AIRCRAFT ENGINES

FUTURE OF AIRCRAFT PROPULSION

ISABE 2017
Manchester, UK

Dr Jerome BONINI
VP Research & Technologies

SAFRAN

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

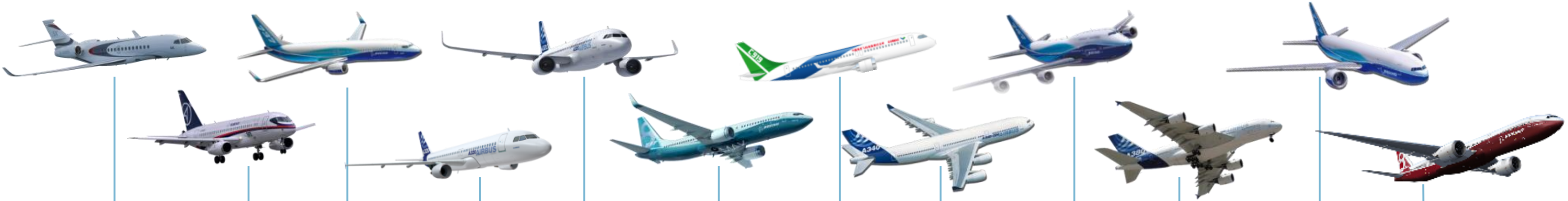
€15.8 bn
Sales in 2016

Near **58,000**
Employees

30 countries
Global presence

Safran Aircraft Engines – Military and commercial aircraft propulsion

Alpha Jet	Mirage F1	Rafale	Mirage 2000	A400M
Larzac ®	Atar	M88	M53	TP400 (3)
14kN	49kN	75kN	95kN	11 000 shp



Falcon 5X	SSJ100	737	A320	A320neo	737MAX	C919	A340	747	A380	777	777X
Silvercrest®	SaM146(1)	CFM56-7B(2)	CFM56-5B(2)	LEAP-1A(2)	LEAP-1B(2)	LEAP-1C(2)	CFM56-5C(2)	CF6(4)	GP7200(4)	GE90(4)	GE9X(4)
9 500 to 12 000 lb	15 400 to 17 800 lb	19 500 to 27 300 lb	21 600 to 33 000 lb	21 500 to 33 000 lb	21 500 to 28 000 lb	21 500 to 30 000 lb	31 200 to 34 000 lb	52 500 to 72 000 lb	70 000 to 85 100 lb	93 700 to 115 300 lb	~ 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

€8.1 bn
Sales in 2016

15,000+
Employees

35 facilities
Global presence

SAFRAN

CFM56® – The world's best selling commercial engine

800 MILLION FLIGHT HOURS

AIRBUS

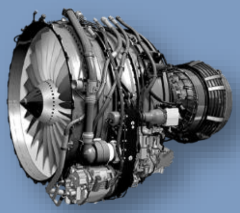
A320ceo

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

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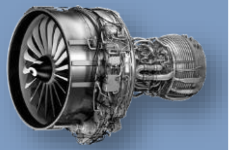
LEAP® – Combining the best technologies from Safran Aircraft Engines and GE

AIRBUS

A320neo

EASA Certified FAA



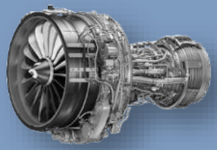
LEAP-1A

Entry into service
August 2016

BOEING

737 MAX

EASA Certified FAA



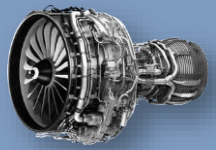
LEAP-1B

Entry into service
May 2017

COMAC

C919

EASA Certified FAA



LEAP-1C

Entry into service
2018

cfm LEAP

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

-15% lower fuel consumption*

-15% reduction in CO_2 emissions*

* Compared with previous-generation engines

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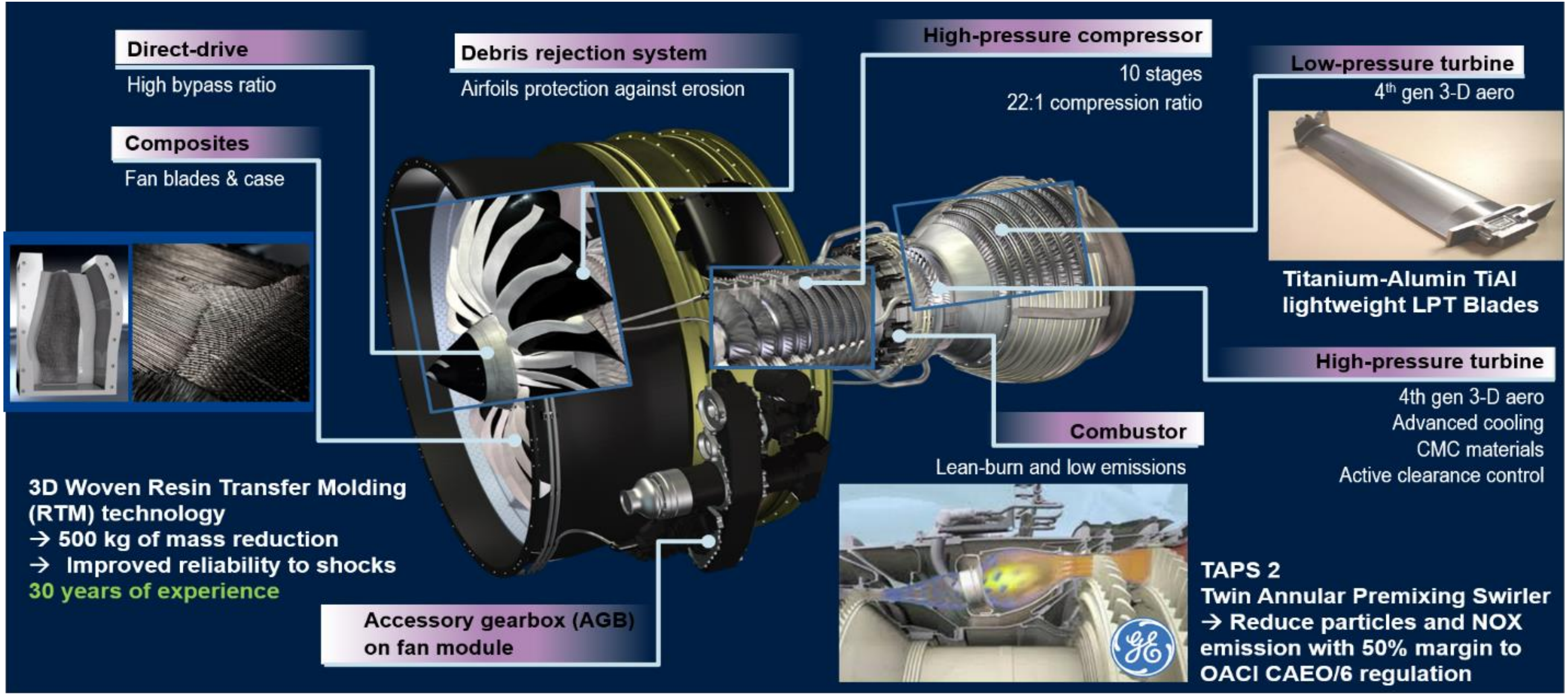
LEAP® – Combining the best technologies from Safran Aircraft Engines and GE



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

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What’s next ?

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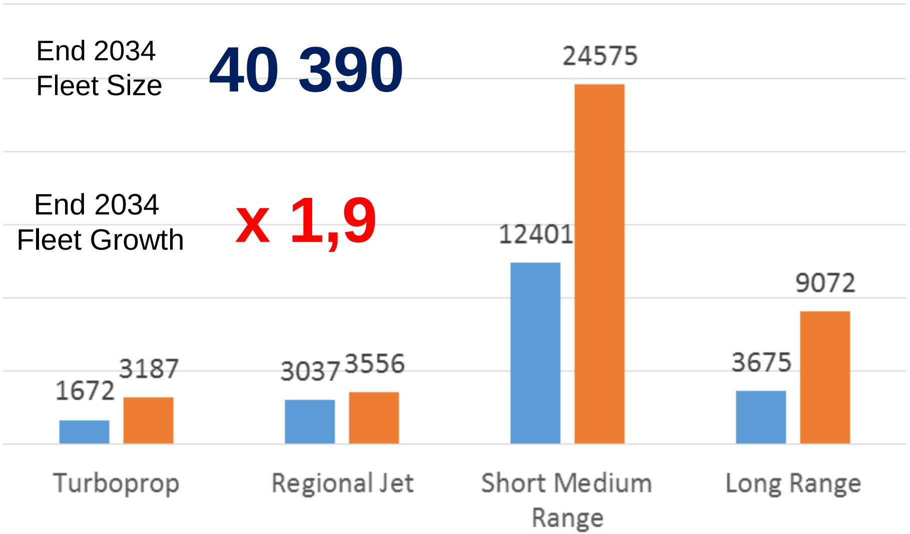
Ensure sustainable growth of air traffic

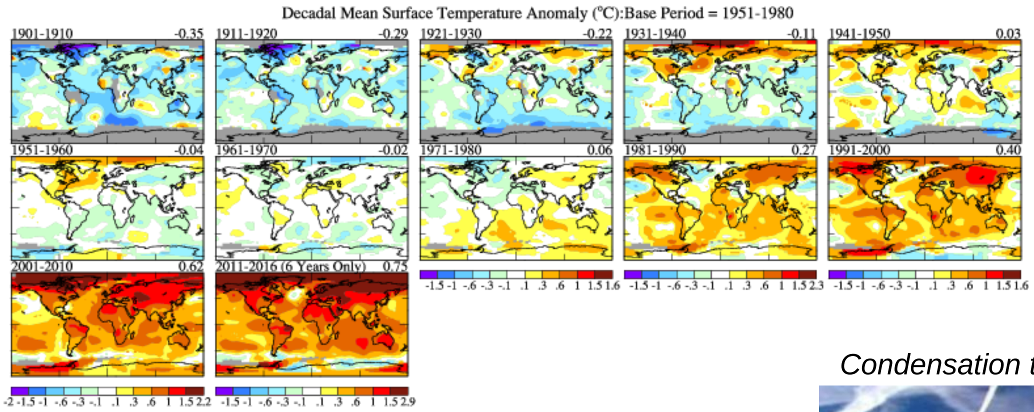
End 2034 Fleet Evolution by Aircraft Type (36+ pax)

