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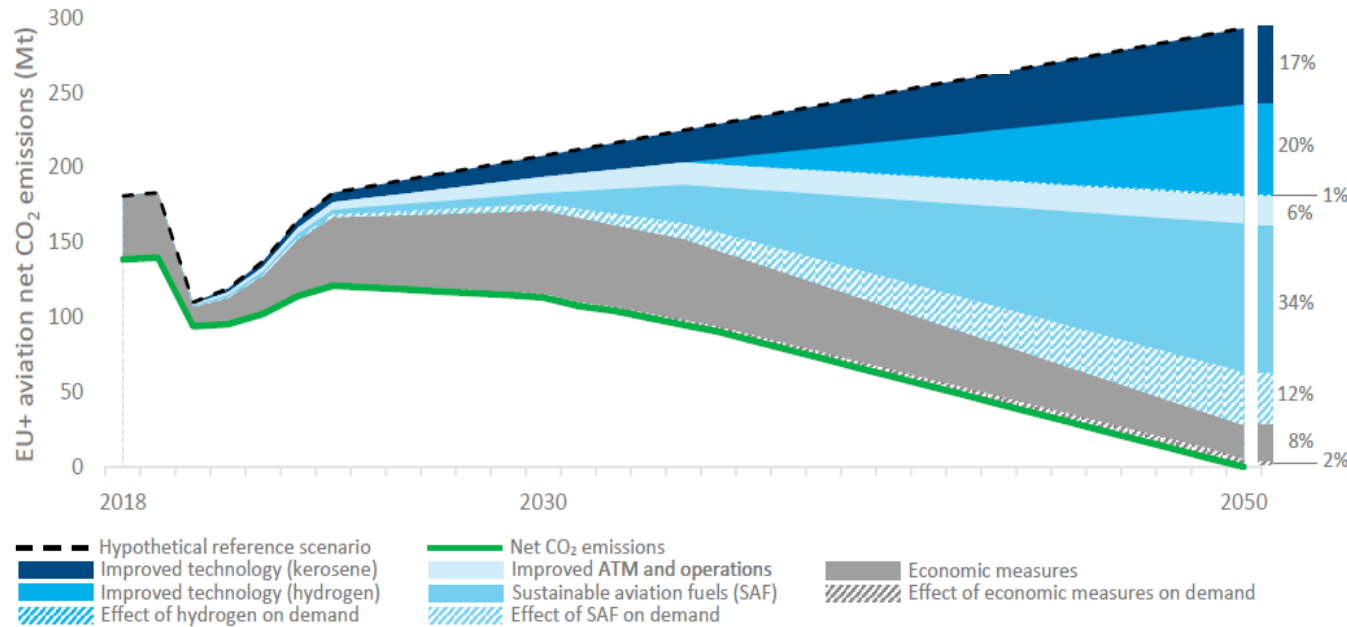
AUBERT&DUVAL



# L'AVION DU FUTUR : OPPORTUNITÉS OU MENACES POUR A&D

# Challenges : Fuel burn and Noise reduction

## DECARBONISATION ROADMAP FOR AVIATION



Results are presented for all flights within and departing from the EU region<sup>2</sup>. Improving aircraft and engine technology, ATM and aircraft operations, SAF and economic measures all hold decarbonisation potential. Modelled for 2030 and 2050, the impacts are linearly interpolated. The base year for this study is 2018.

### 4 pillars to achieve net zero CO<sub>2</sub> emissions in 2050

- ◆ Aircraft and engine technology (efficiency improvements)
- ◆ Air traffic management and aircraft operations
- ◆ Sustainable alternative fuels
- ◆ Smart economic measures



75% ↓ CO<sub>2</sub>

90% ↓ Nox

65% ↓ Noise

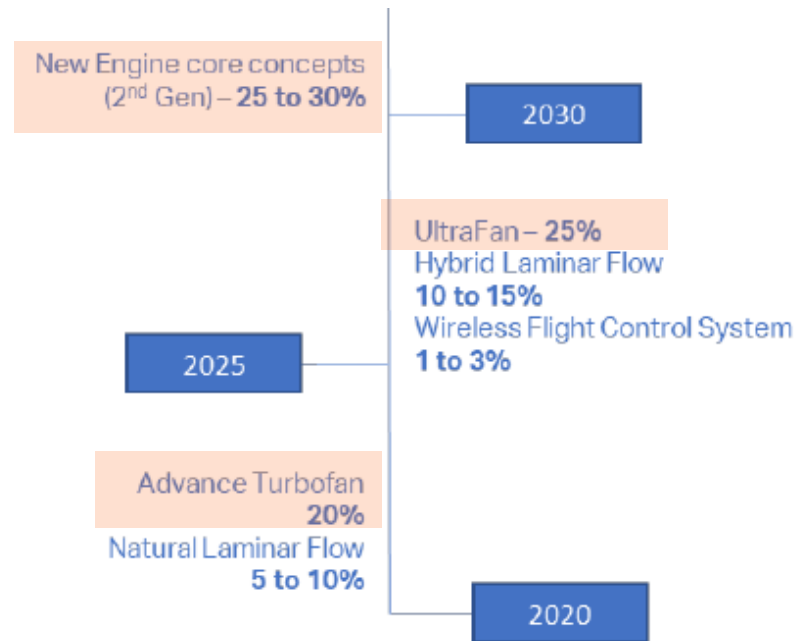
0 emissions tax

}

2050  
vs. 2000

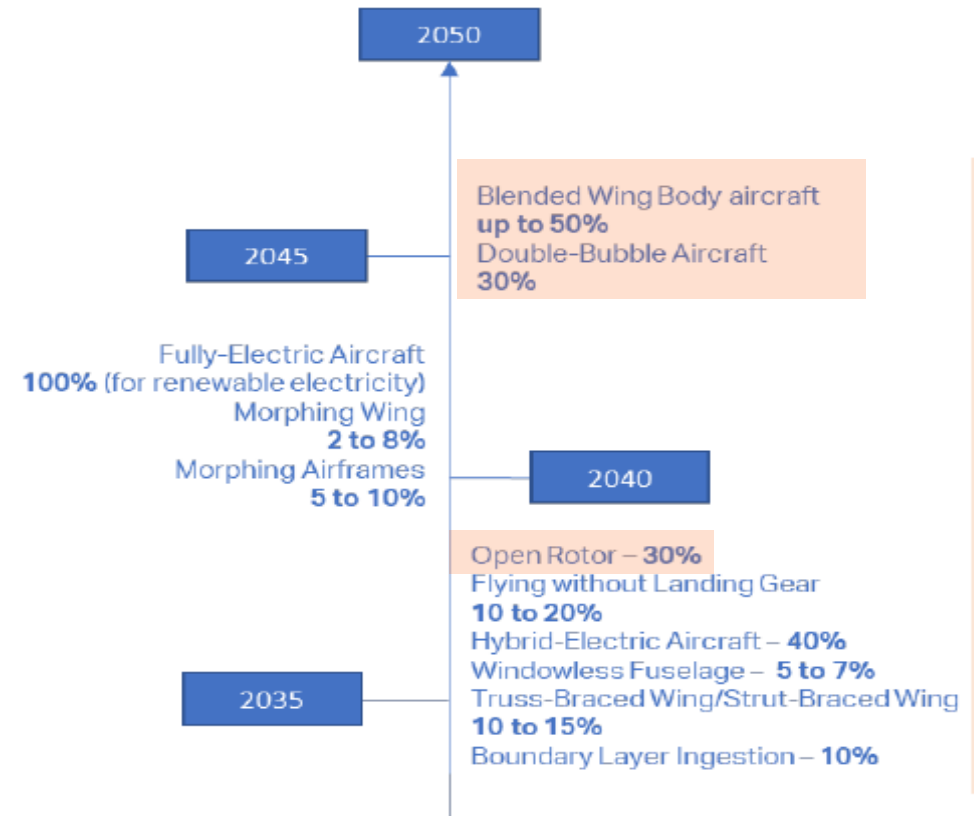
# IATA Roadmap for fuel efficiency improvements by 2050

## Incremental Innovation



**EVOLUTIONARY  
TECHNOLOGIES**

## Disruptive Innovation



**REVOLUTIONARY  
TECHNOLOGIES**

# Sustainable aircraft : 2 objectives



## CONSUME LESS

- Improving propulsion efficiency and integration
- Maximizing weight reduction
- Improving aerodynamics



