



An inevitable decline in fuel world reserves ... but still an acceptable cost

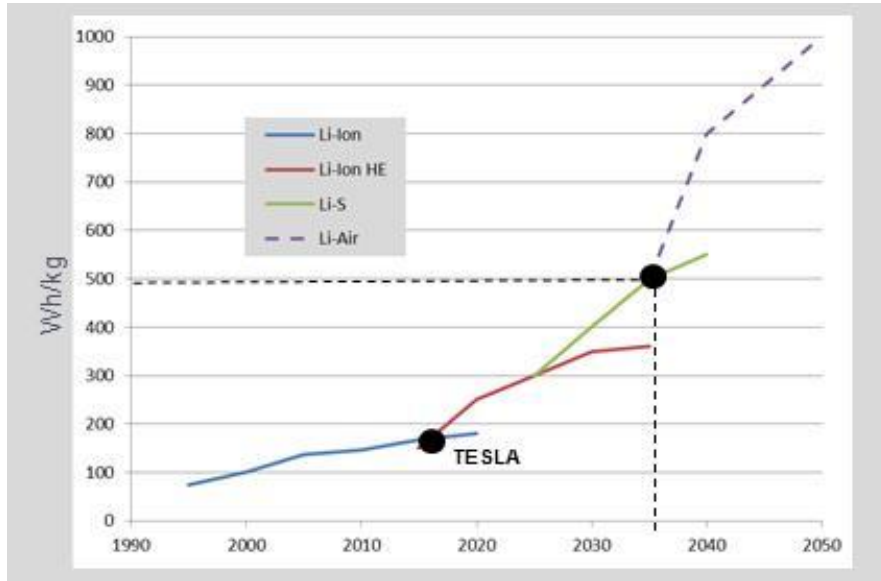


Biofuel successfully tested on CFM56 engine in 2007 and in operation on Air France A321 in 2015 ... but need for industrialization of production and overall CO2 impact estimation



Full Electrical propulsion : a distant option for large aircraft

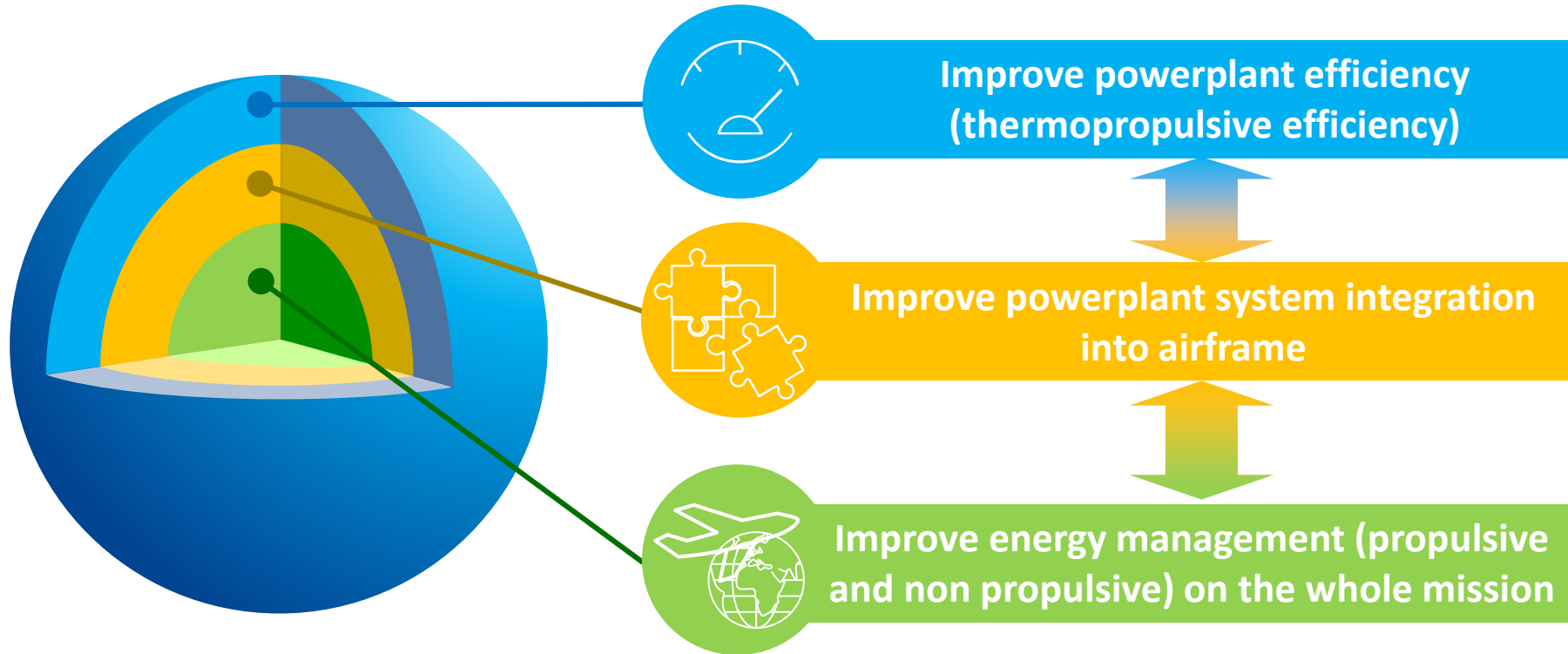
System-Level Battery Energy Density

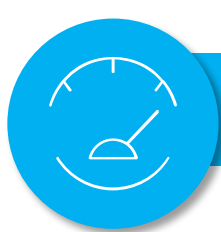


Even @1000 Wh/kg, an All-Electric Airbus A320 would require 170 t of batteries

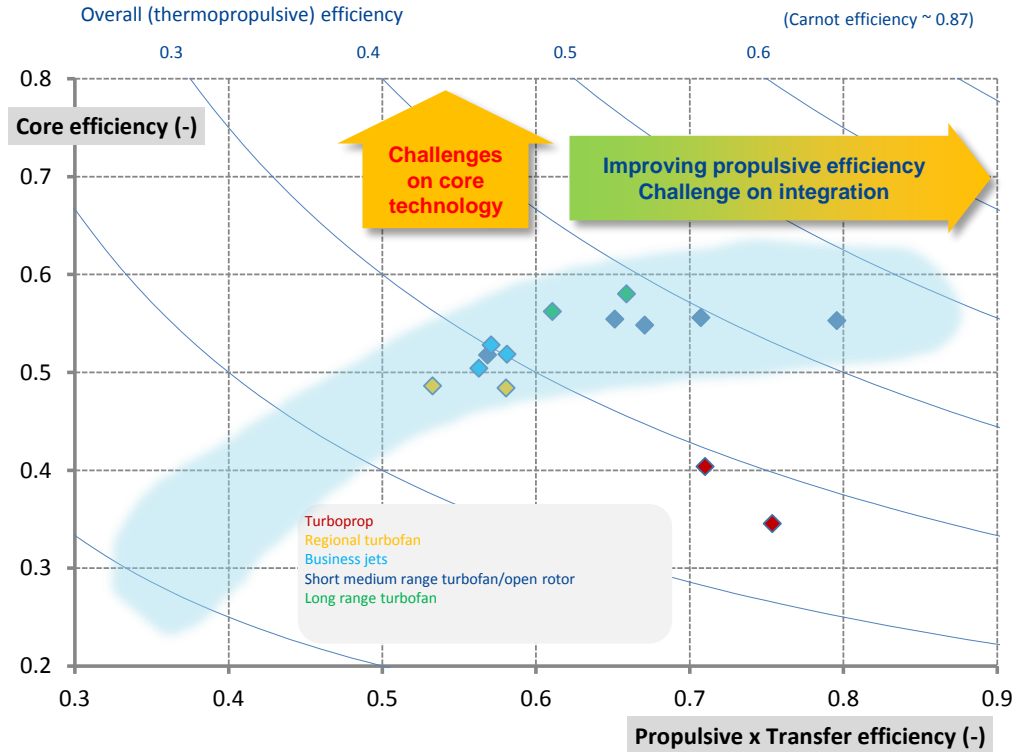
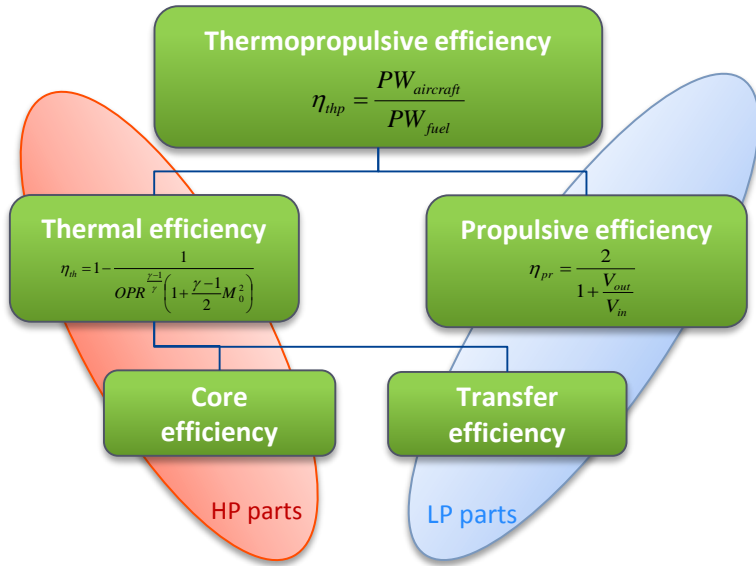