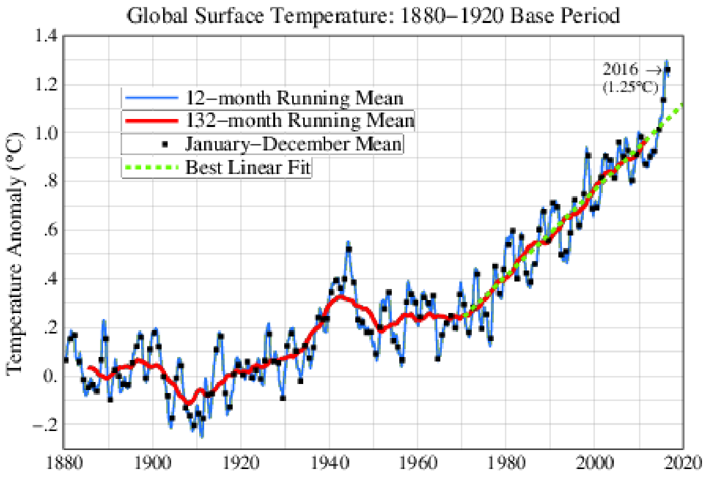


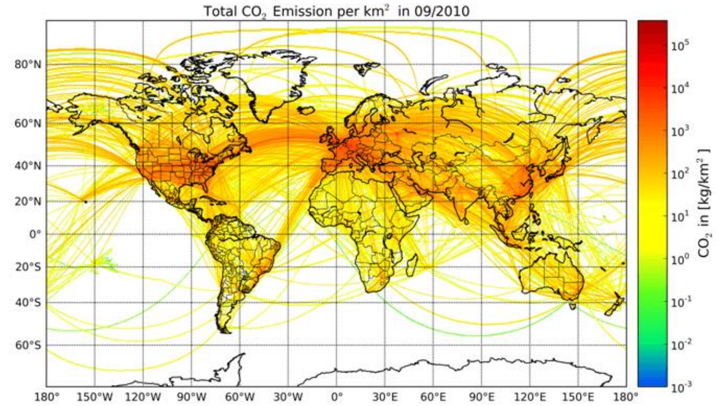
World fleet to double by 2034
more than 40 000 new aircraft
54% in SMR category

Today and 2030 air traffic

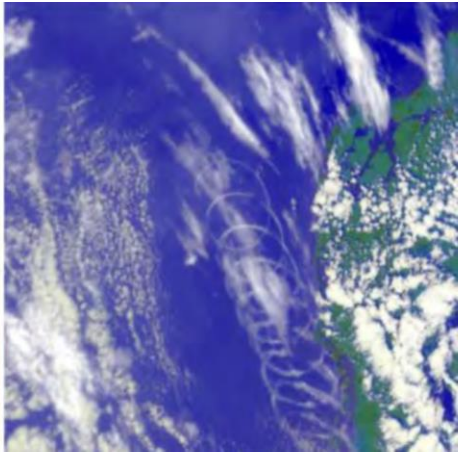
Environmental impact







Condensation trails

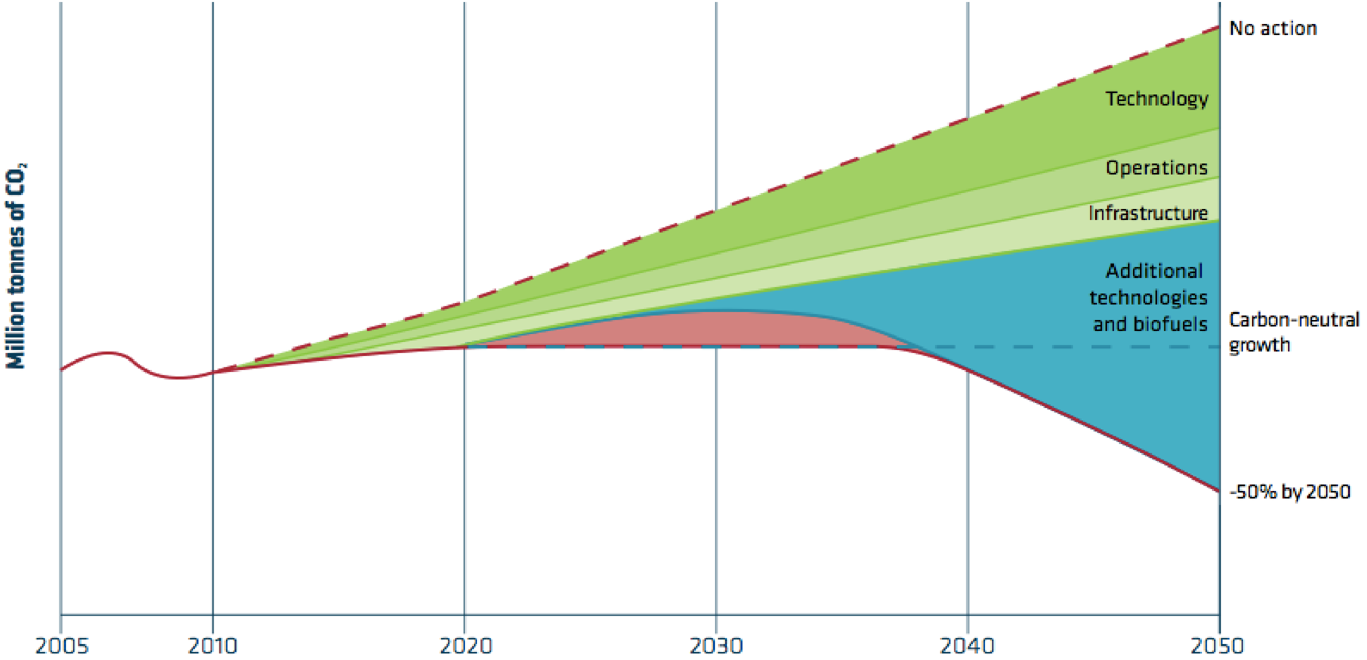


Environmental engagement

ACARE

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

2050
vs. 2000



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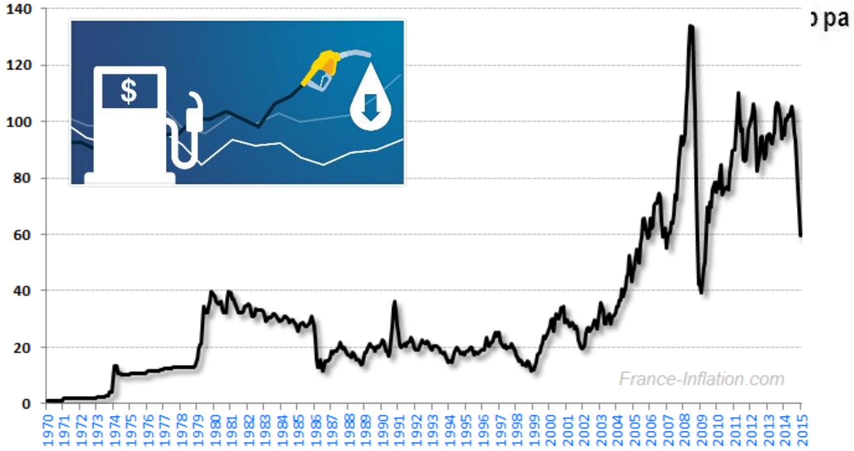
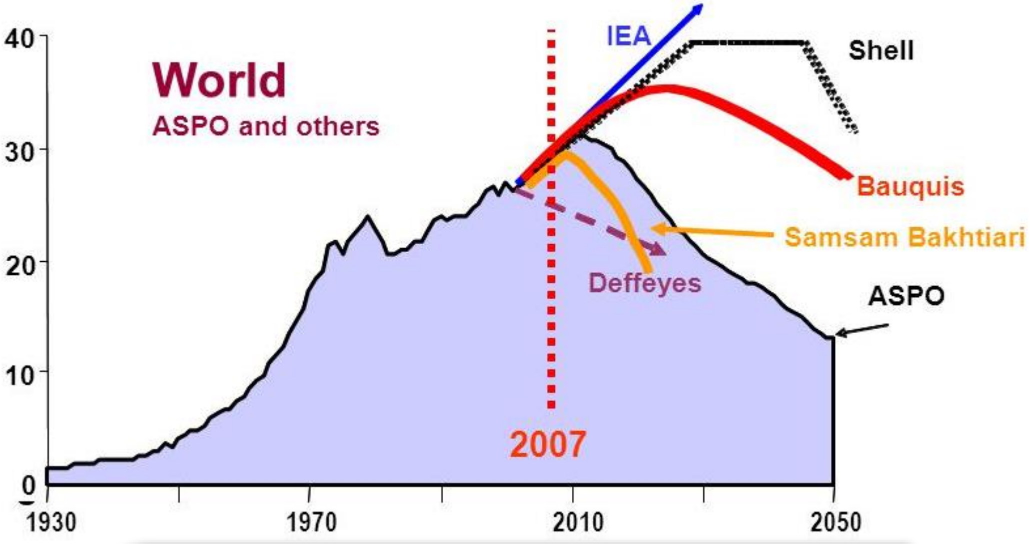
Fuel forecast