## CONSUME BETTER

- Sustainable Aviation Fuels
- Hydrogen

Cost-cutting policy

SUSTAINABLE  
AIRCRAFT



**CONSUME LESS**



1

POWERPLANT EFFICIENCY & INTEGRATION

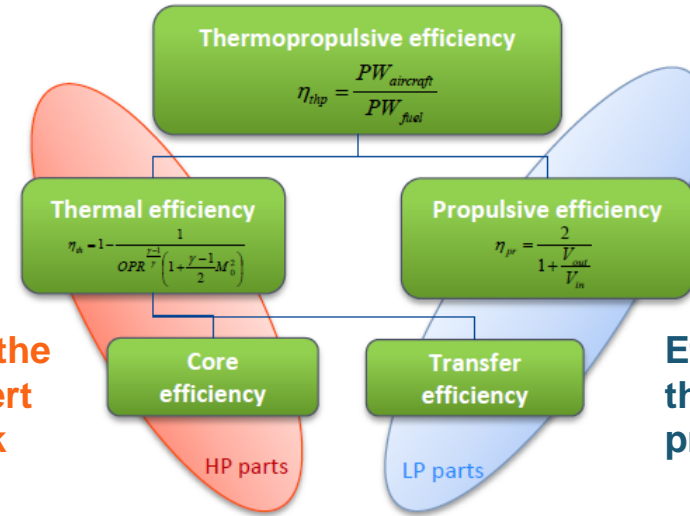
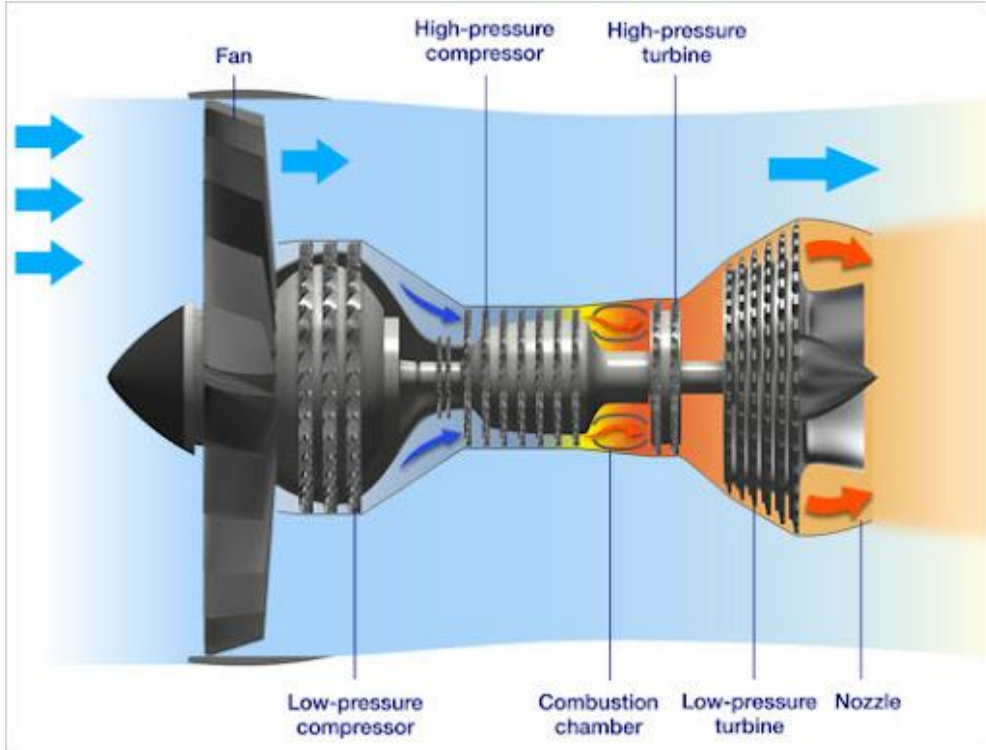
2

WEIGHT REDUCTION

3

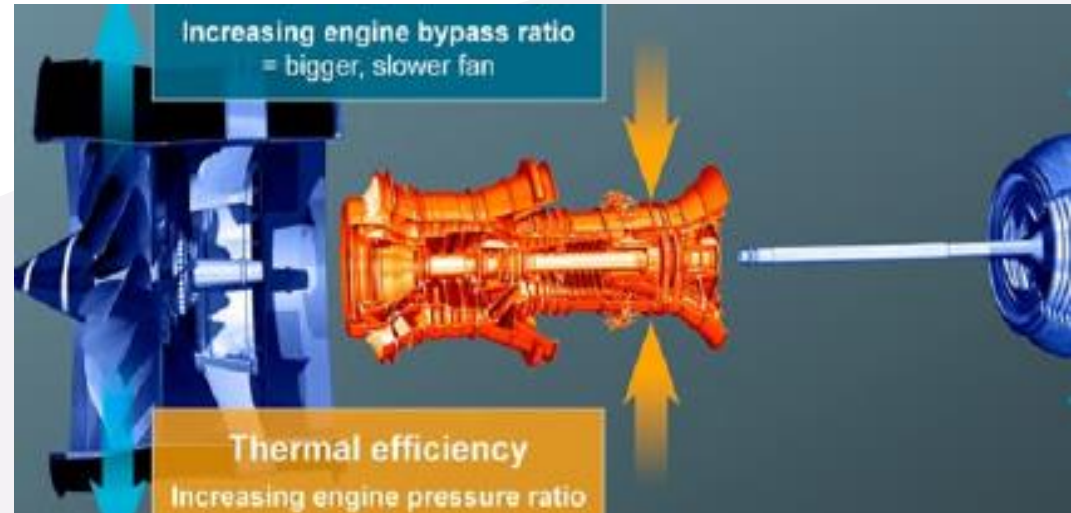
AERODYNAMICS

# Powerplant Efficiency driven by thermal and propulsive efficiency...



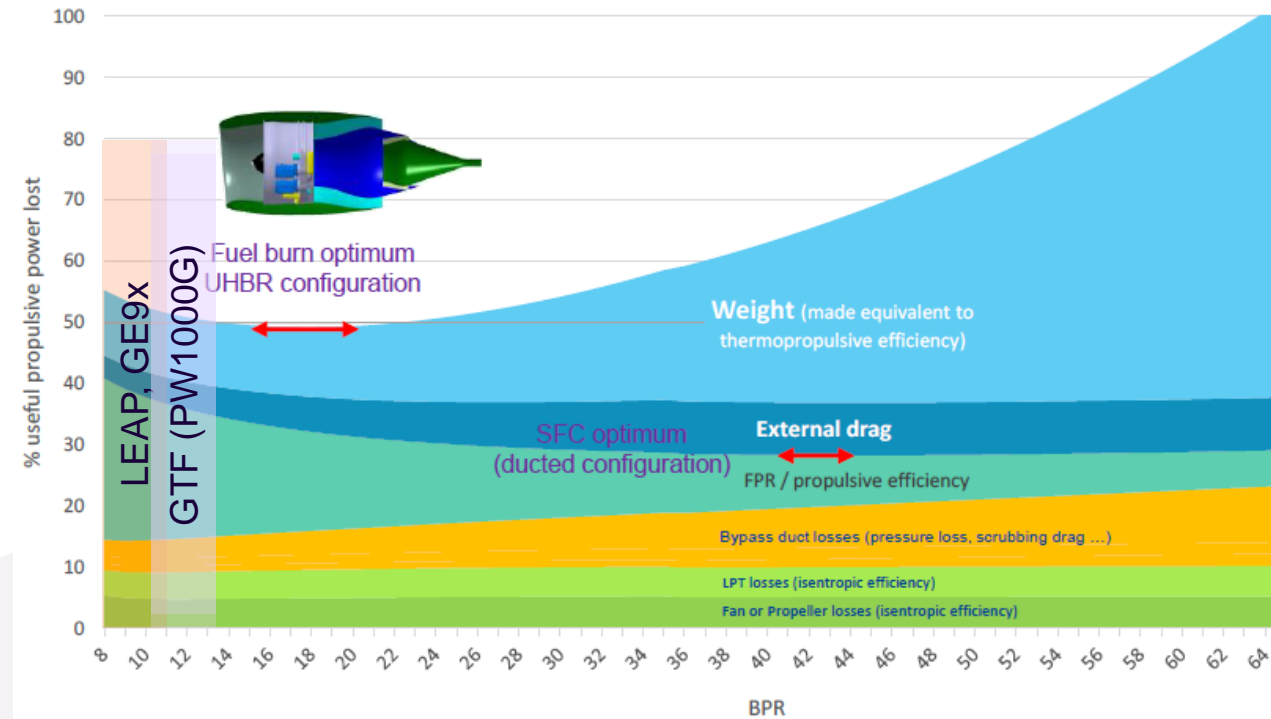
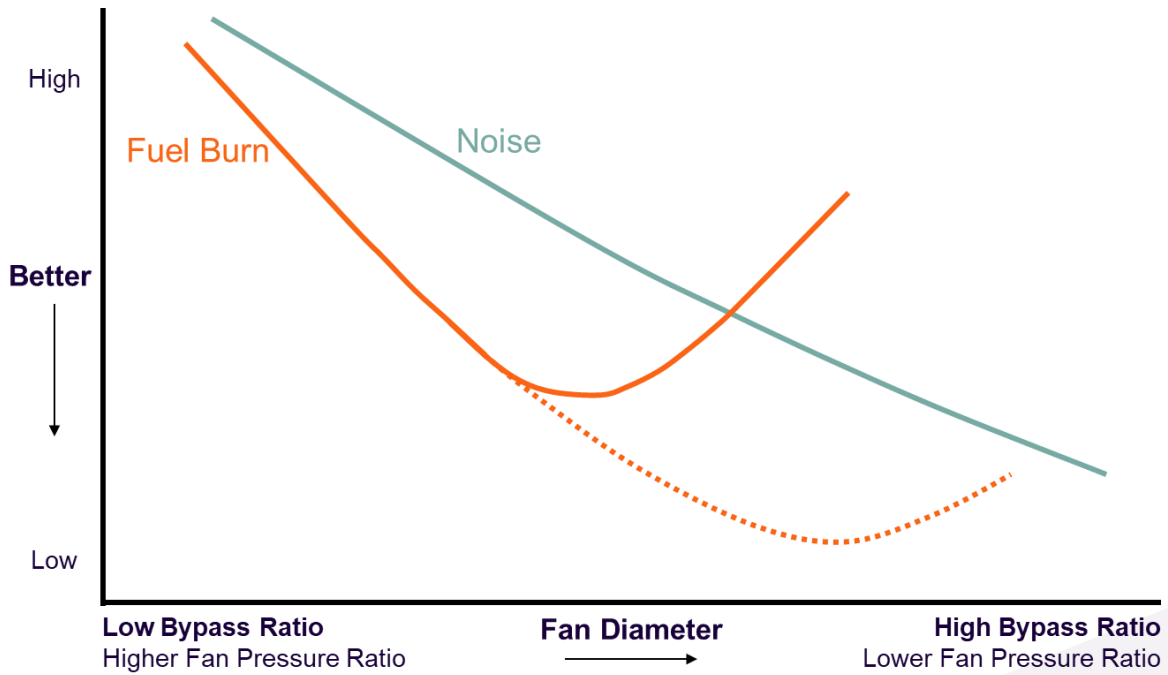
Efficiency of the core to convert fuel into work