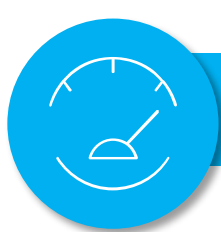
Our way to future propulsion : working on the three layers of efficiency





Improving powerplant efficiency

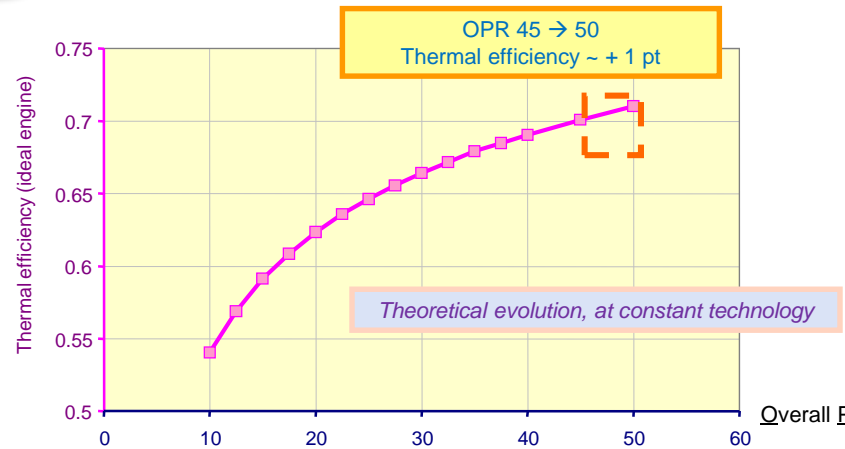




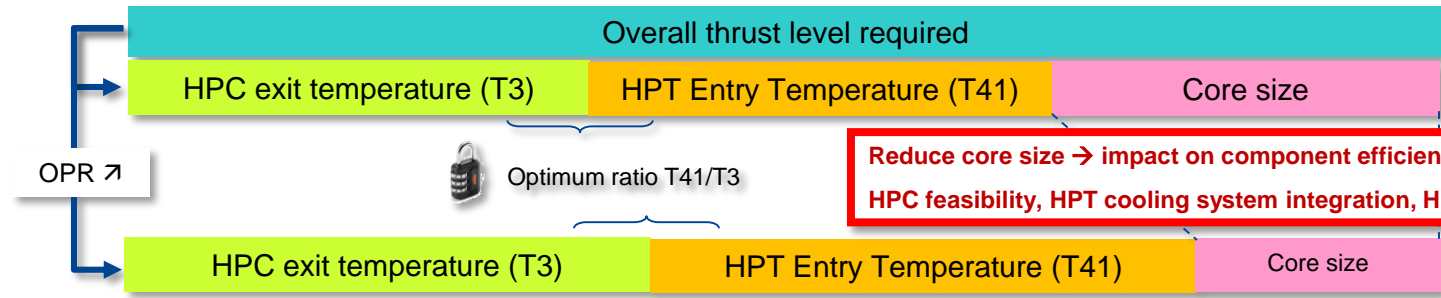
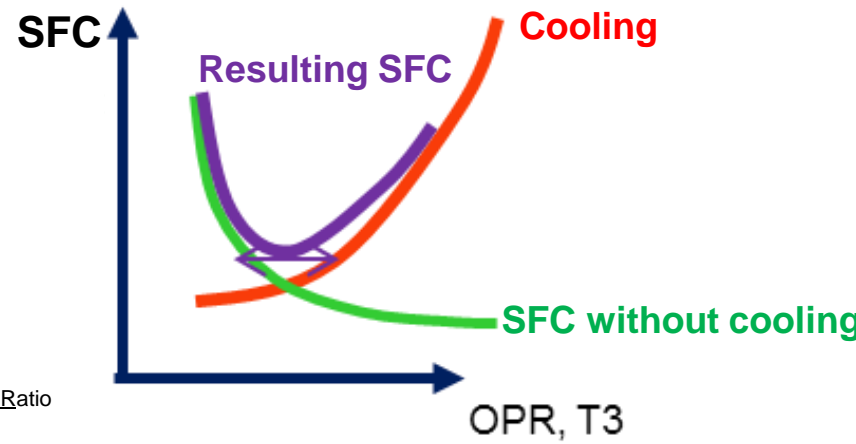
Improving powerplant efficiency



Increase OPR



Increase engine temperatures
 → Need for higher cooling amount
 → Partially offsets / annihilates SFC improvement



Reduce core size → impact on component efficiencies :
HPC feasibility, HPT cooling system integration, HP materials ...



Ceramic Matrix Composites ...
beyond metals

20%
Higher thermal capability

1/3 less
the weight cooling air



Blades and Nozzle

New-generation **combustor**



New-generation **single-crystal** materials and advanced cooling techniques to improve engine core performance



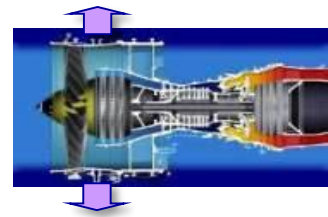
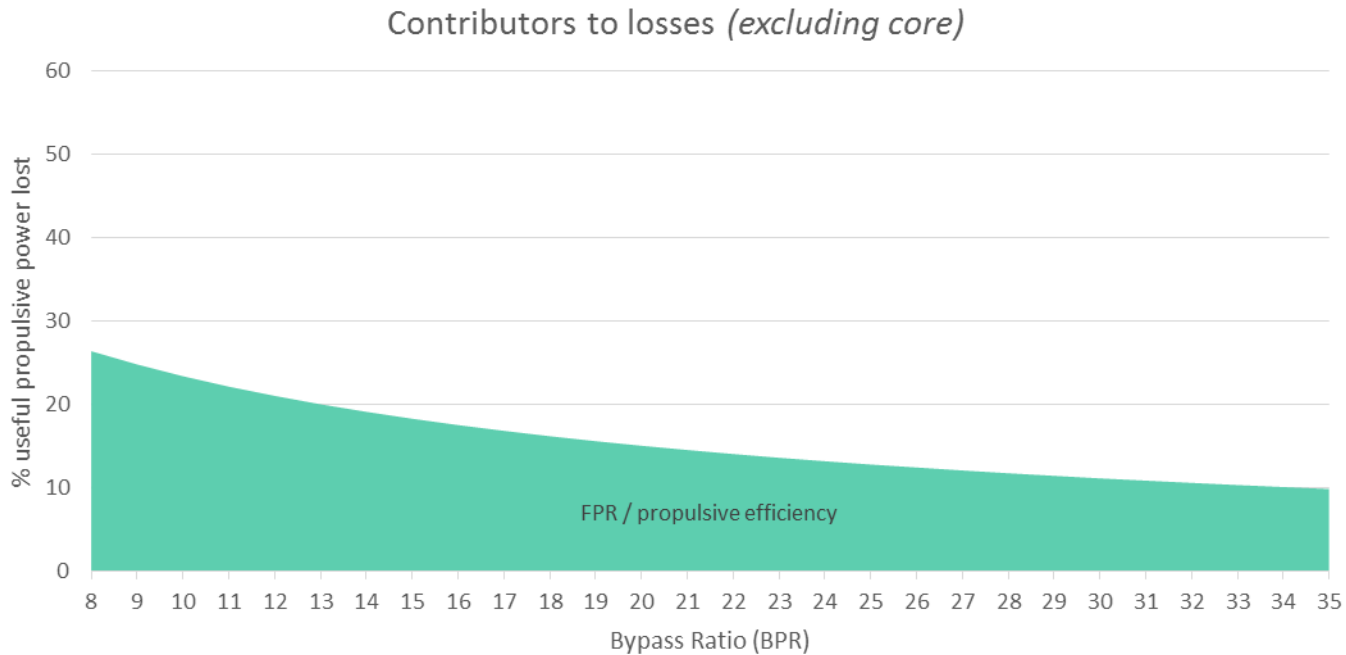
New, high-performance **metallic alloys**, such as titanium aluminide (**TiAl**), which are lighter and resist very high temperatures