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

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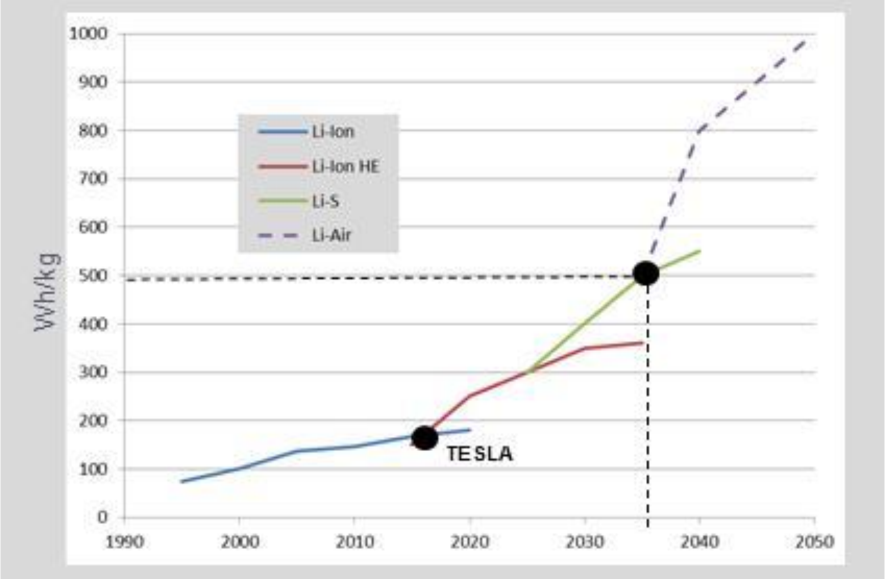
Full Electrical propulsion : a distant option for large aircraft

System-Level Battery Energy Density



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

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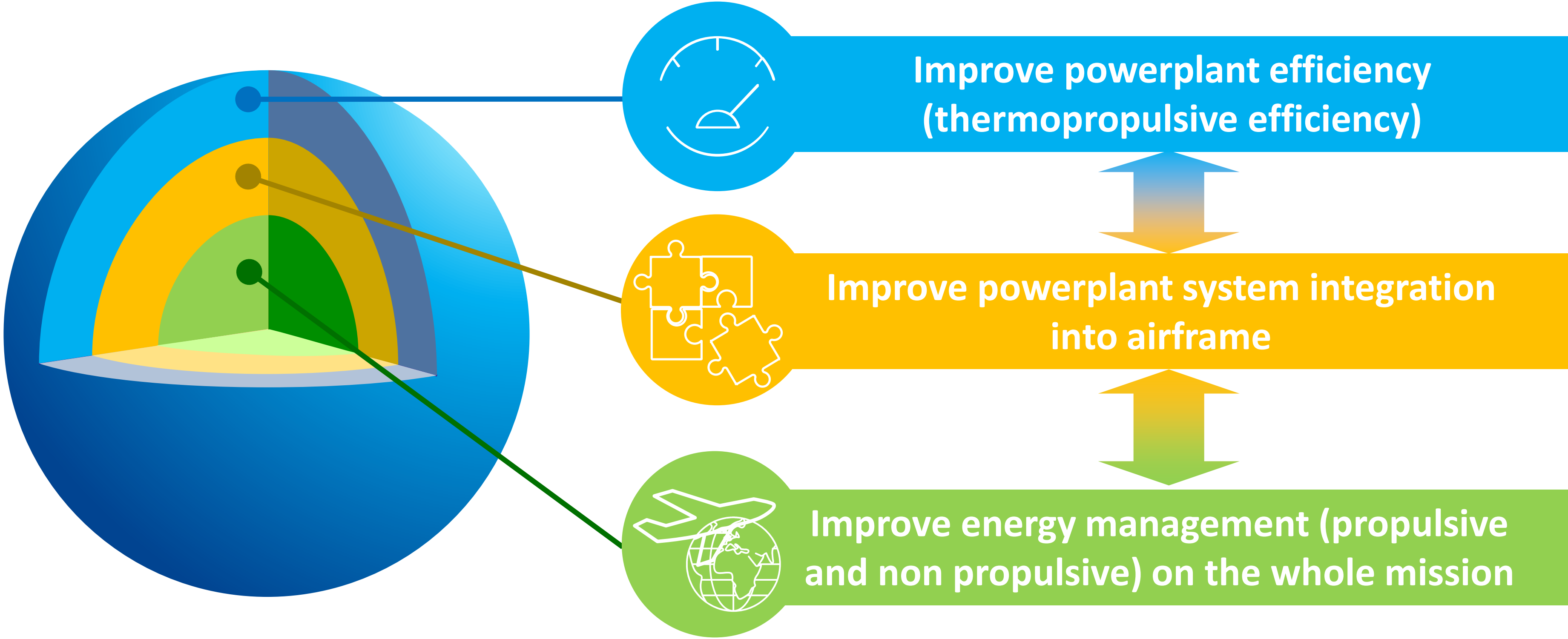
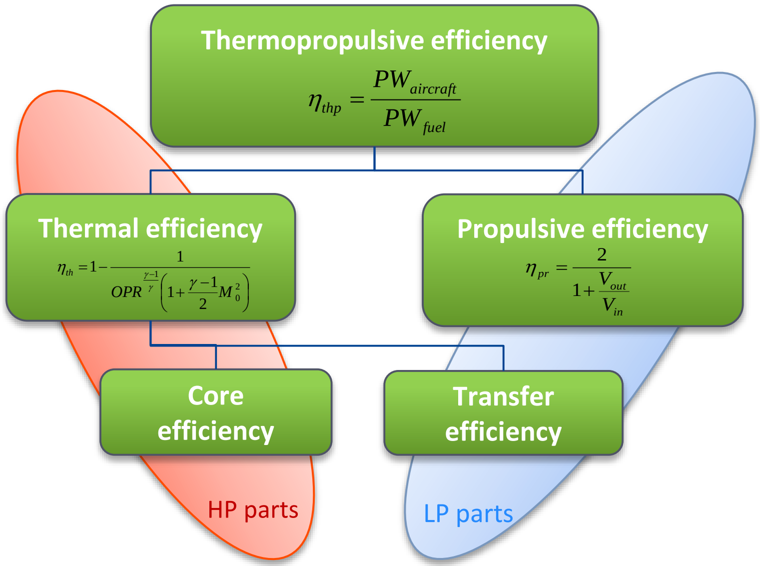
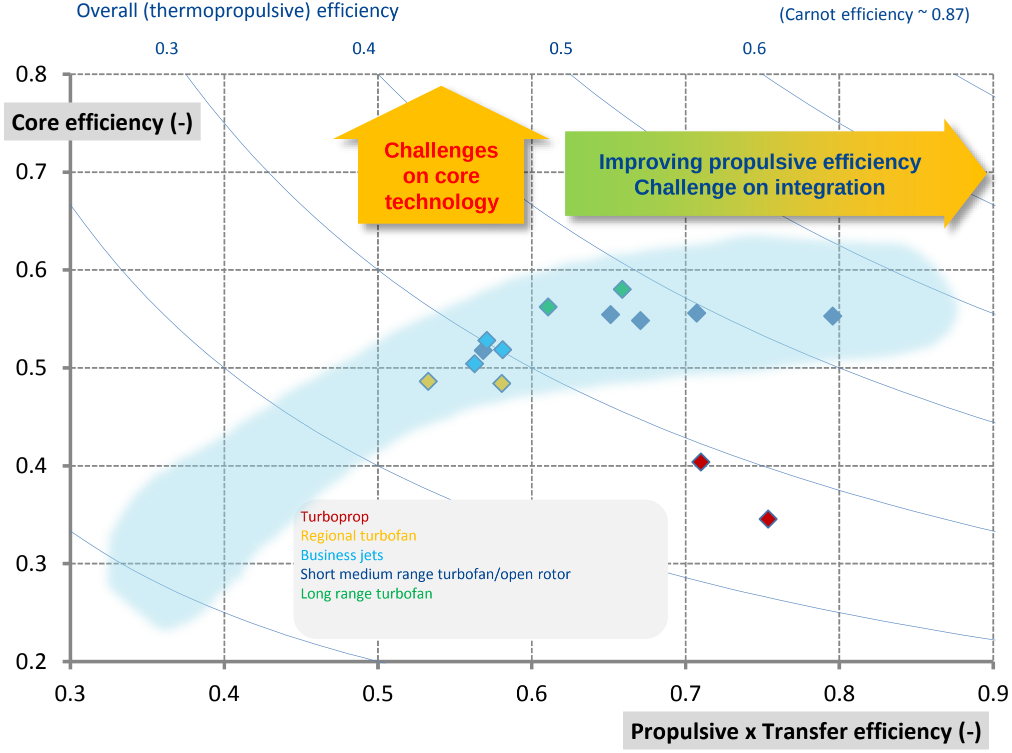
Our way to future propulsion : working on the three layers of efficiency