Efficiency of the fan to produce thrust



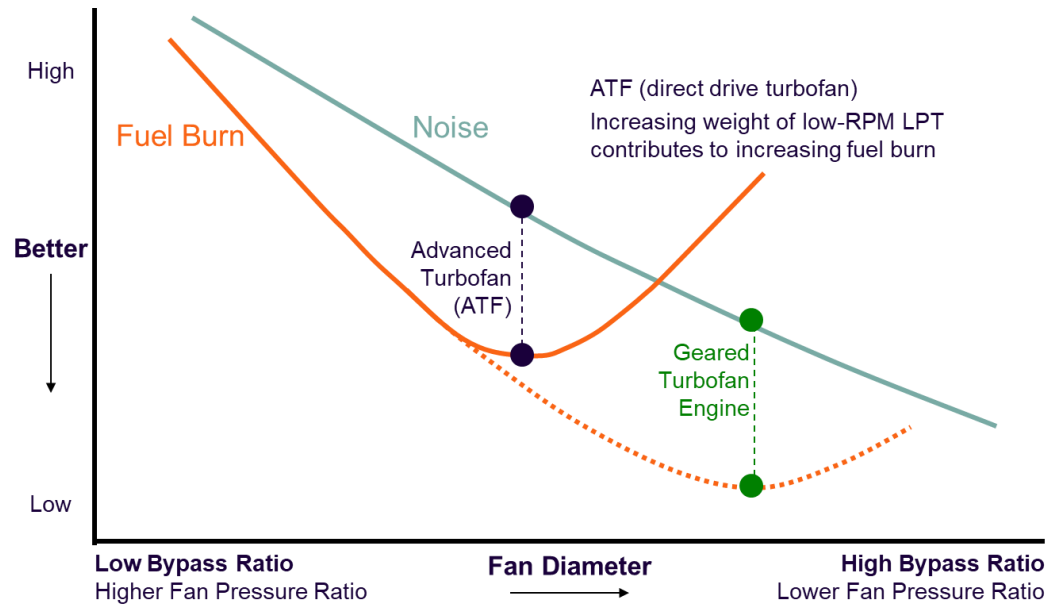
# ...but with some limits

⇒ Increasing bypass ratio is key but it brings about new constraints: Fan pressure, weight

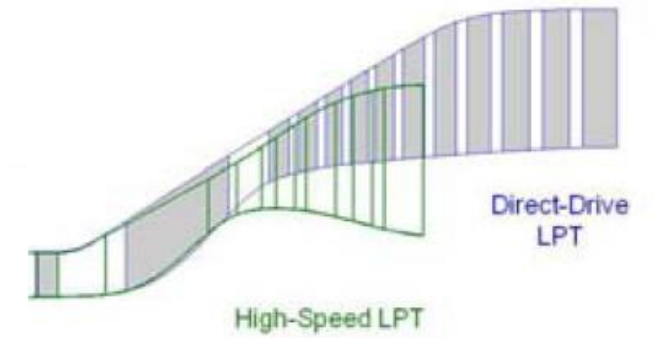
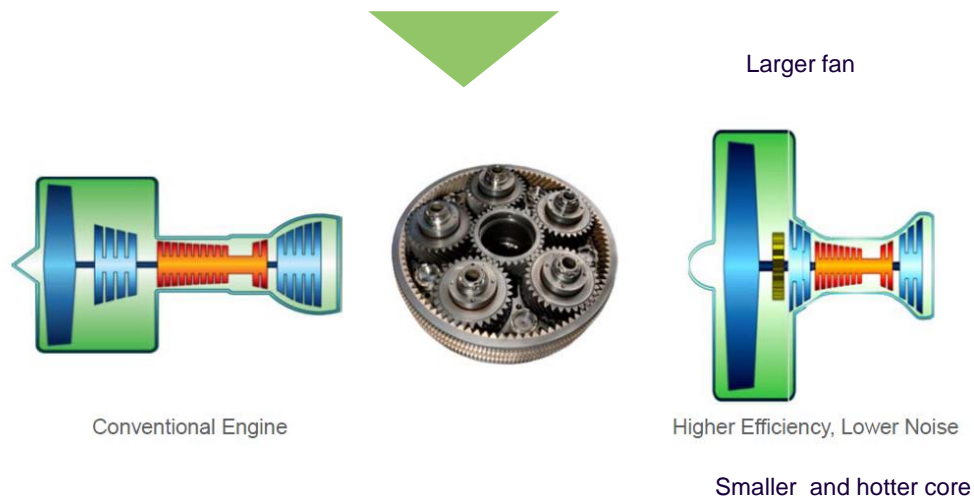
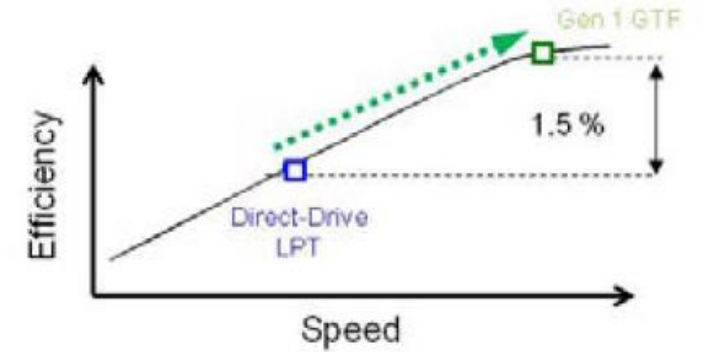


# 1st solution : Integration of a reduced gearbox

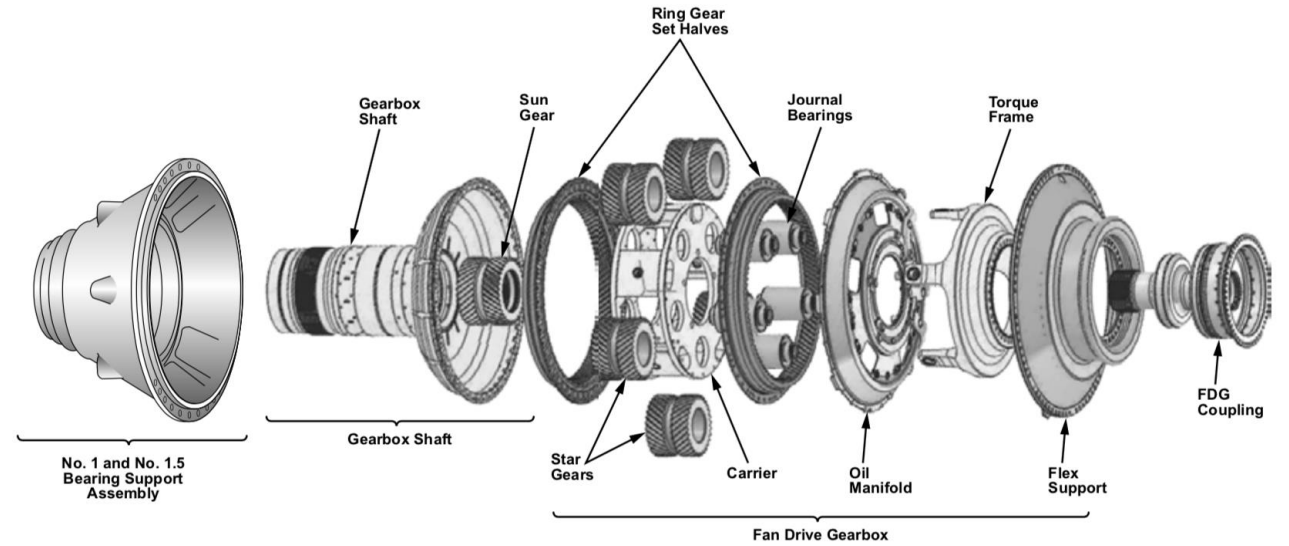
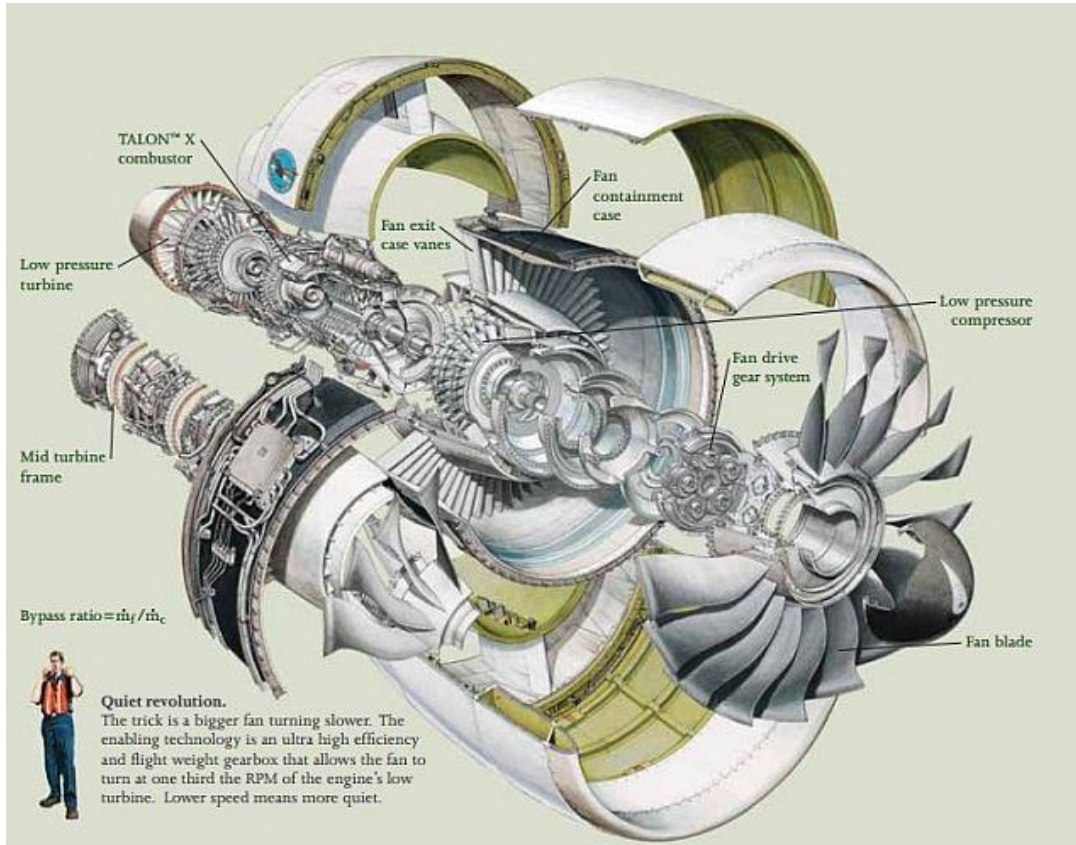
Incremental