Improving powerplant efficiency



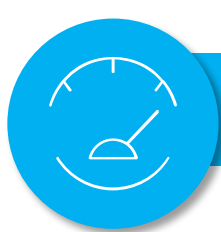
Decrease FPR → Increase BPR



$$FN = W \times \Delta V$$

constant Decrease to improve propulsive efficiency

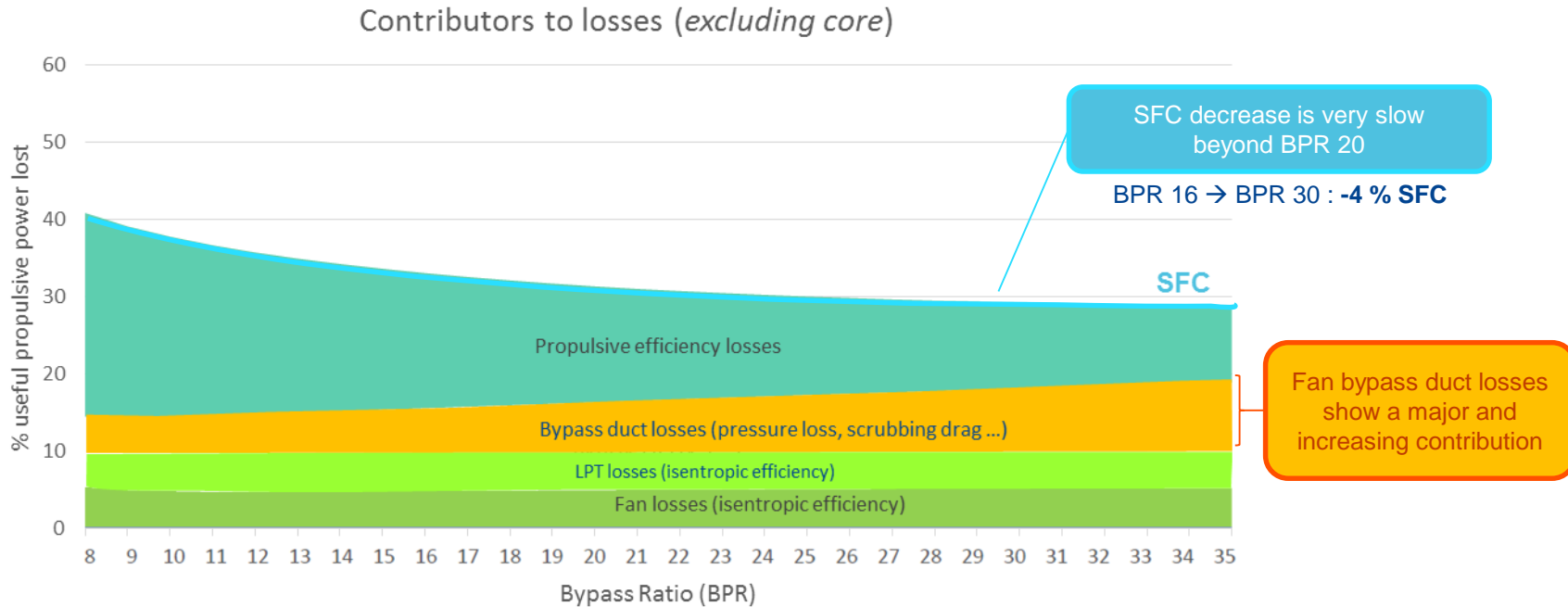
Increase massflow !