Improving powerplant efficiency

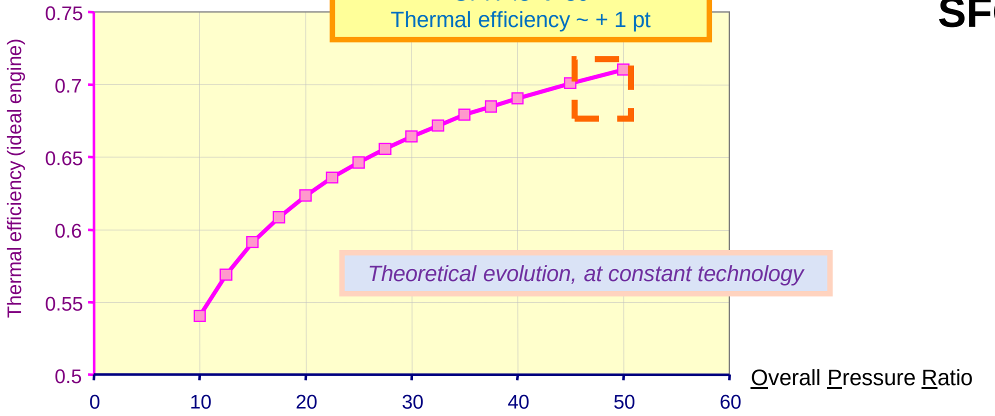




Improving powerplant efficiency

Increase OPR

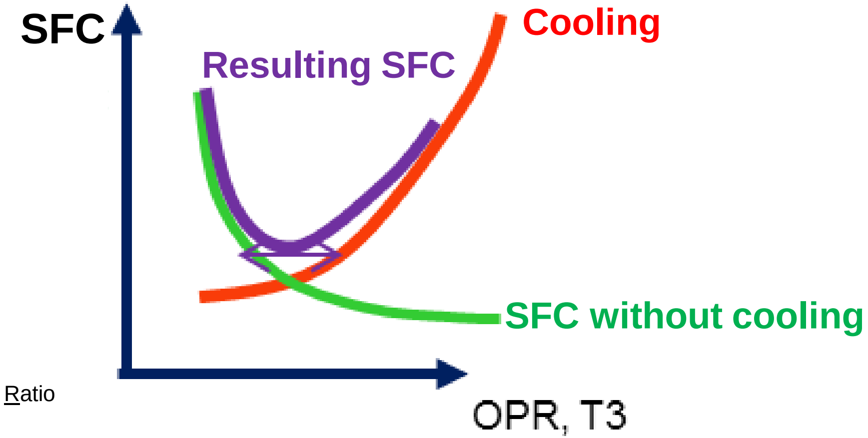
OPR 45 → 50
Thermal efficiency ~ + 1 pt



Increase engine temperatures

→ Need for higher cooling amount

→ Partially offsets / annihilates SFC improvement



Overall thrust level required

HPC exit temperature (T3)	HPT Entry Temperature (T41)	Core size

OPR ↗

Optimum ratio T41/T3

Reduce core size → impact on component efficiencies :

HPC feasibility, HPT cooling system integration, HP materials …

HPC exit temperature (T3)	HPT Entry Temperature (T41)	Core size

2020

Ceramic Matrix Composites …
beyond metals

20%
Higher thermal capability

1/3 **the weight**

less **cooling air**

Blades and Nozzle

New-generation **combustor**

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

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

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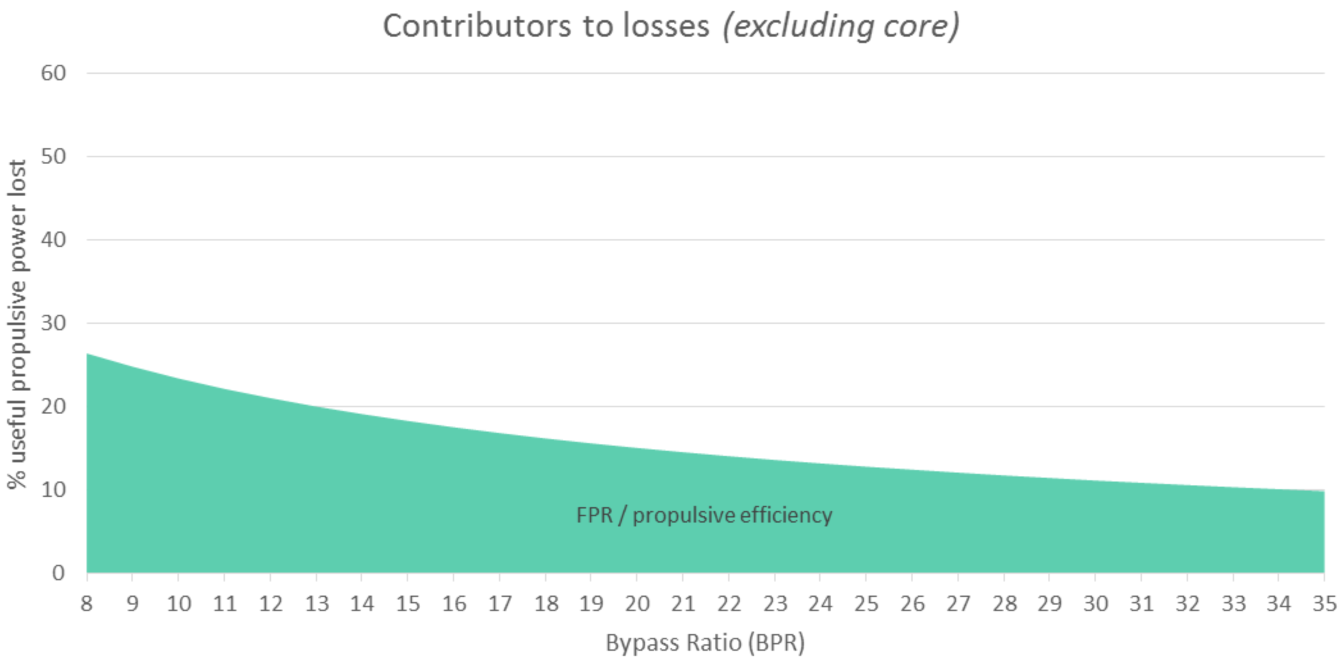
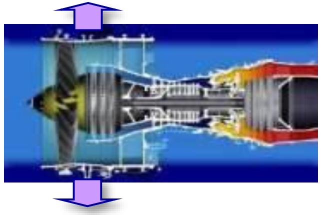
Improving powerplant efficiency

Decrease FPR → Increase BPR



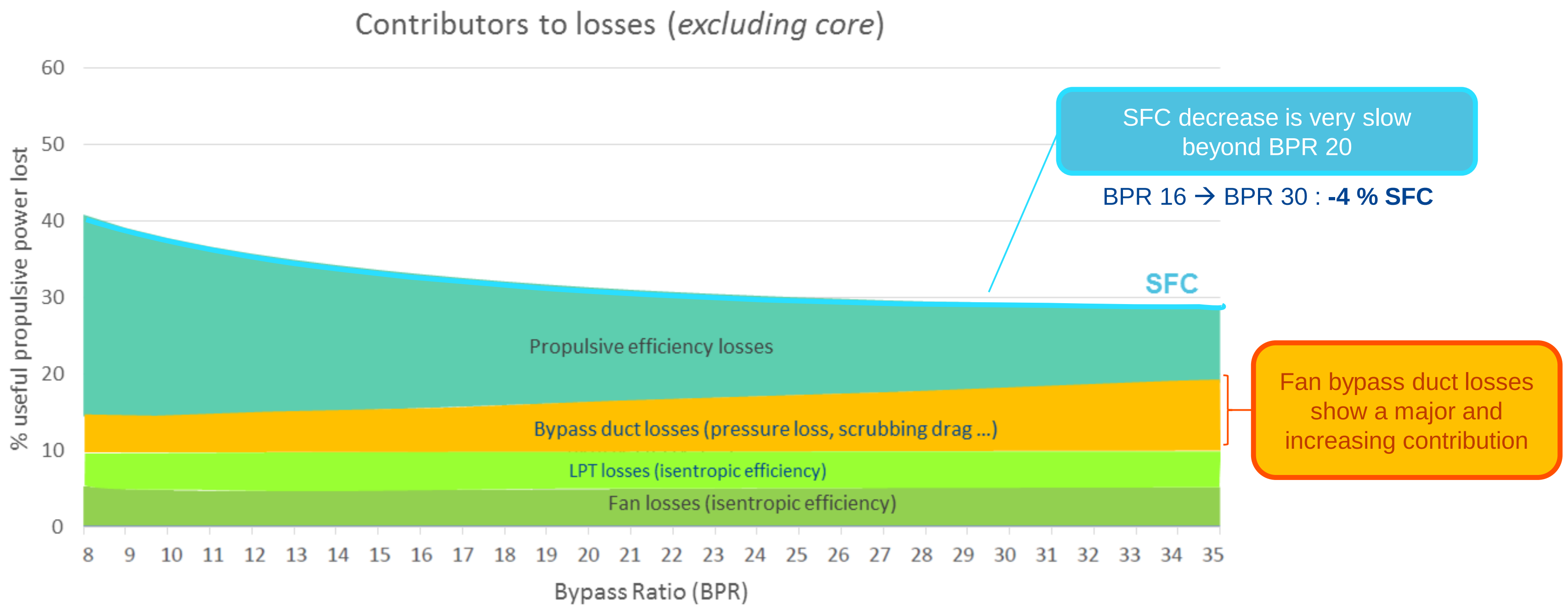


$$FN = W \times \Delta V$$

- FN: constant
- W: Increase massflow !
- ΔV: Decrease to improve propulsive efficiency