## LPT Impact : smaller, less stages

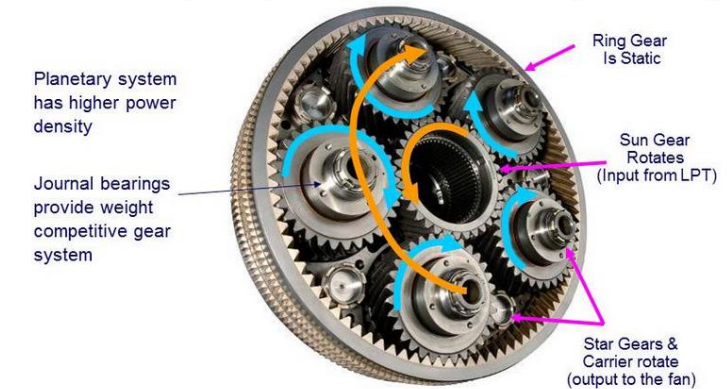


# Fan drive gear system (gearbox)



## Planetary Fan Drive Gear System (FDGS)

Enables higher gear ratios; more compact design

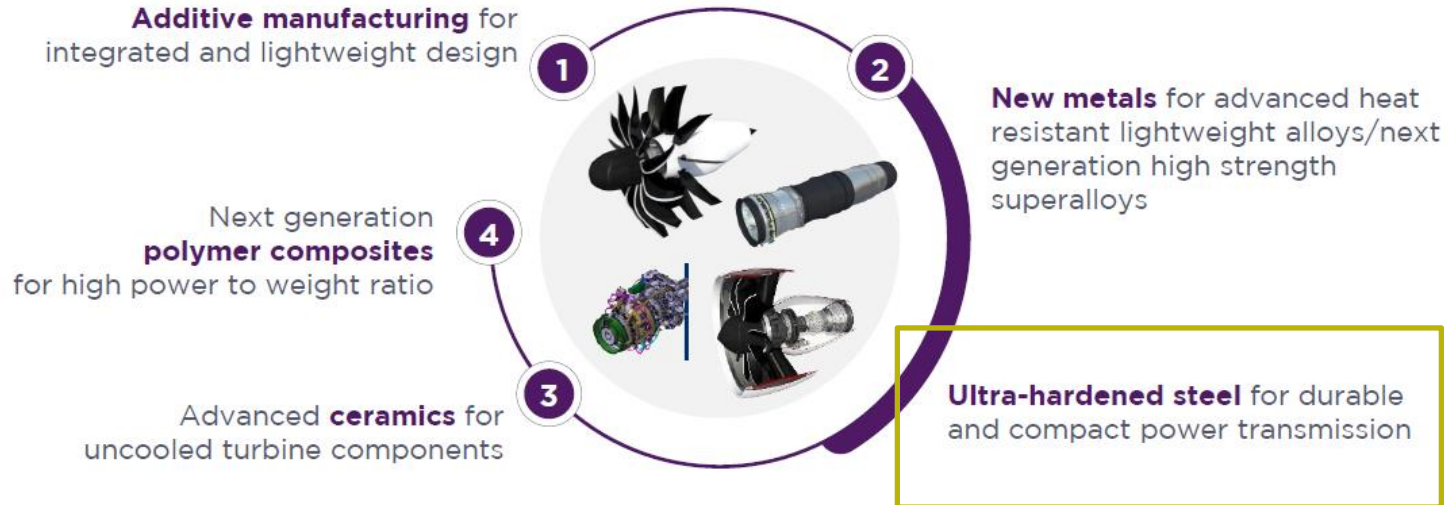


Higher gear ratios Improve Propulsive  $\eta$

# Fan drive gear system (gearbox) : gearbox manufacturers

MATERIALS AND PROCESSES

## Materials and processes



- Race for high modulus steel for reliable and compact reduction gearboxes
  - Nitrited steels for higher fatigue strength
  - Optimised dimensioning thanks to digital

**Ultra-hardened steel** for durable and compact power transmission

**+ INVESTMENT IN MATERIALS AND ORGANISATION FOR DIFFERENTIATING TECHNOLOGIES**



Heat treatment furnace



# Fan drive gear system (gearbox) : bearing manufacturers



Project Information

**BrEATHE**  
Grant agreement ID: 820843


**Start date** 1 January 2019 **End date** 30 April 2022

**Funded under**  
H2020-EU.3.4.  
H2020-EU.3.4.5.5.

**Overall budget**  
€ 998 918

**EU contribution**  
€ 998 918

**Coordinated by**  
SKF AEROSPACE FRANCE  
France



Project Information

**PROBATE**  
Grant agreement ID: 738029


**Start date** 1 January 2017 **End date** 31 December 2022

**Funded under**  
H2020-EU.3.4.  
H2020-EU.3.4.5.5.

**Overall budget**  
€ 771 615

**EU contribution**  
€ 498 246

**Coordinated by**  
SKF AEROSPACE FRANCE  
France



Project Information

**HILOGEAR**  
Grant agreement ID: 755602


**Start date** 1 May 2017 **End date** 30 June 2022

**Funded under**  
H2020-EU.3.4.5.5.

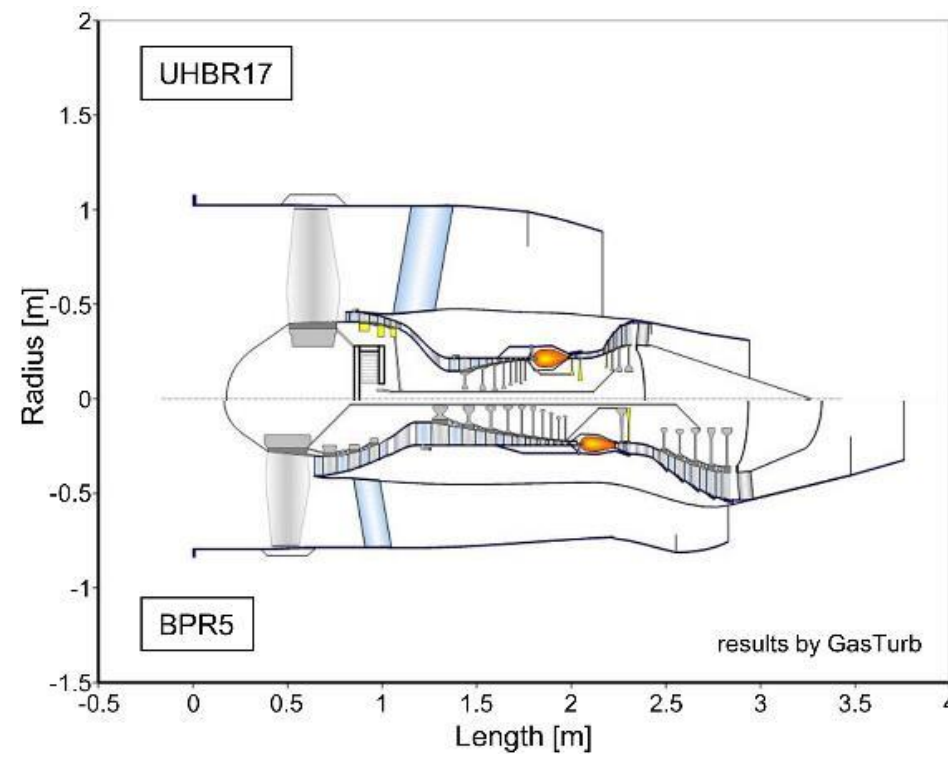
**Overall budget**  
€ 683 565

**EU contribution**  
€ 450 000

**Coordinated by**  
AM TESTING SRL  
Italy



# 1st solution : Fan optimization with UHBR – Ultra High By-pass Ratio



Parameter	Unit	BPR5	UHBR17
Max. engine diameter	[m]	1.748	2.258
Max. engine length	[m]	2.829	2.165
Max. nacelle length	[m]	3.759	3.269
Mass breakdown			
Inlet	[kg]	356.1	702.7
LPC (FAN)	[kg]	46.9	80.9
Booster	[kg]	162.6	105.1
HPC	[kg]	172.3	52.1
Brunner	[kg]	48.3	45.4
HPT	[kg]	44	21.2
LPT	[kg]	248.8	61.9
Ducts	[kg]	42.9	64.9
Exhaust	[kg]	100.6	20.7
Bypass	[kg]	274.4	143.1
Core nozzle	[kg]	26.5	59.2
Shafts	[kg]	30.3	29.6
Gear box	[kg]	-	197
Accessories <sup>a</sup>	[kg]	455	433
Total mass	[kg]	2,009	2,017