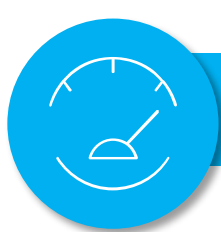


Improving powerplant efficiency



Decrease FPR → Increase BPR

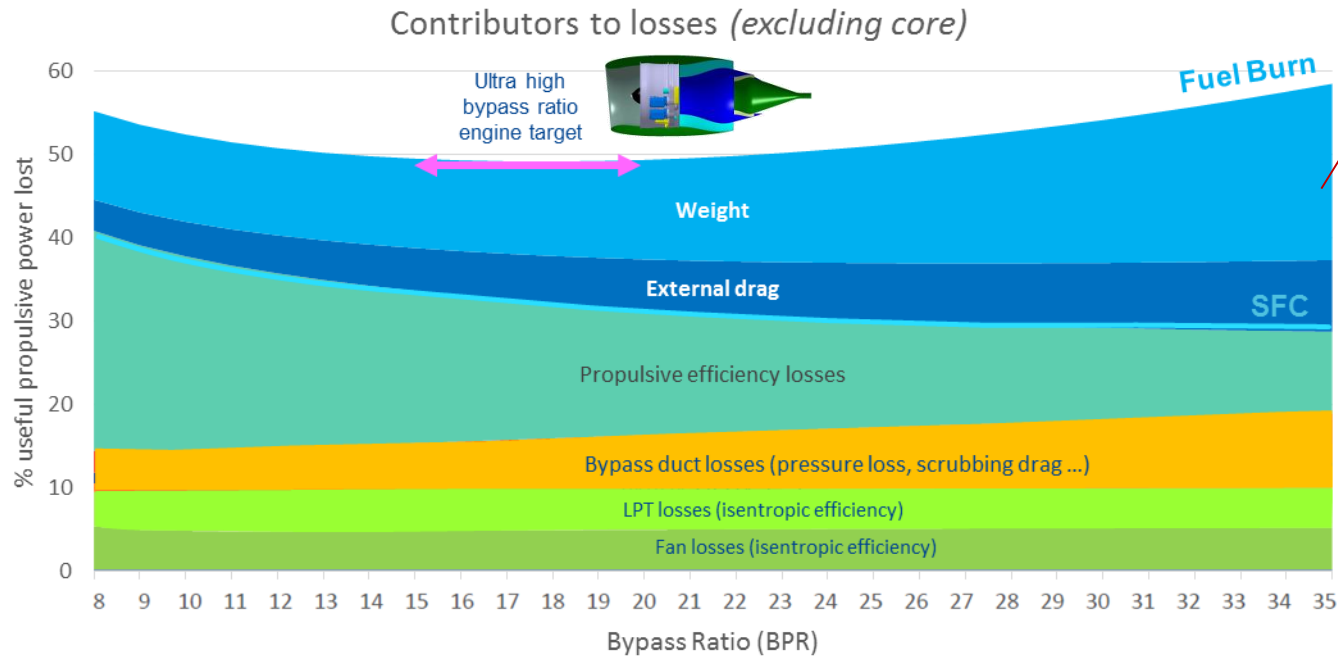




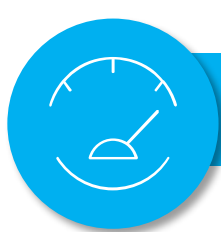
Improving powerplant efficiency



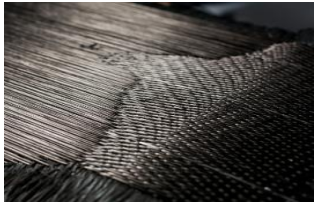
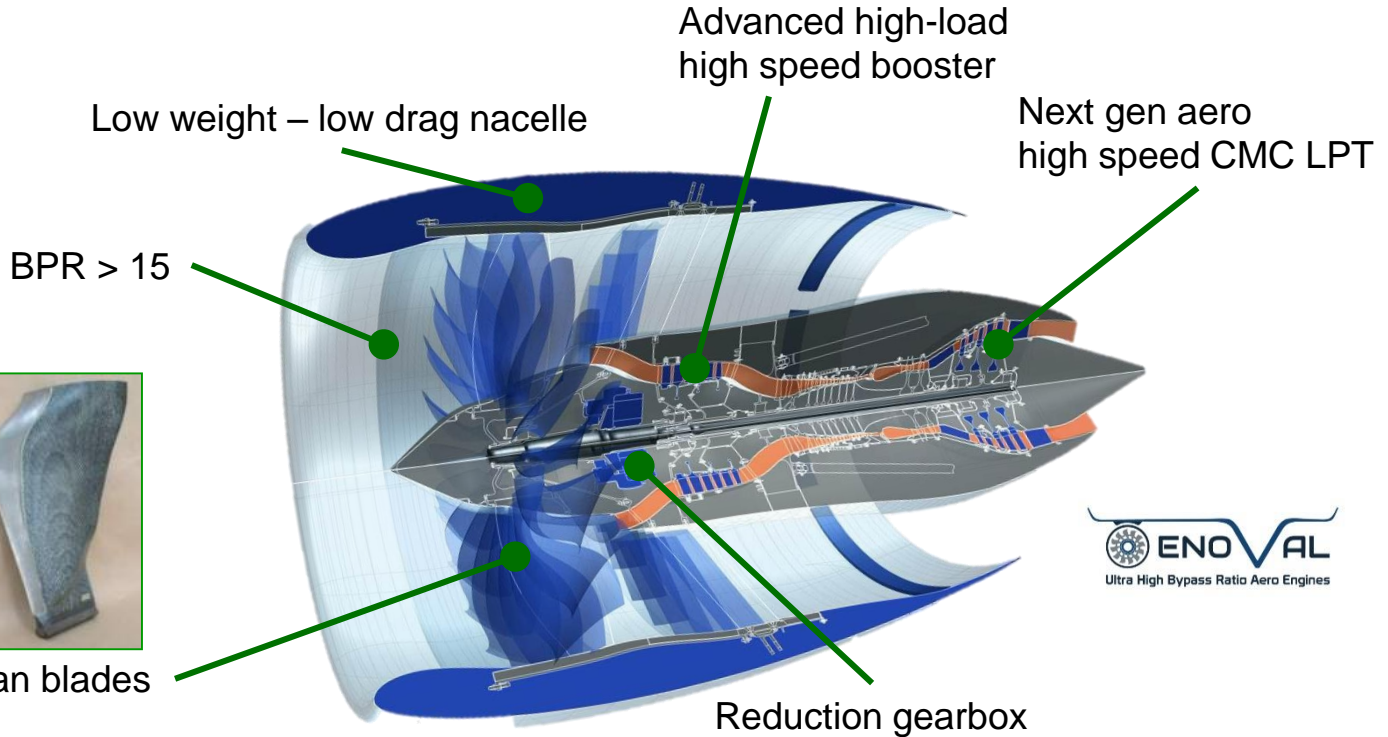
Decrease FPR → Increase BPR



Installation effects linked to drag and weight are key contributors to losses for ultra high bypass ratio configurations



UHPE : UHBR concept demonstrator



3D RTM woven fan blade



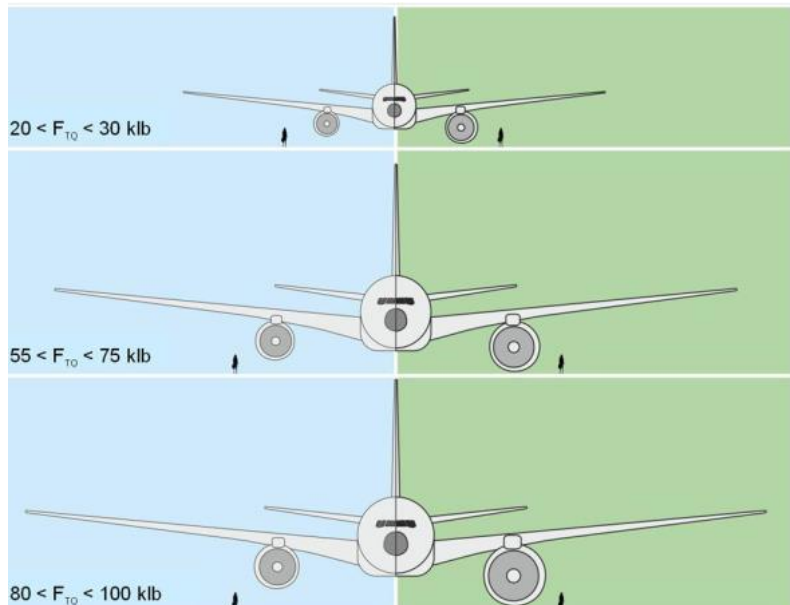
Next gen composite fan blades



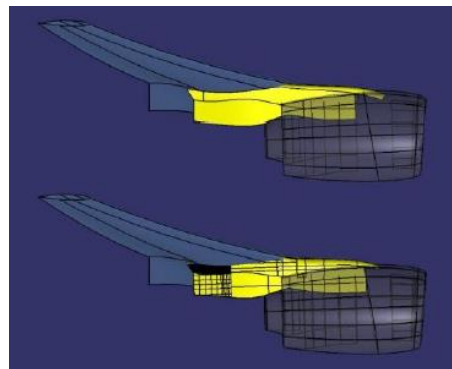


Improving powerplant system integration into airframe

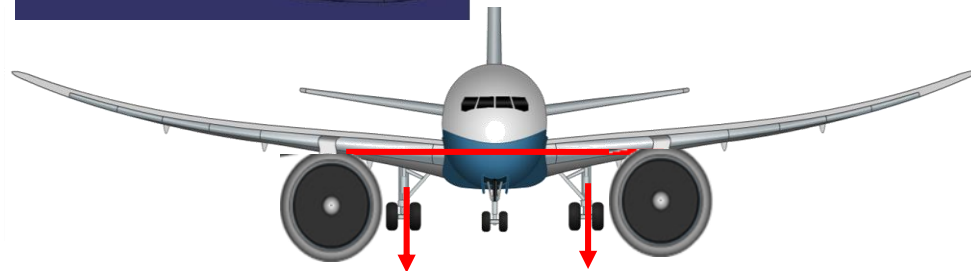
Installation challenge



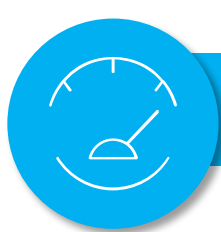
- Additional challenge on integration constraints
- Drag, weight for ducted configurations



→ Pylon & nacelle geometry and wing shape optimization



- Impact on landing systems length and weight
- Snowball effect on aircraft structures

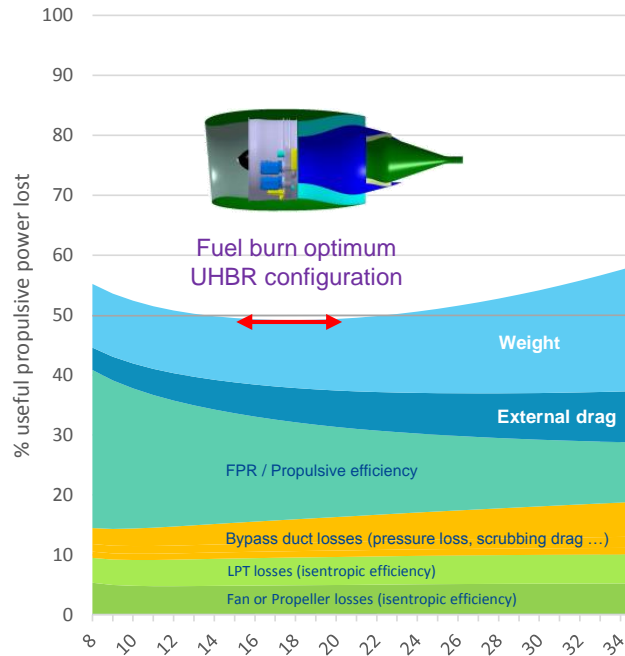


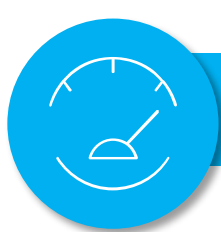
Improving powerplant efficiency



Let's go further...