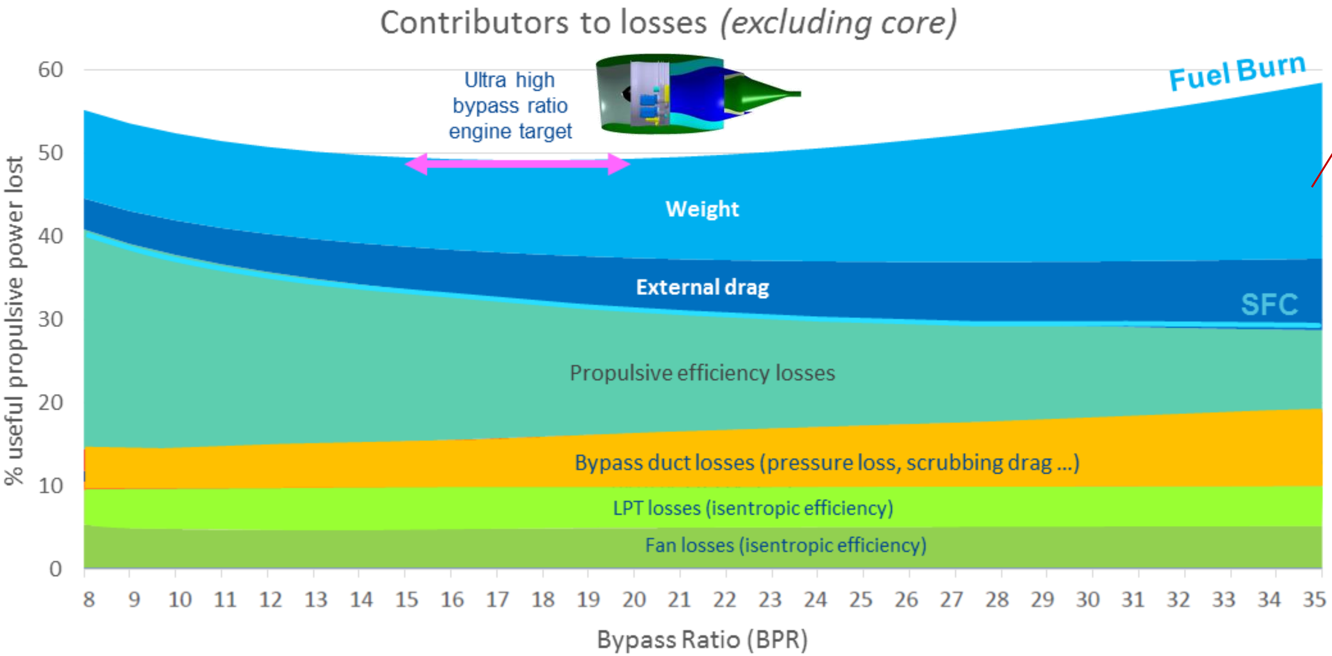
Improving powerplant efficiency

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

Improving powerplant efficiency

2025

UHPE : UHBR concept demonstrator

Clean Sky 2

3D RTM woven fan blade

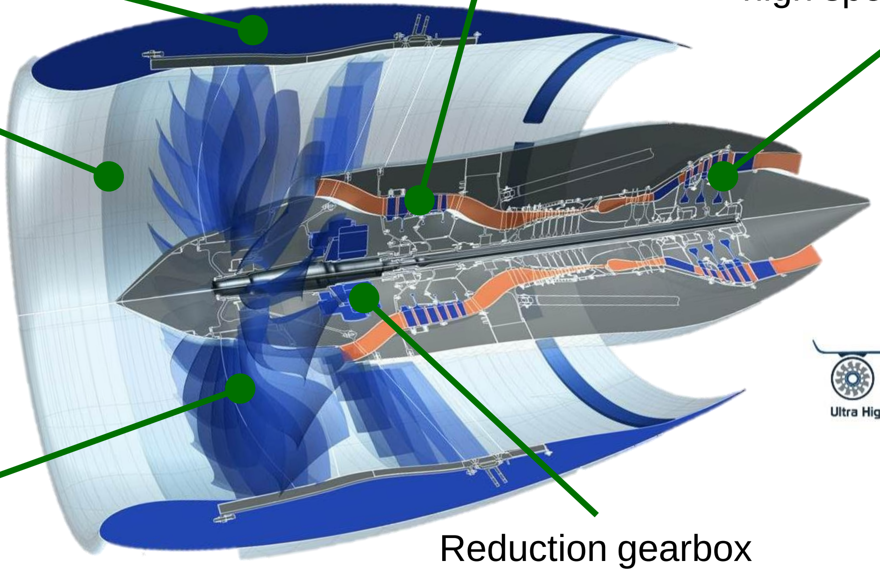
Next gen composite fan blades

BPR > 15

Low weight – low drag nacelle

Advanced high-load high speed booster

Next gen aero high speed CMC LPT



Reduction gearbox

ENOVAL
Ultra High Bypass Ratio Aero Engines

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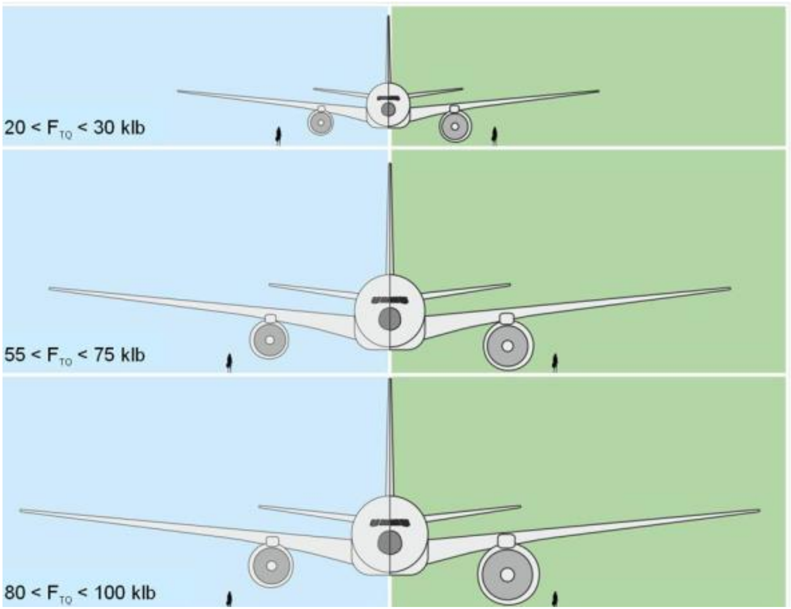
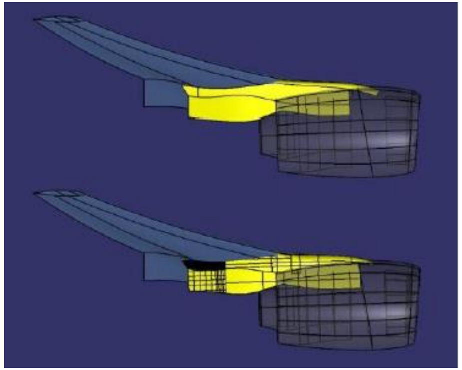
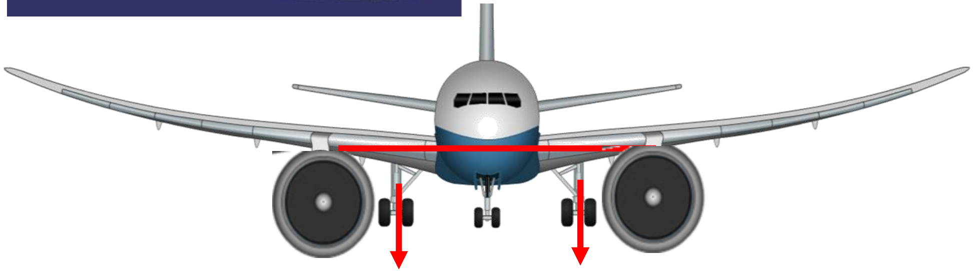
Installation challenge





→ Pylon & nacelle geometry and wing shape optimization

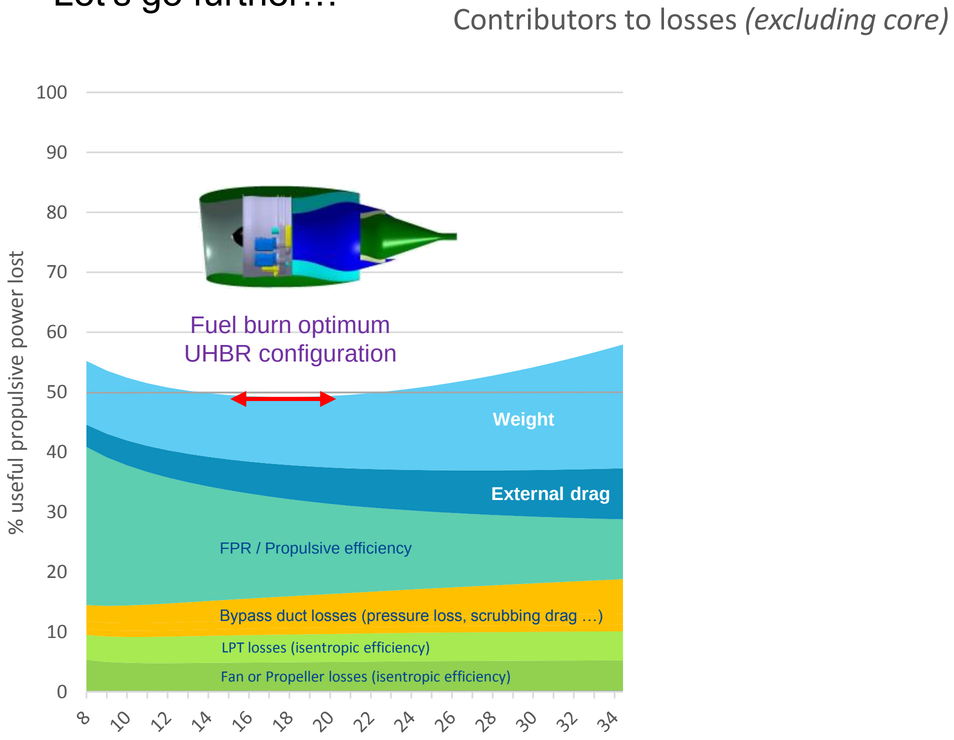


→ Additional challenge on integration constraints
→ Drag, weight for ducted configurations