<sup>a</sup> 30% of net engine mass

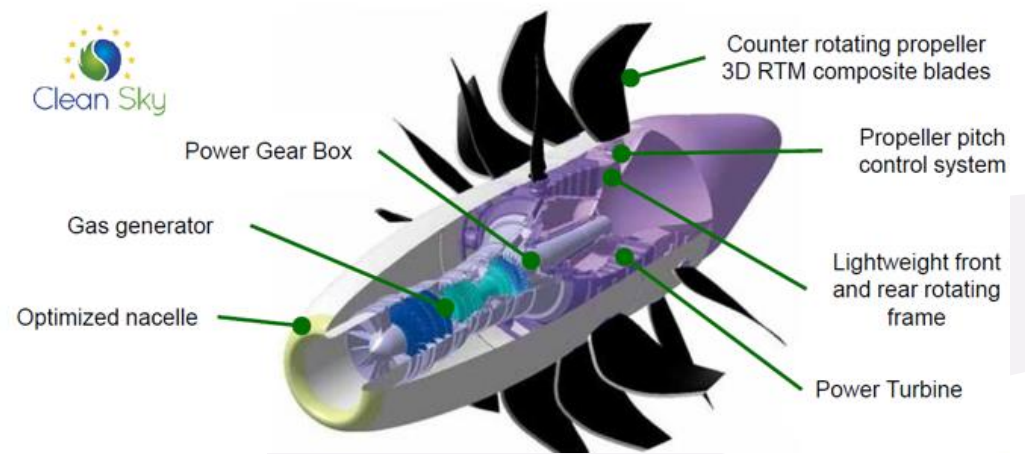
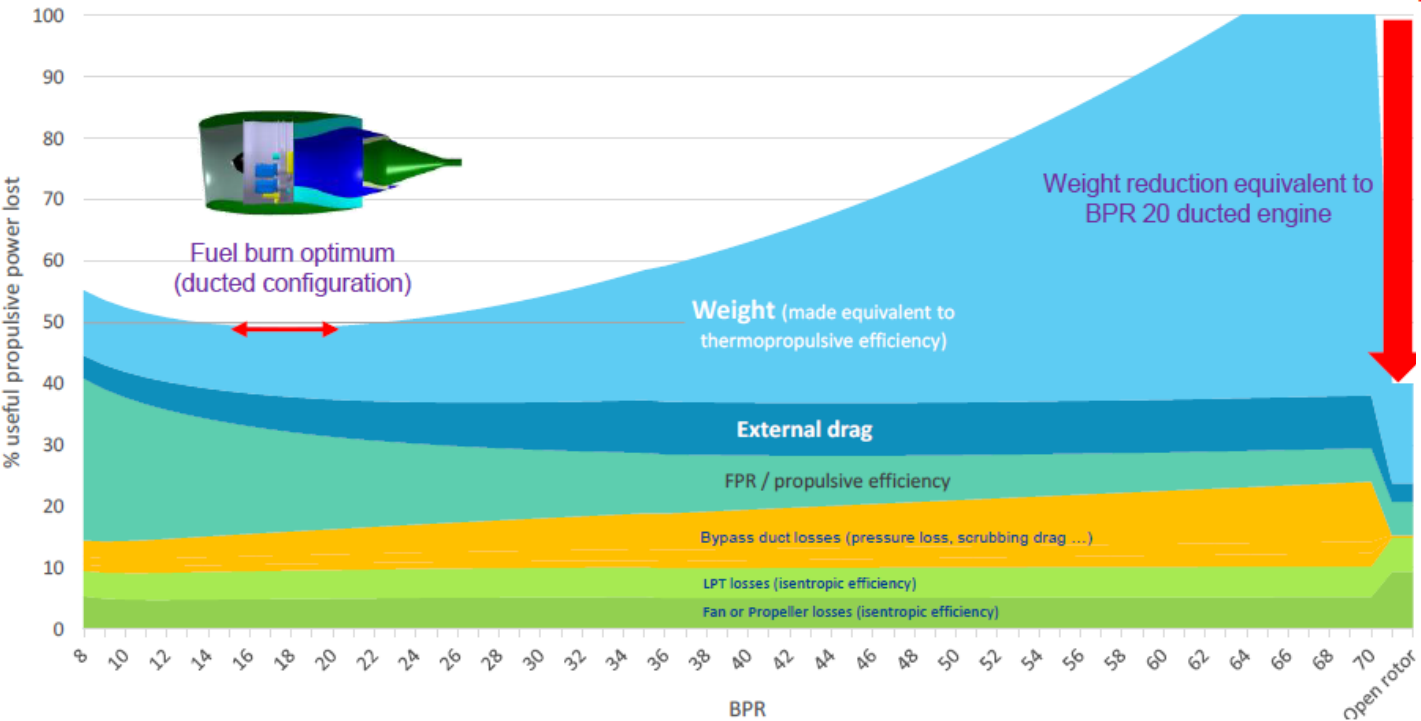
Vision 5 Advance	Vision 10 UltraFan
Redistributes workload between the IP and HP compressors and turbines	An enhanced IP turbine drives the fan via a power gearbox, allowing deletion of the LP turbine

# 2nd solution to stretch the limits : Open-Rotor Disruptive

Let's go further...

Contributors to losses (excluding core)

Remove casings and  
Switch from ducted turbofan  
to unducted open rotor

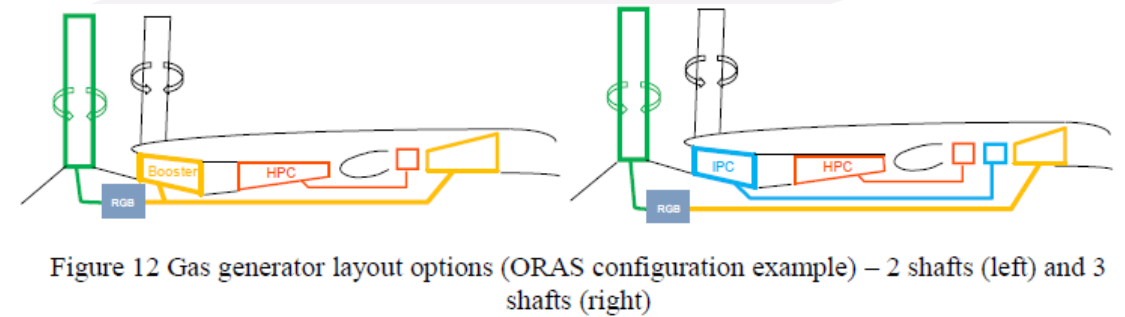
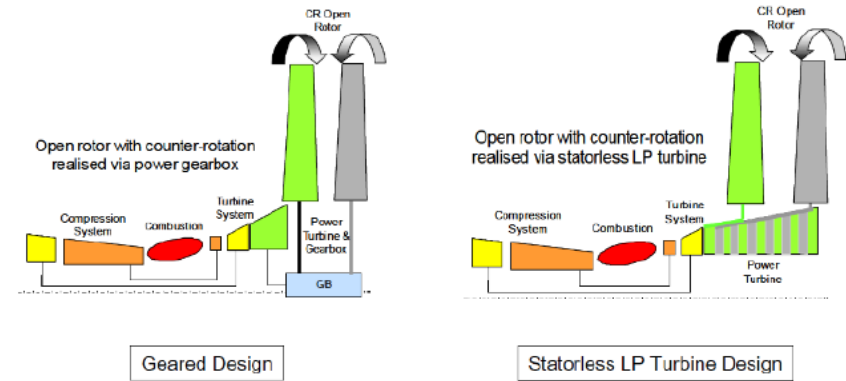
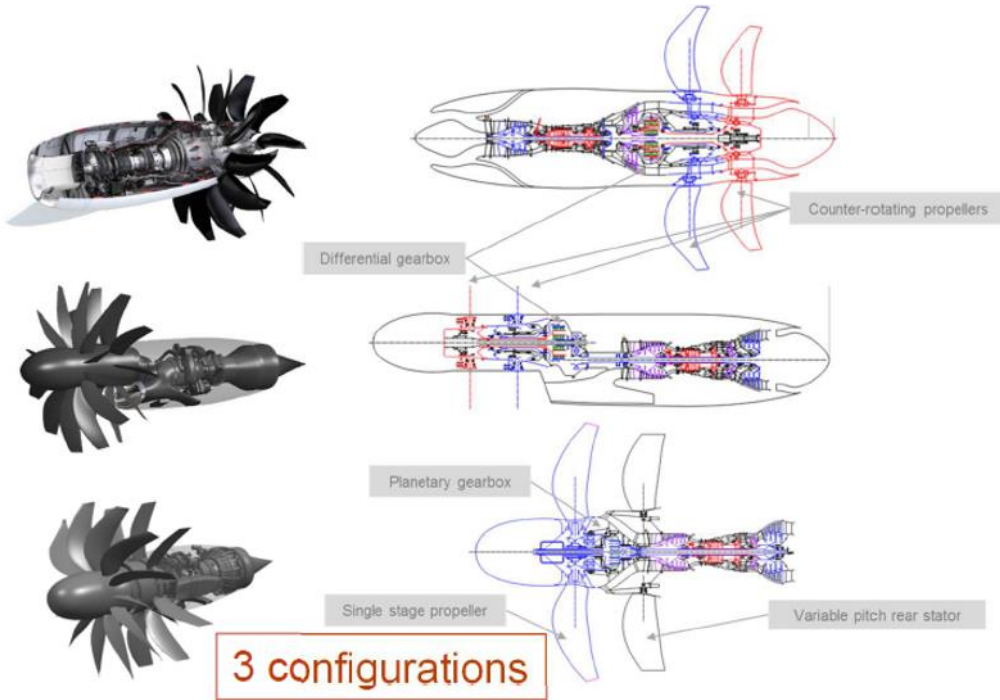