Contributors to losses (*excluding core*)



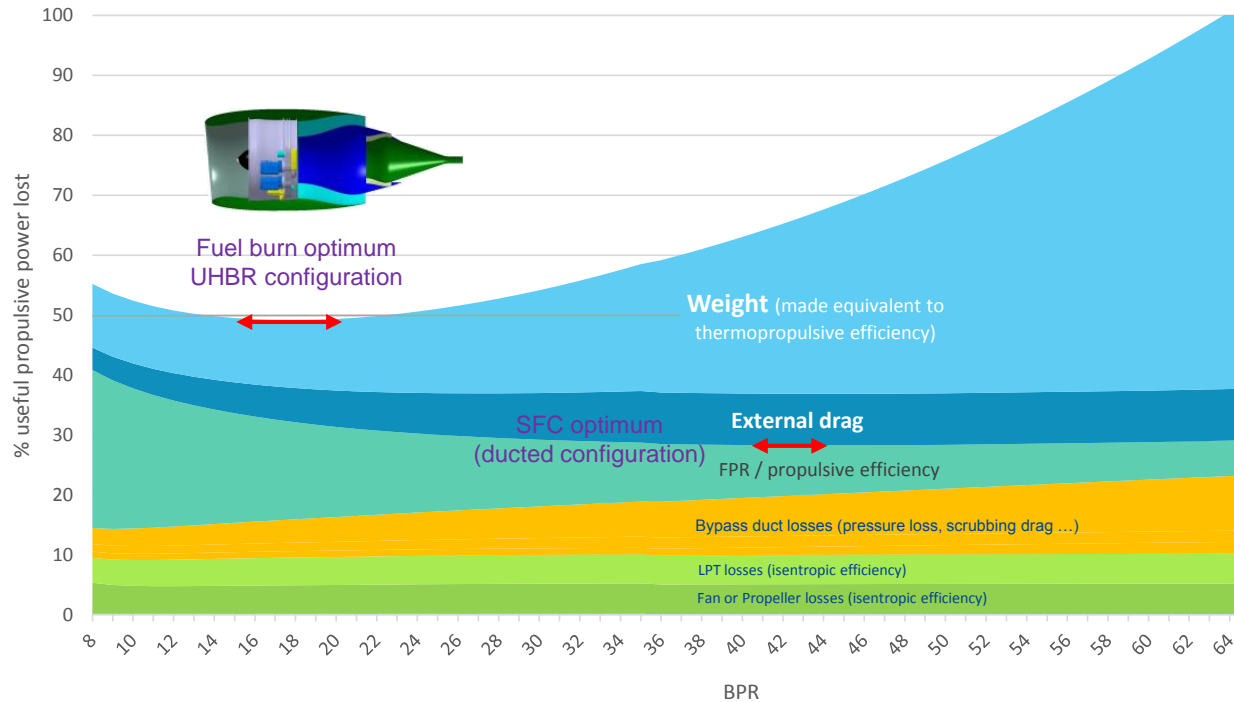


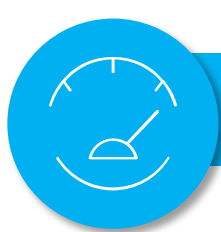
Improving powerplant efficiency



Let's go further...

Contributors to losses (excluding core)



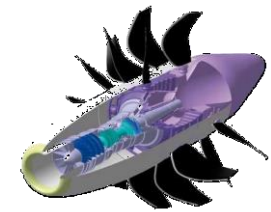
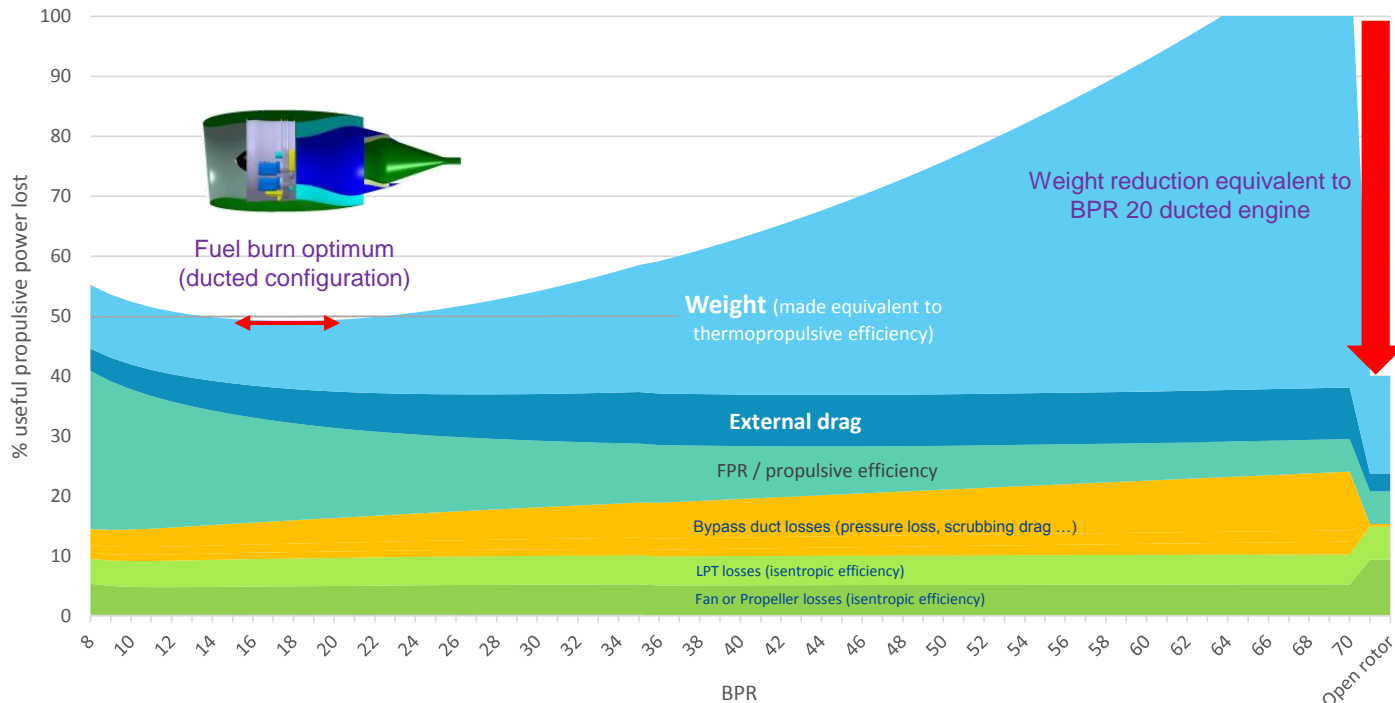


Improving powerplant efficiency



Let's go further...

Contributors to losses (excluding core)