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

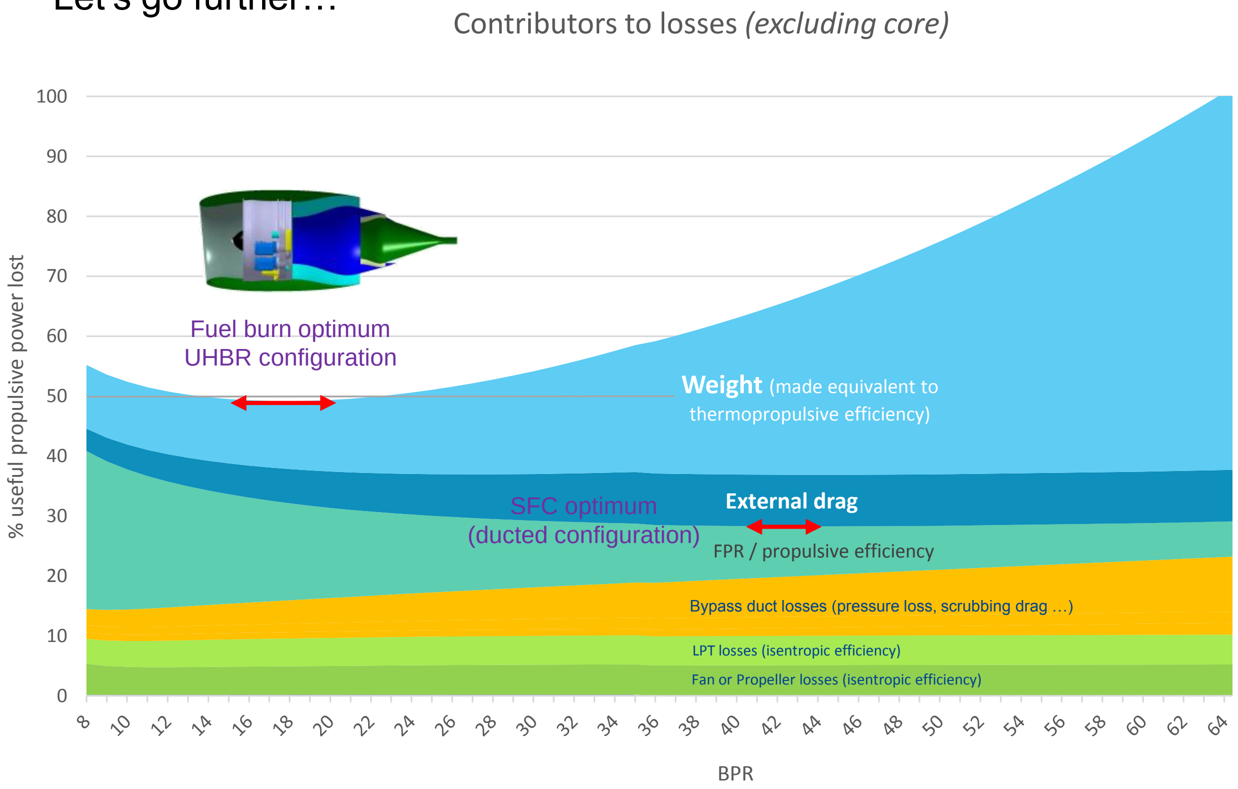
Improving powerplant efficiency

Let's go further…



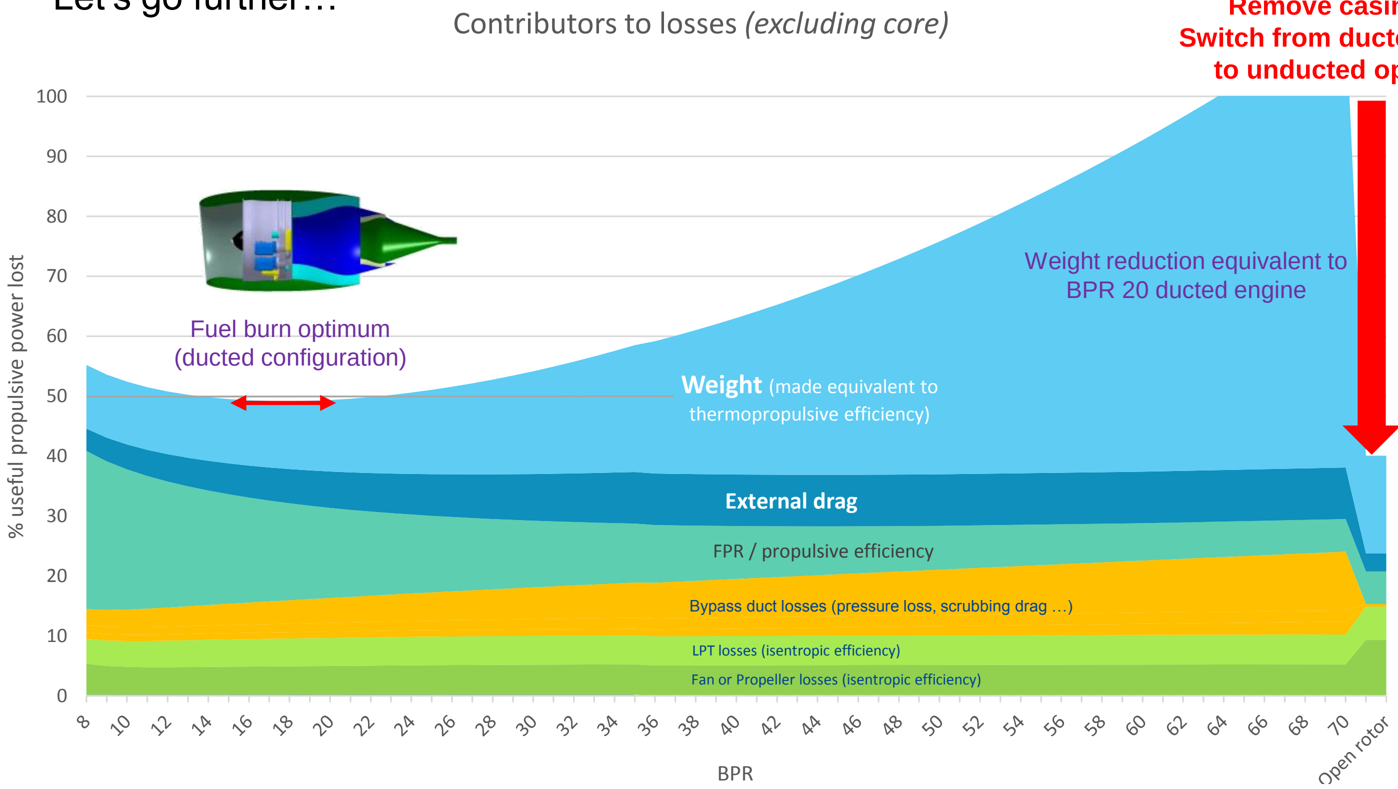
Improving powerplant efficiency

Let's go further…

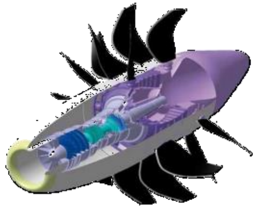


Improving powerplant efficiency

Let's go further…



Remove casings and Switch from ducted turbofan to unducted open rotor



Mechanical transmission similar to geared turbofan

Lower nacelle drag

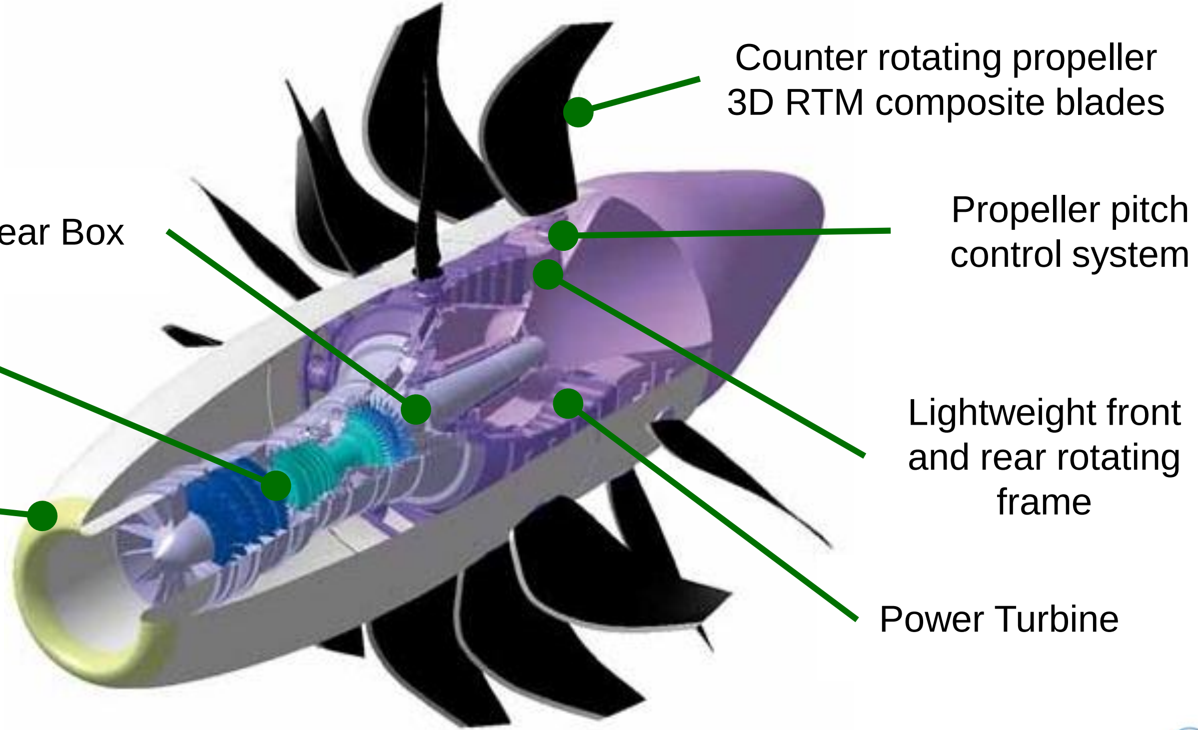
No by pass duct loss

Propeller with lower efficiency than ducted fan

Improving powerplant efficiency

2030

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 mechanichal 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**

Clean Sky

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Improving powerplant system integration into airframe

2030

Aircraft Integration challenge

Improving powerplant system integration into airframe

2030

A way to decrease fan inlet speed : Boundary Layer Ingestion

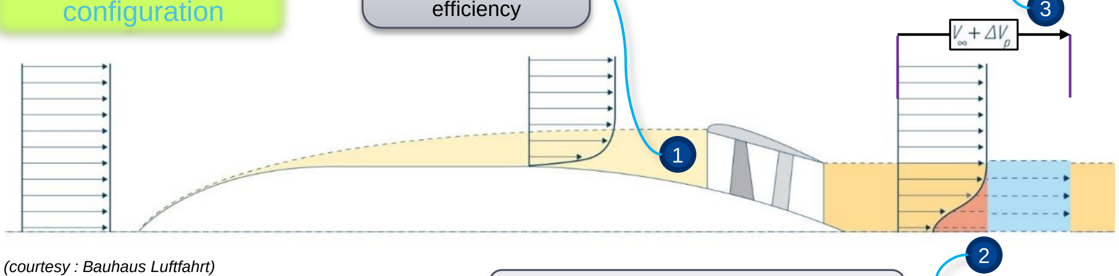
Additional advantages :
- Reduced **external drag** (part of the nacelle is not a wetted surface)
- Reduced **pylon weight**