Lower nacelle drag  
No by pass duct loss  
Propeller with lower efficiency than ducted fan

# 2nd solution to stretch the limits : Open-Rotor Disruptive



Counter rotating propellers (CROR, UDF)	Pusher config.
Recovery vane (ORAS, USF)	Puller config.



# CFM announcement (14/06/2021)

**CFM RISE PROGRAM**  
REVOLUTIONARY INNOVATION FOR SUSTAINABLE ENGINES  
TARGETING MORE THAN **20%** LOWER CO<sub>2</sub> EMISSIONS

**Advancing open fan architectures**

**Advanced materials**

**100% SAF, hydrogen capability**

**Step change in propulsive efficiency**

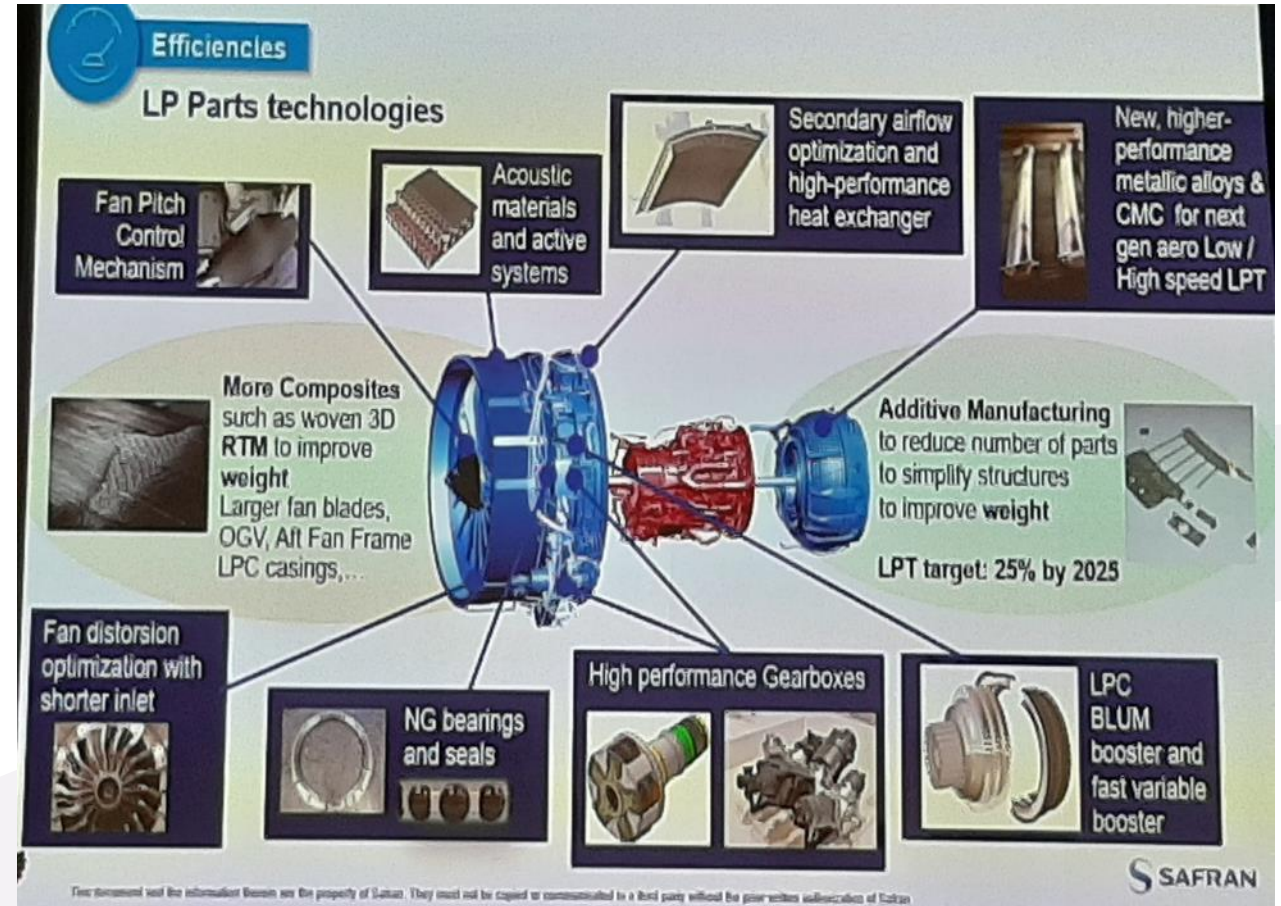
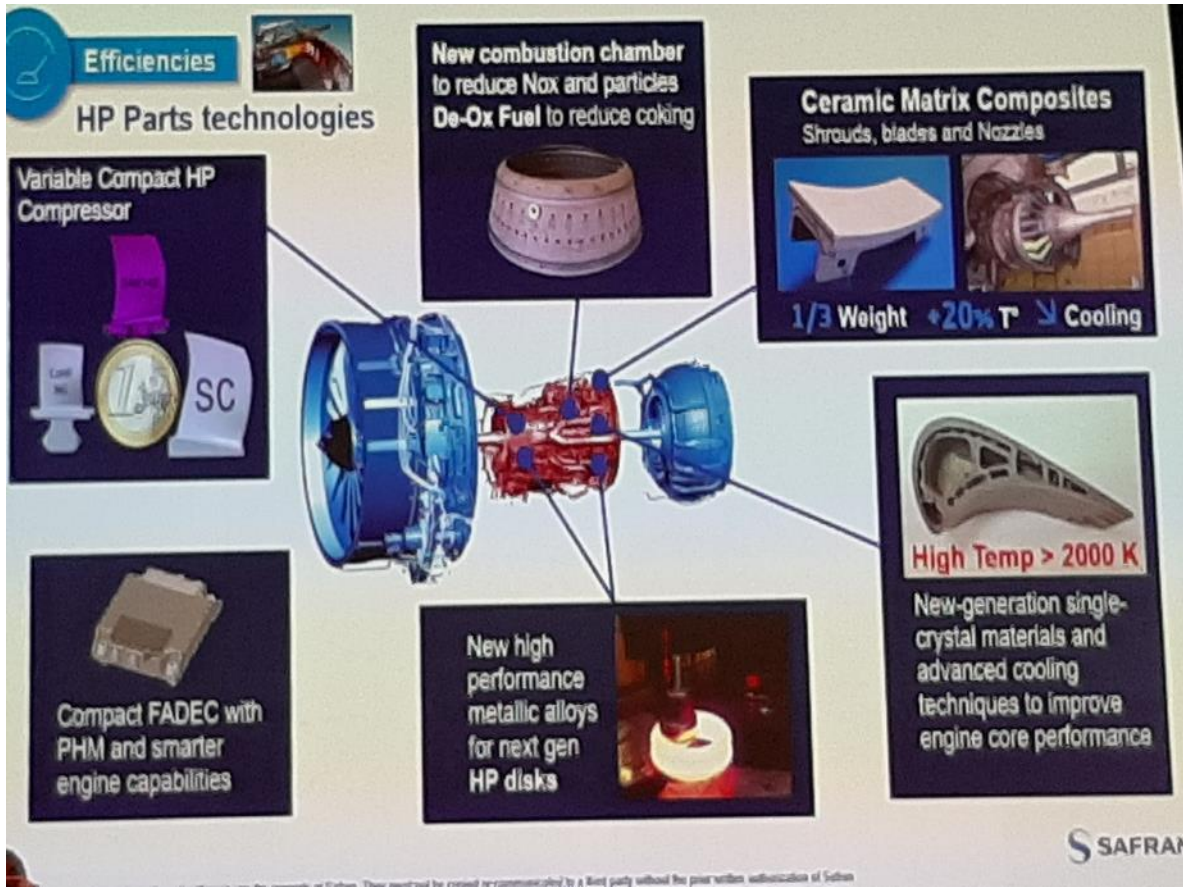
**Hybrid-electric**