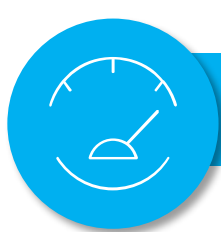


Mechanical transmission similar to geared turbofan

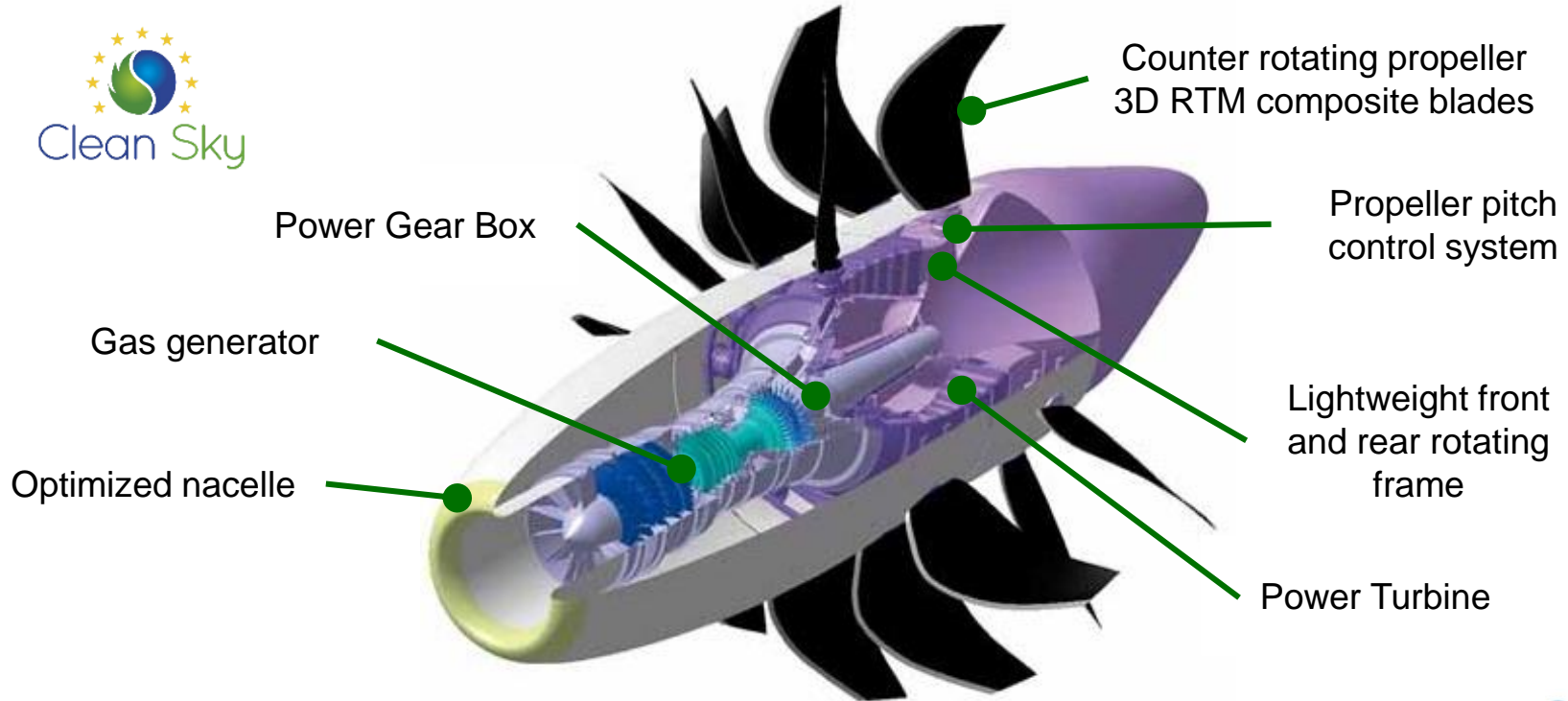
Lower nacelle drag

No bypass duct loss

Propeller with lower efficiency than ducted fan



OpenRotor concept : only engine architecture allowing a **30% reduction of fuel consumption** and **CO2 emissions** compared to the CFM56 engine





OpenRotor concept : Safran demonstration plan

Mechanics tests

Preliminary tests of the specific control system with a Pitch and its efficiency, in terms of mechanical integration, has been demonstrated on a full scale mock-up.

2015



Aero-acoustics tests

Wind-tunnel tests done

Same emitted noise as the LEAP engine (compliance with Chapter 14 requirements, including a margin).

2015



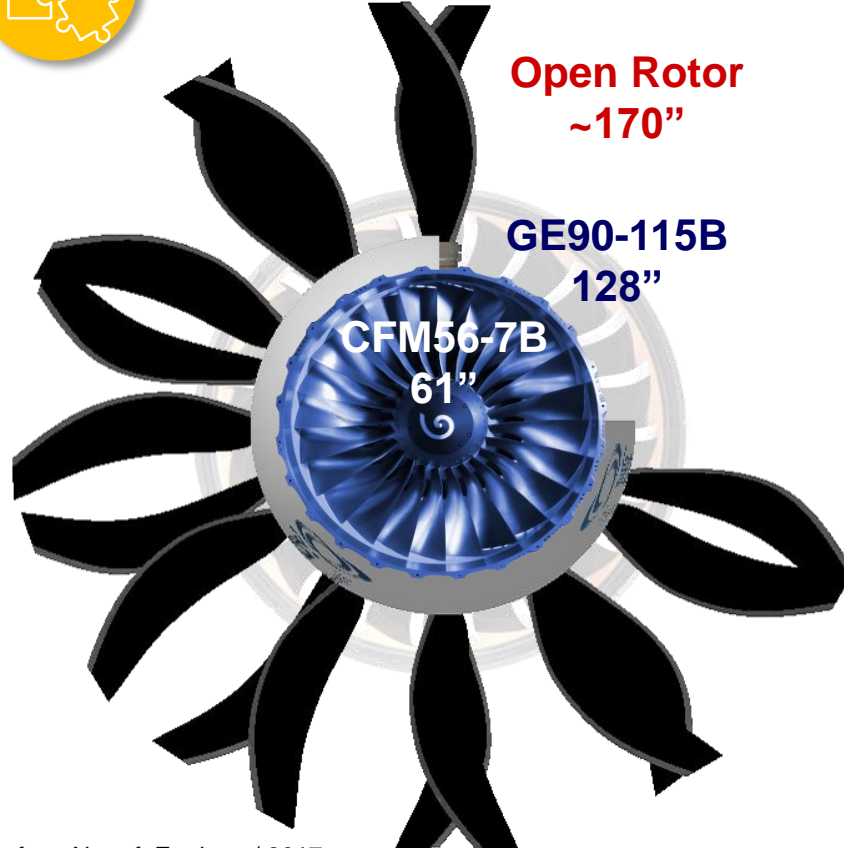
Ground test demo

Full-Scale Open Rotor to test Propulsion System Integration



Test plan in progress





Open Rotor
~170"

GE90-115B
128"

CFM56-7B
61"

Aircraft Integration challenge





Improving powerplant system integration into airframe

A way to decrease fan inlet speed : Boundary Layer Ingestion

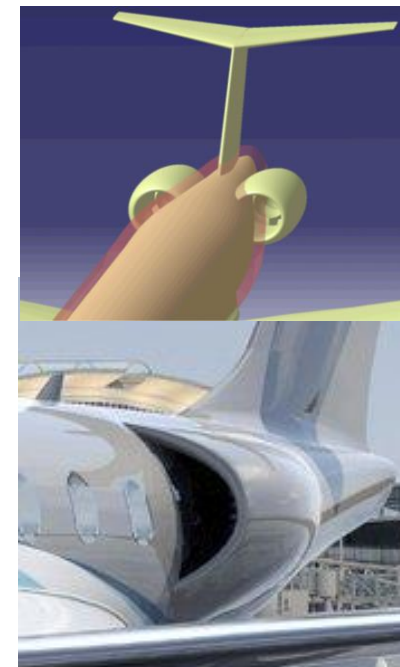
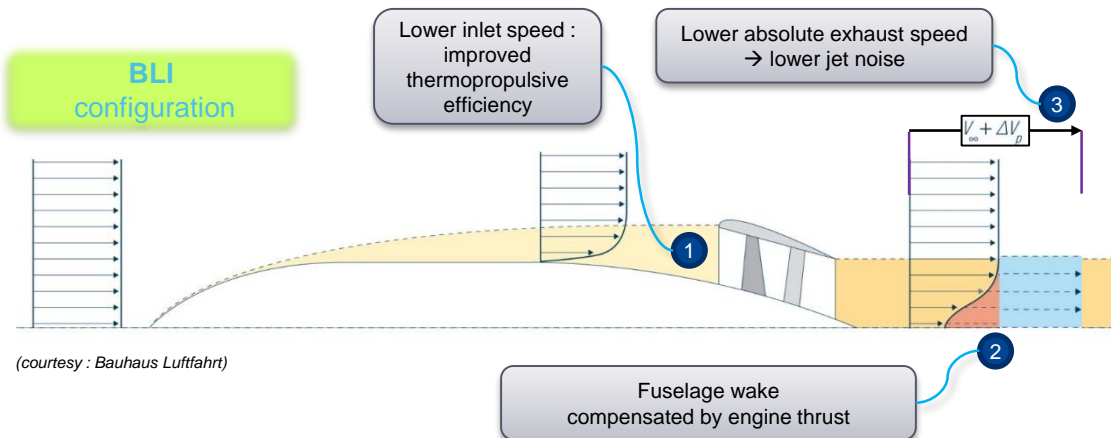
Additional advantages :

- Reduced **external drag** (part of the nacelle is not a wetted surface)
- Reduced **pylon weight**