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

BLI configuration

Lower inlet speed : improved thermopropulsive efficiency

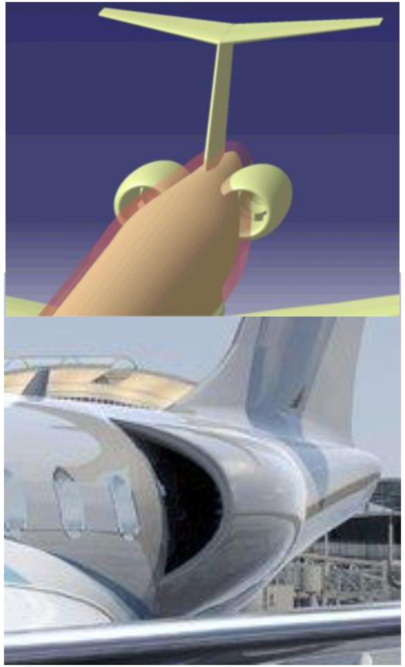
Lower absolute exhaust speed → lower jet noise



(courtesy : Bauhaus Luftfahrt)

Fuselage wake compensated by engine thrust

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

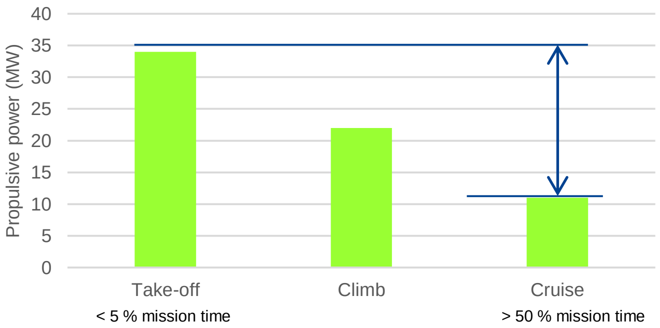


Improving powerplant efficiency

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

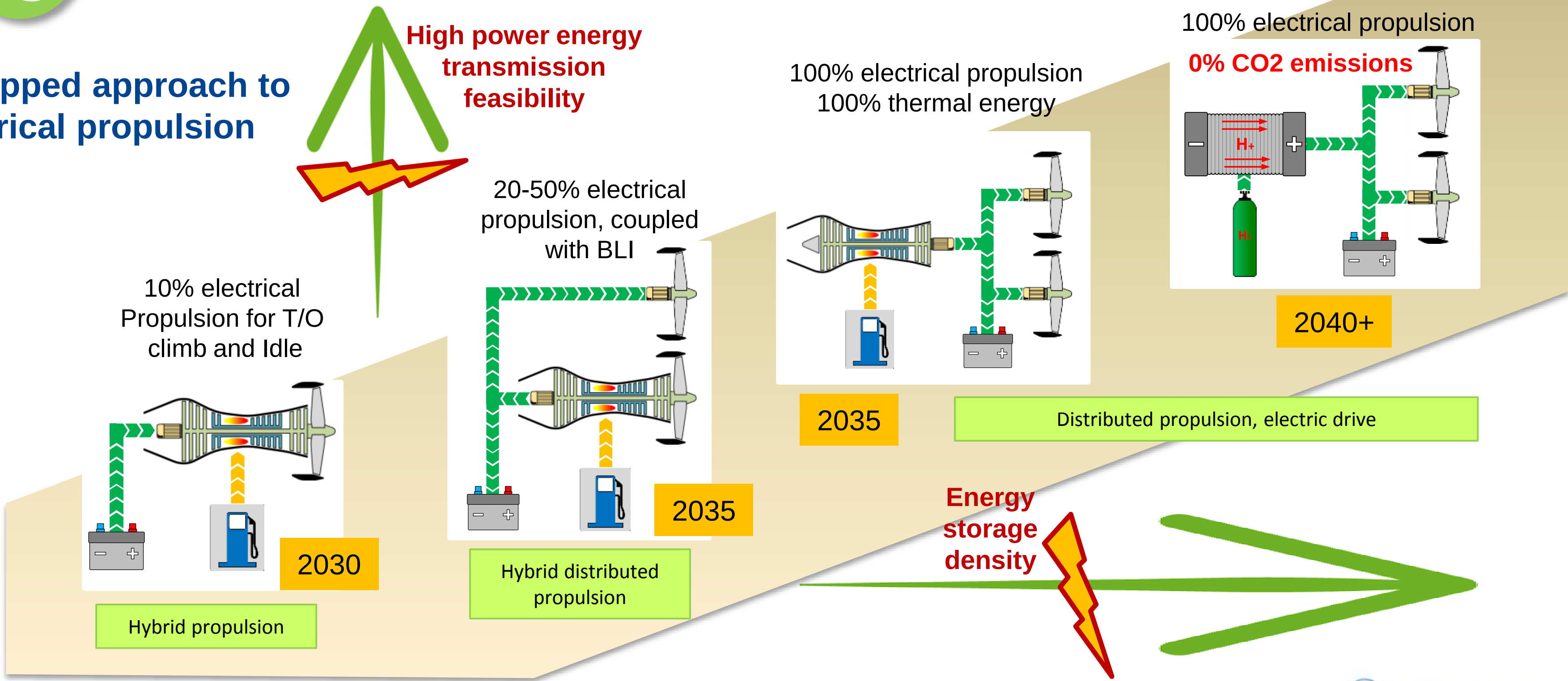
Use of electricity → Hybridization

Improving powerplant efficiency

Improving powerplant system integration into airframe

Improving energy management (propulsive and non propulsive)

A stepped approach to electrical propulsion



Improving powerplant efficiency

Improving powerplant system integration into airframe

Improving energy management (propulsive and non propulsive)

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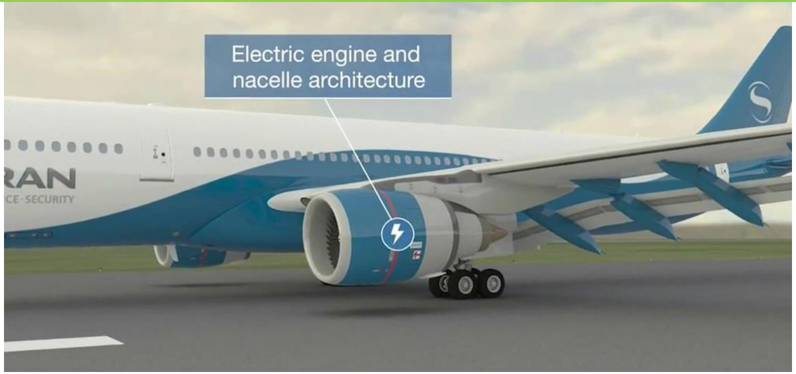
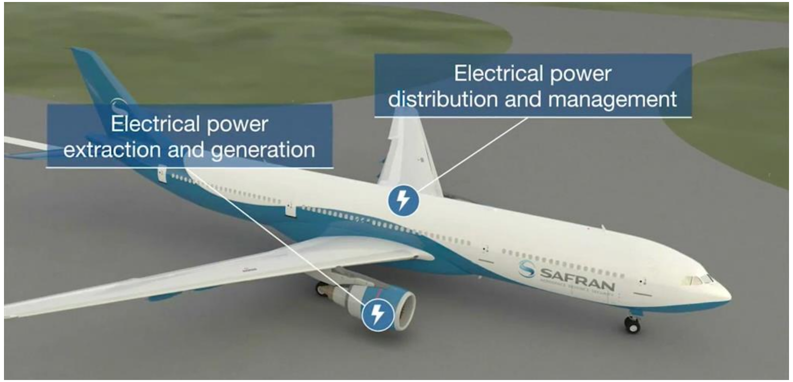
- Aircraft Engines
- Nacelles
- Power Units
- Electrical & Power
- Landing Systems
- Transmission Systems