**Build on proven technologies**

Technology Maturation | Ground & flight tests | EIS by the mid-2030s

# 3rd solution : New engine core concepts

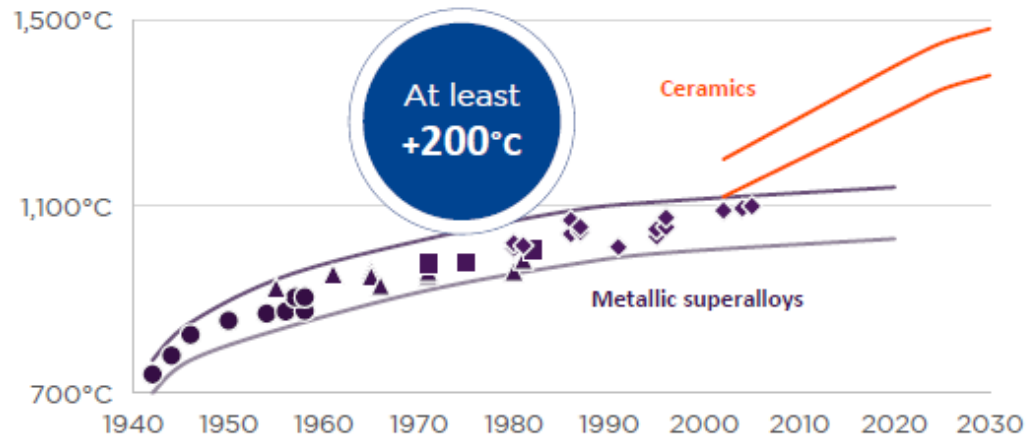
Incremental



## 3rd solution : New engine core concepts

**HOTTER & LIGHTER: MAJOR LEVER FOR ENGINE DECARBONIZATION**

**Maximum temperature of turbine materials**



**3x lighter than comparable metallic components**

- **New nickel-based superalloys to improve thermo-mechanical performance**
  - Mastering metallurgy of turbine disks
  - Development of materials for turbine and compressor blades



Forging high pressure turbine disk



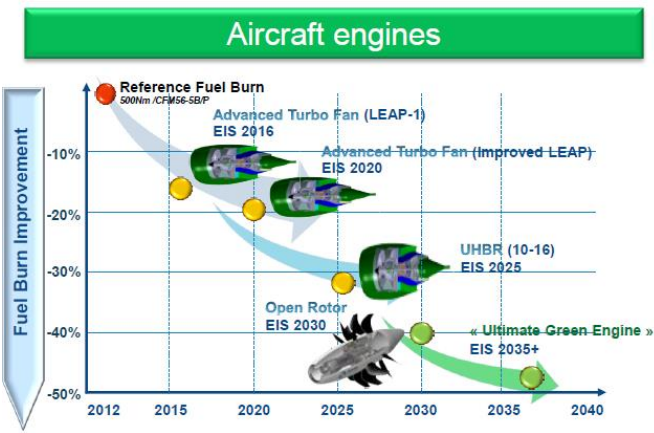
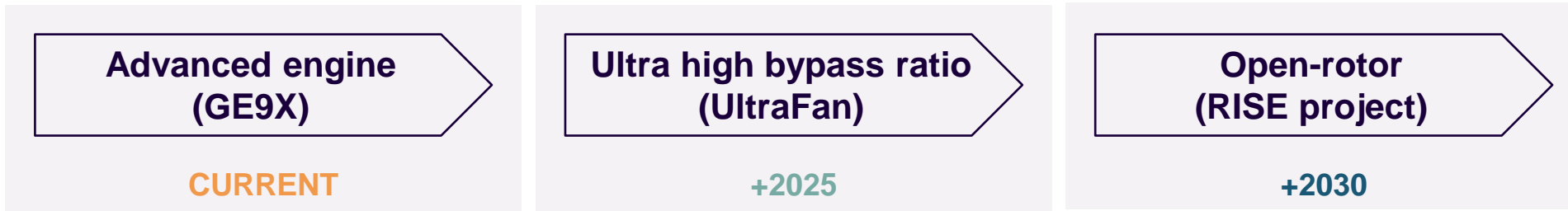
High pressure turbine disk



High pressure turbine blade coated with low conductivity thermal barrier coating

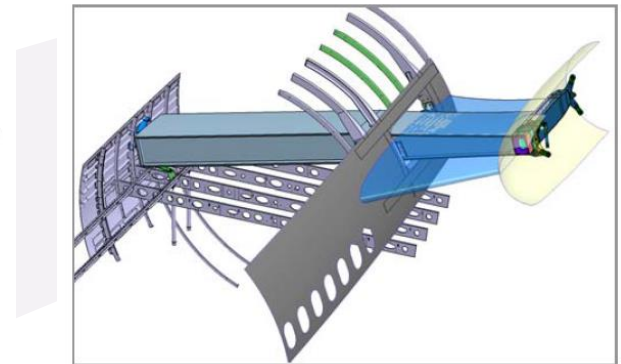
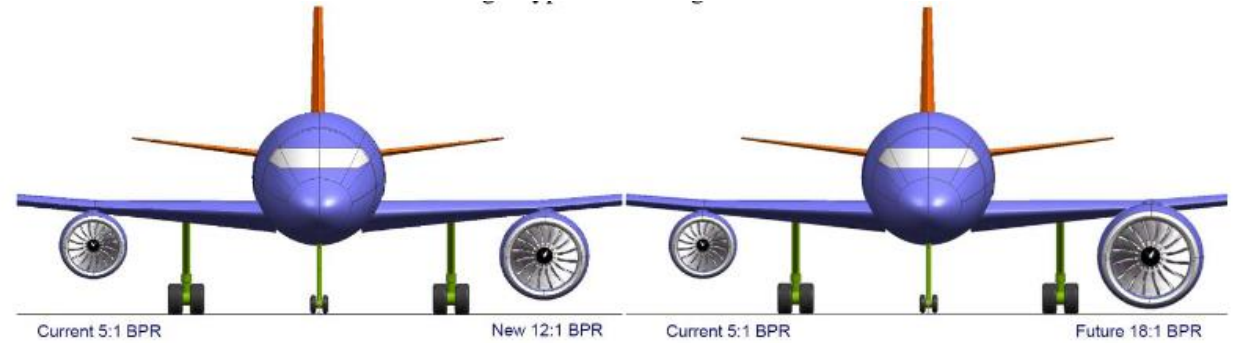
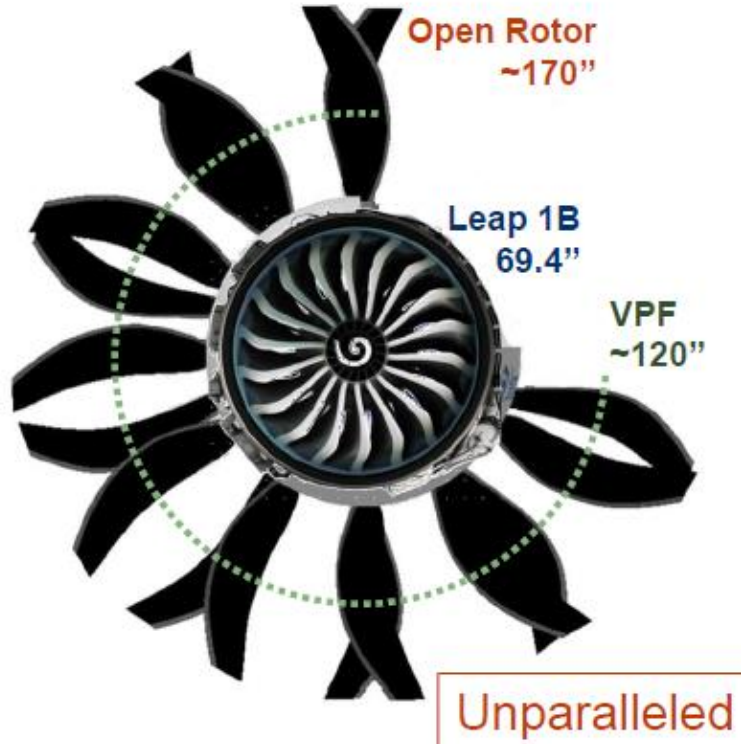
# Improving propulsion efficiency and integration