Challenges :

- **Strong fan distortion**
- **Water ingestion** dripping from fuselage to engine
- **New boundaries between airframer and propulsion manufacturer**

- Fuselage boundary layer
- Propulsion system jet flow field
- Jet momentum equivalent for ideal fuselage wake compensation
- Jet momentum equivalent for aircraft residual thrust requirement



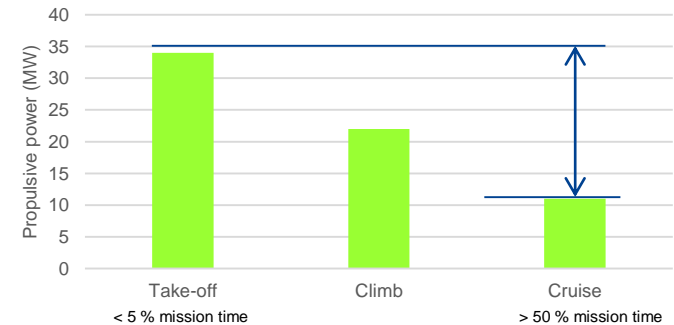
Improving powerplant efficiency

Improving powerplant system integration into airframe

Improving energy management (propulsive and non propulsive)



A single powerplant makes it all ...



Various energy sources management and coupling, as well as distribution of functions over the whole airframe, can bring significant energy savings

Use of electricity → Hybridization

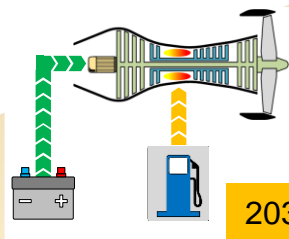


A stepped approach to electrical propulsion



High power energy transmission feasibility

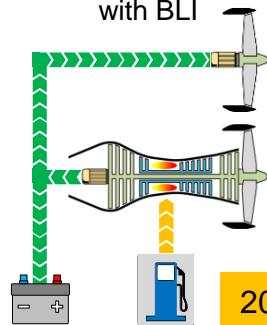
10% electrical Propulsion for T/O climb and Idle



2030

Hybrid propulsion

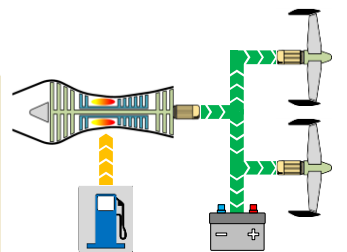
20-50% electrical propulsion, coupled with BLI



2035

Hybrid distributed propulsion

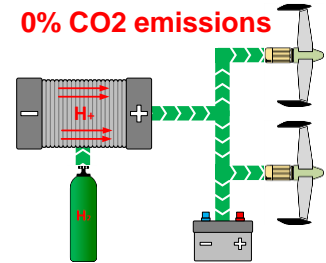
100% electrical propulsion
100% thermal energy



2035

100% electrical propulsion

0% CO2 emissions



2040+

Distributed propulsion, electric drive

Energy storage density



Improving powerplant efficiency

Improving powerplant system integration into airframe

Improving energy management (propulsive and non propulsive)



SAFRAN

Aircraft Engines

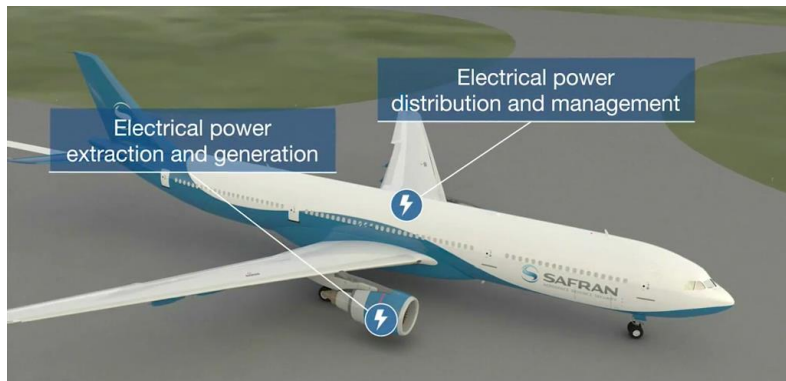
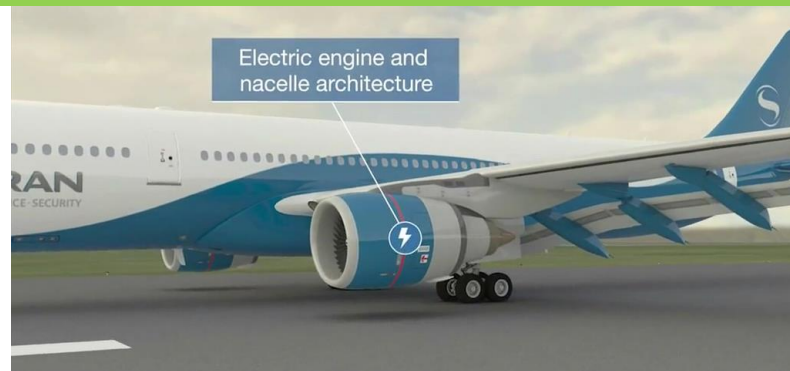
Nacelles

Power Units

Electrical & Power

Landing Systems

Transmission Systems



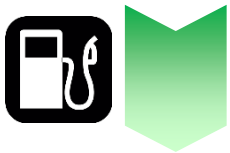
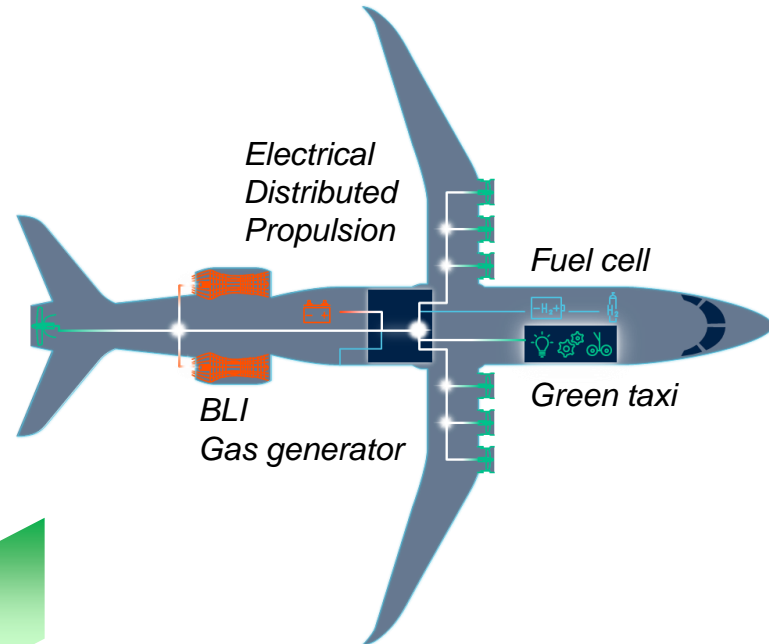
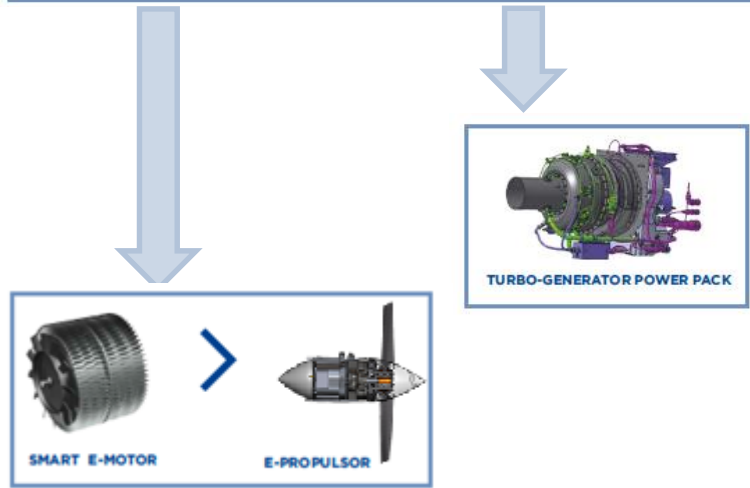
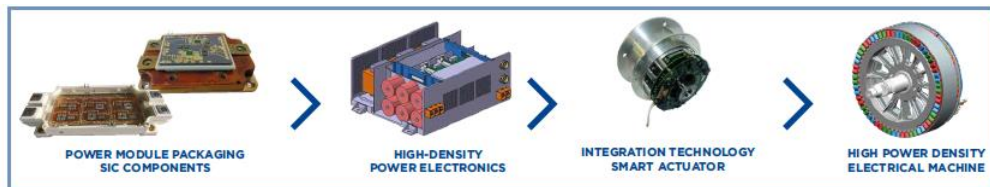
Improving powerplant efficiency