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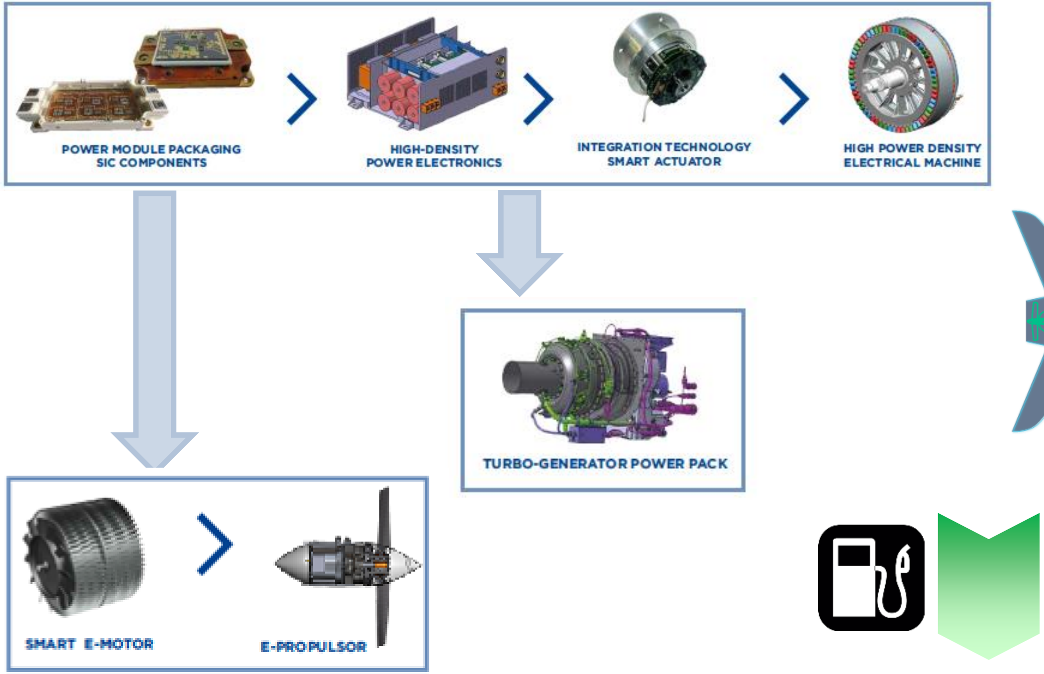
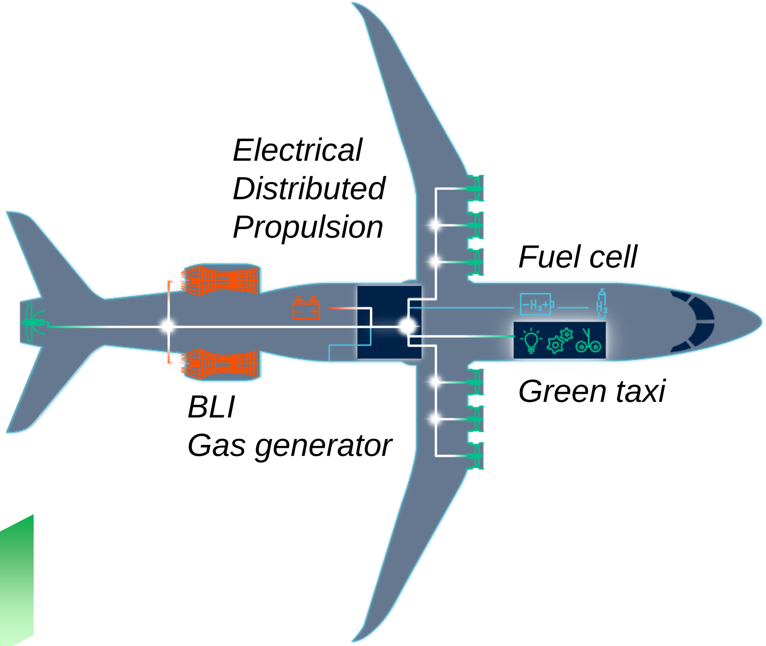
Improving powerplant efficiency

Improving powerplant system integration into airframe

Improving energy management (propulsive and non propulsive)

One configuration studied…



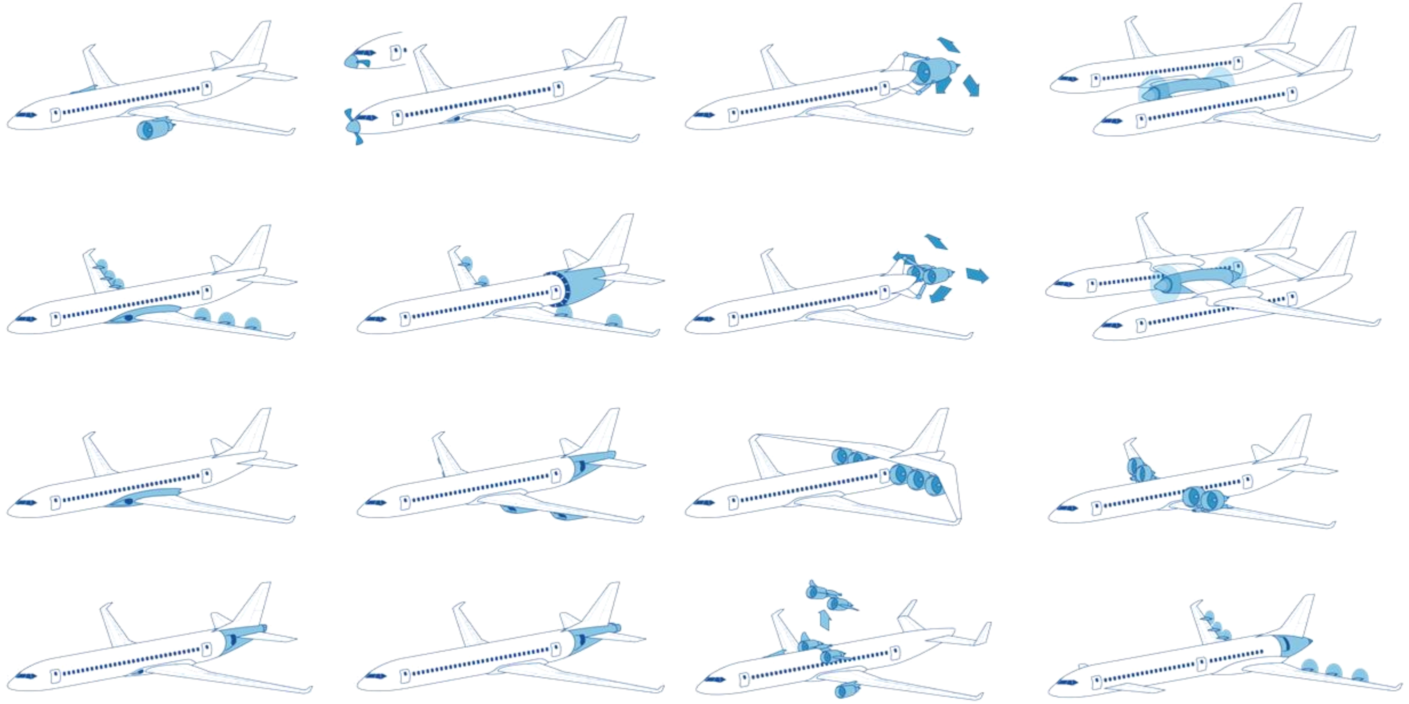


Improving powerplant efficiency

Improving powerplant system integration into airframe

Improving energy management (propulsive and non propulsive)

… On numerous others configurations explored



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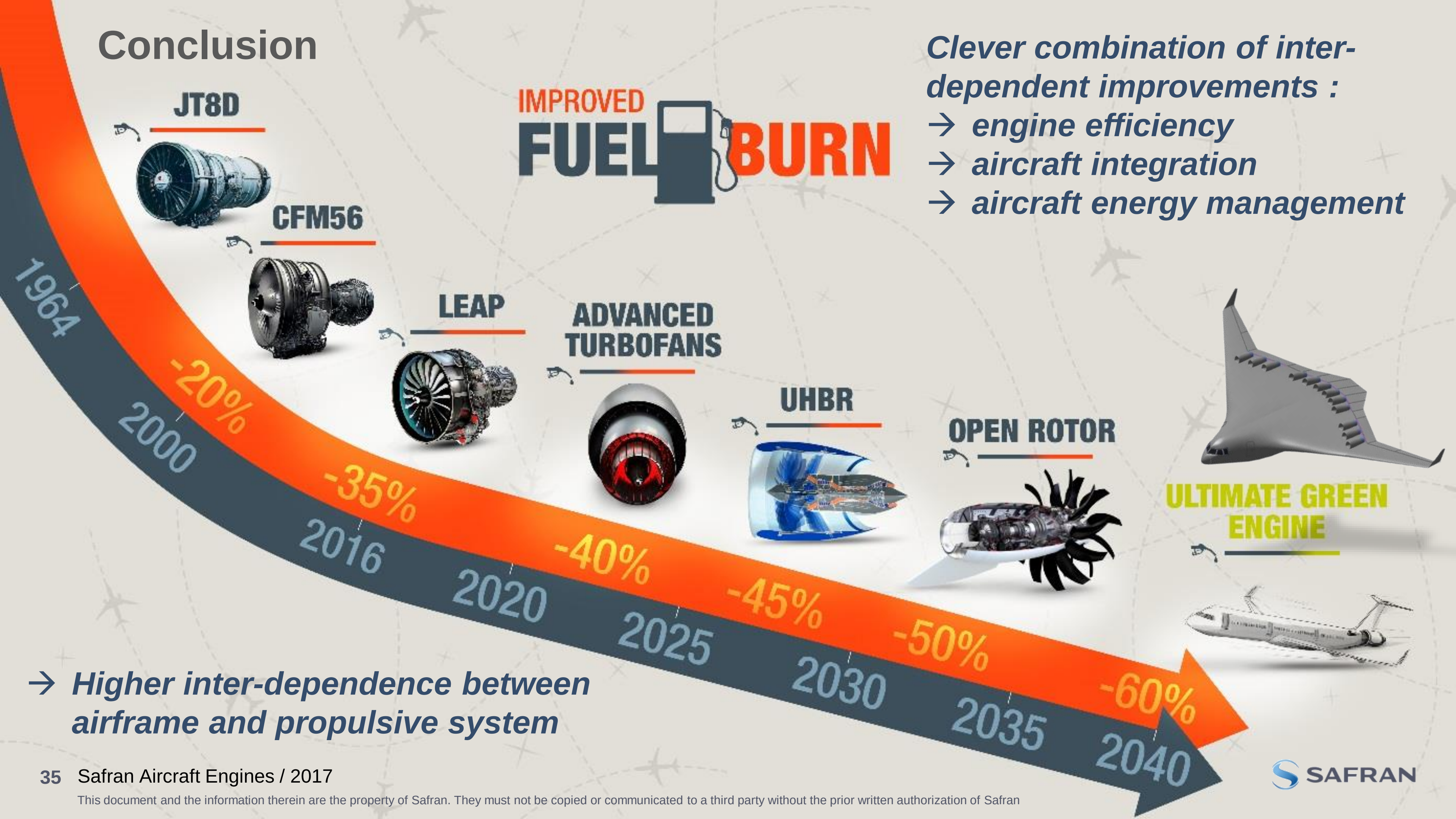
Conclusion

Clever combination of inter-dependent improvements :

- → *engine efficiency*
- → *aircraft integration*
- → *aircraft energy management*



→ ***Higher inter-dependence between airframe and propulsive system***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TO YOUR DOORSTEP.
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