Improving powerplant system integration into airframe

Improving energy management (propulsive and non propulsive)

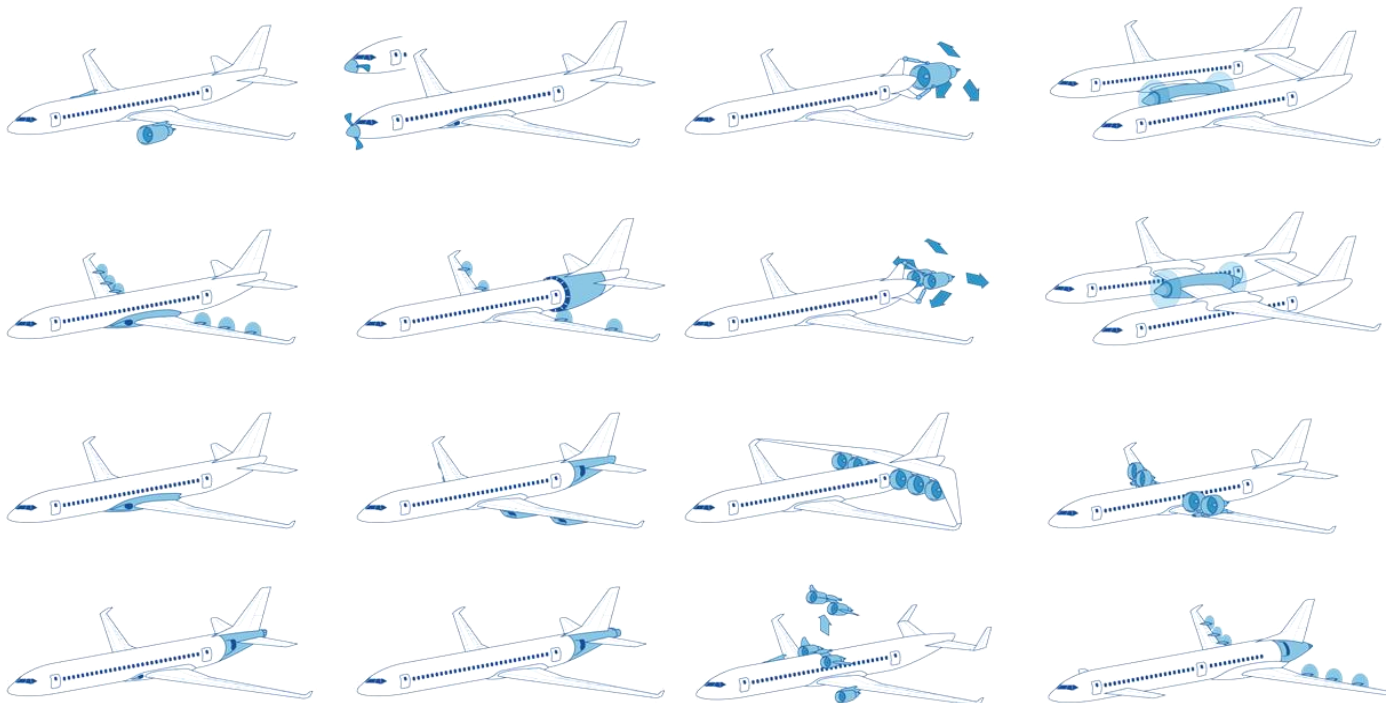


One configuration studied...





... On numerous others configurations explored

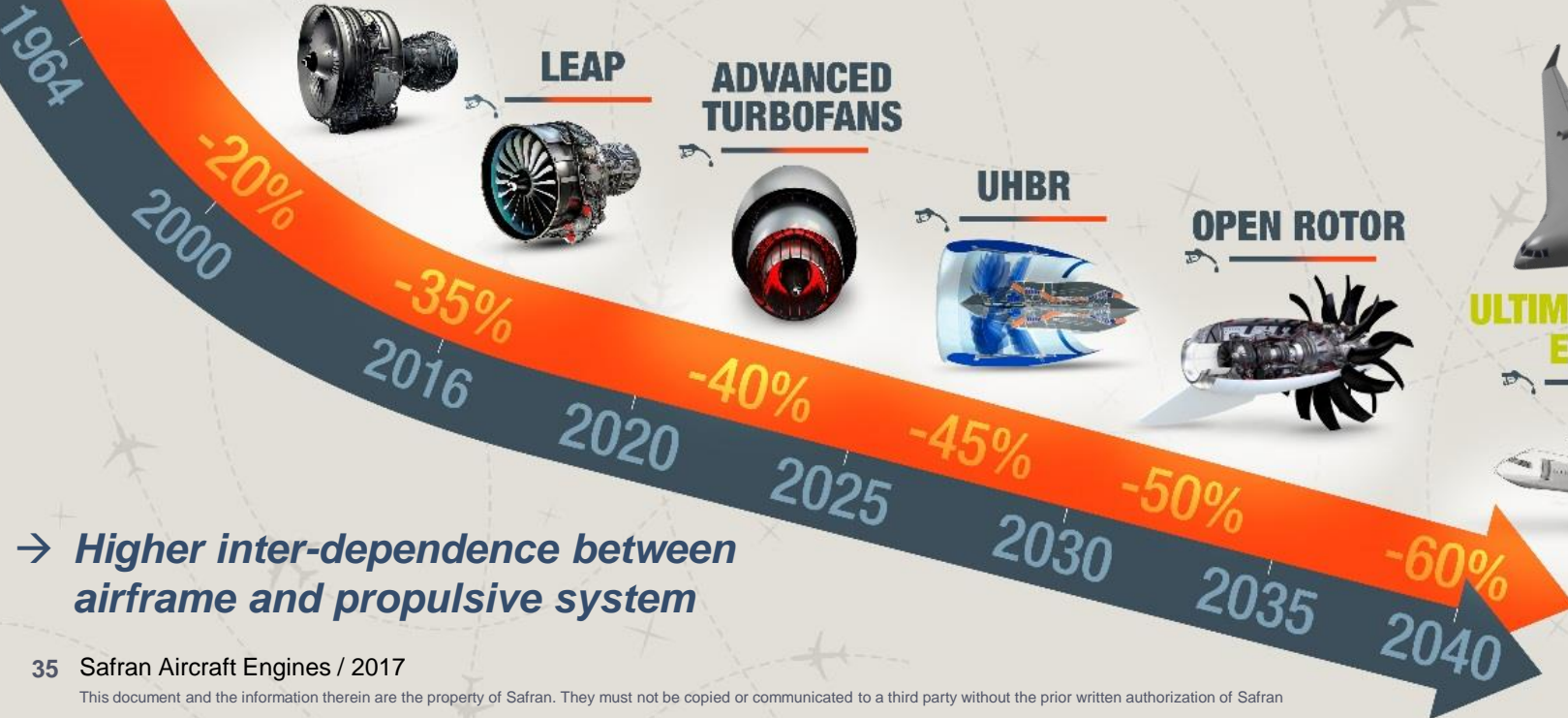


Conclusion

IMPROVED FUEL BURN



- Clever combination of inter-dependent improvements :*
- *engine efficiency*
 - *aircraft integration*
 - *aircraft energy management*



→ *Higher inter-dependence between airframe and propulsive system*

A large white commercial airplane is the central focus, parked on a tarmac. The aircraft's nose and cockpit are prominent on the left. Passengers are seen boarding and disembarking via the stairs. A man in a suit is walking down the stairs, while a woman in a brown jacket is talking on a mobile phone. Other passengers are scattered around the aircraft. The background shows the airport's infrastructure, including a terminal building with a glass facade and a sign that partially reads "Nat". The sky is clear and blue.

**WE BRING THE FUTURE
TO YOUR DOORSTEP.**



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