Same roadmap for all engine manufacturers

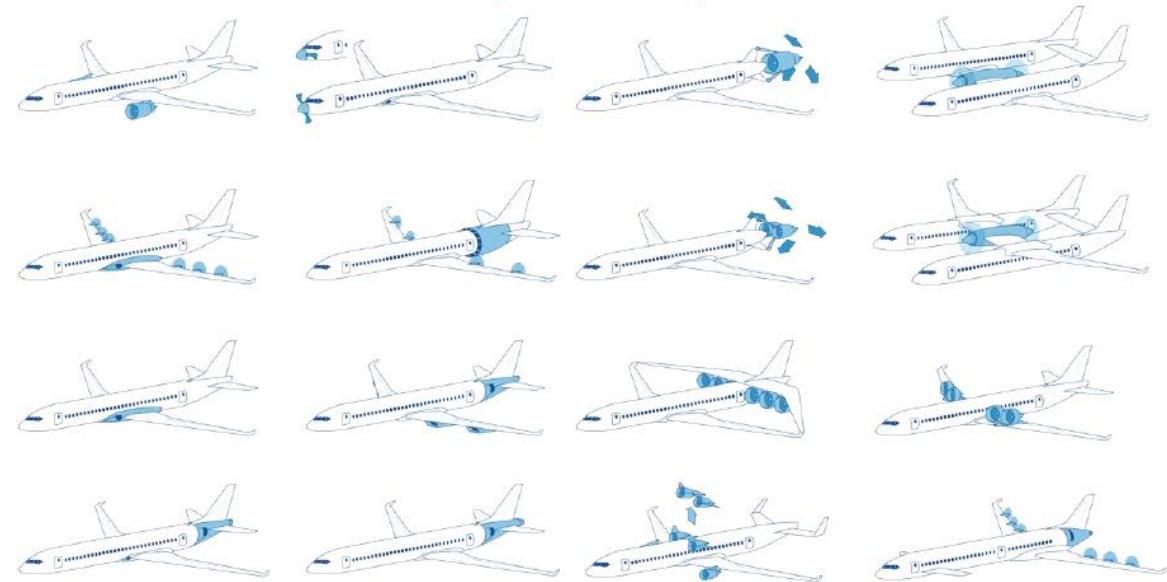
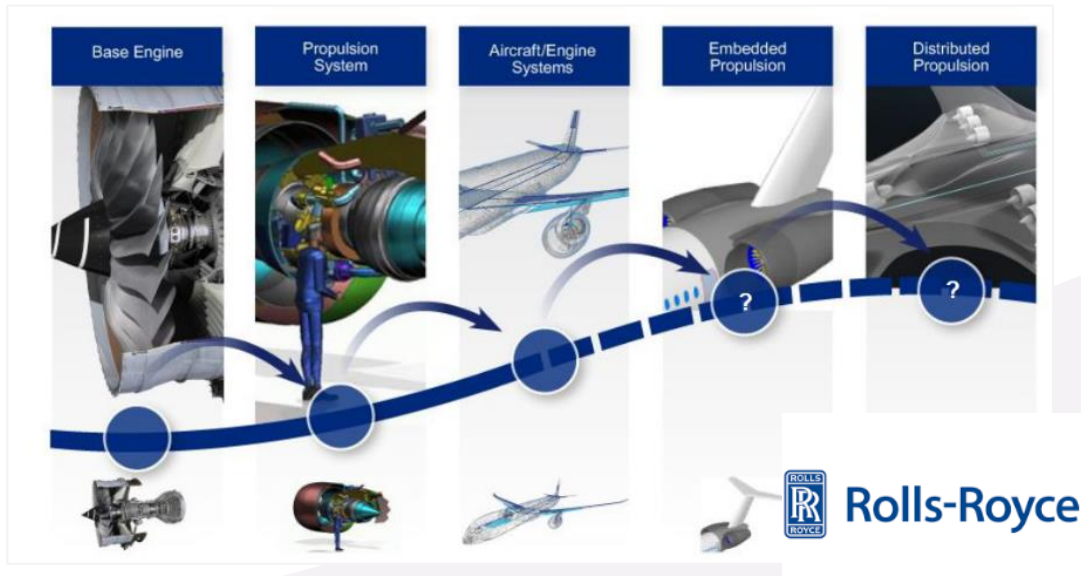
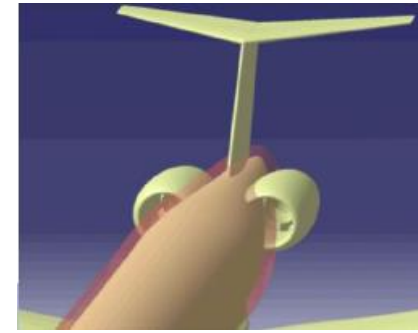
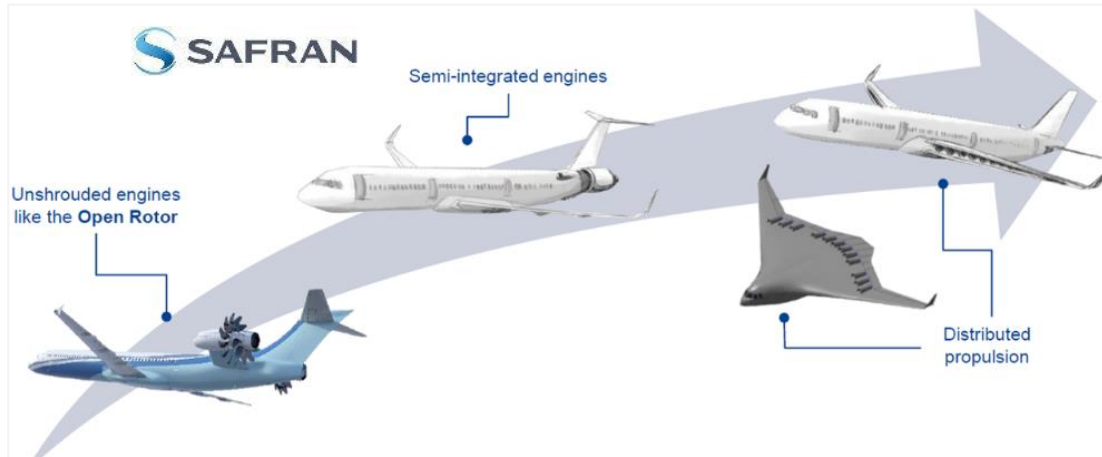


	LEAP 2016	GE9X 2019	2025+
<b>Advanced Materials</b>	• CMC Shroud	• Gen1 CMC HPT • CMC Combustor • High Temp Disk	Gen2 CMC HPT
<b>FAN &amp; LPT</b>	• Composite Fan • 18 blades • Improved Aero	• Composite OGV • 16 blades • Improved Aero	Low Drag Installation Light weight adv. Components
<b>Core</b>	• NG HPT Blade • Additive mfg fuel nozzle • Adv cooling	• 27:1 Compressor • TAPS III Combustor • Adv. Seals	<b>Beyond 2025+</b> Unducted Fan
<b>Controls</b>	• Adv. FADEC • Lightweight externals	• Distributed Controls • Adv. Fuel Pump	

# Next-gen engines integration: larger fan



# New configurations...





1

POWERPLANT EFFICIENCY & INTEGRATION

2

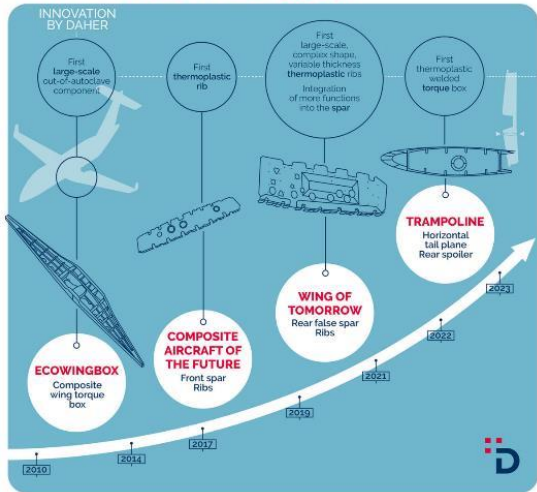
WEIGHT REDUCTION

3

AERODYNAMICS

# Maximizing weight reduction : more composite/thermoplastic parts

## WING-RELATED R&D



## TAPAS PROJECT (NLR / GKN Fokker / Airbus)



**Customer:** Netherlands Enterprise Agency - RVO  
**R&D:** Royal NLR  
**Partners:** GKN Fokker Aerostructures, TenCate, Airbus

Upper Spar



## SPIRIT AEROSYSTEMS PATENT

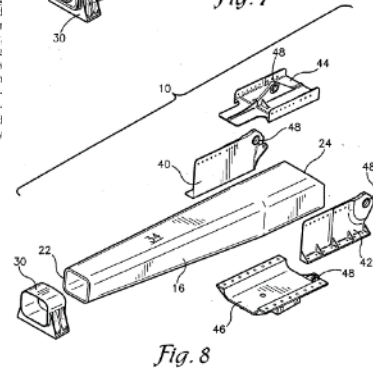
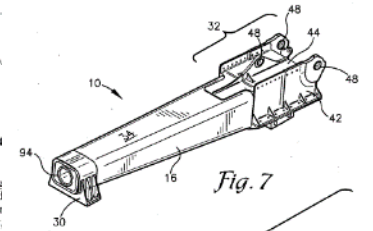
**United States**  
 (12) **Patent Application Publication** (10) **Pub. No.:** US 2009/0212155 A1  
 Huggins et al. (43) **Pub. Date:** Aug. 27, 2009

**Related U.S. Application Data**  
 (60) Provisional application No. 61/031,883, filed on Feb 27, 2008.

**Publication Classification**  
 (51) **Int. Cl.** B64D 27/26 (2006.01)  
 (52) **U.S. Cl.** 244/54  
 (57) **ABSTRACT**  
 A load-bearing structure, such as a pylon or strut, comprising a monolithic tubular-shaped first central structure composed of composite material and a plurality of metal fittings for supporting an engine on an airframe structure of an aircraft, such as a wing. Most of the fittings are integrated into the load-bearing structure through bonding. The metal fittings carry the high bearing loads that are transmitted into the pylon at the engine-eyon and wing-eyon interfaces. The load-bearing structure may also comprise a second central structure of a tubular shape composed of composite material and integrated with one end portion of the first central structure by bonding and/or mechanical fastening means.

**Correspondence Address:**  
 HOVEY WILLIAMS LLP  
 10801 Mastin Blvd., Suite 1000  
 Overland Park, KS 66210 (US)

(73) **Assignee:** SPIRIT AEROSYSTEMS, INC., Wichita, KS (US)  
 (21) **Appl. No.:** 12/185,551  
 (22) **Filed:** Aug. 4, 2008



+ working on the composite recycling and cost manufacturing

# Maximizing weight reduction: buy-to-fly optimization

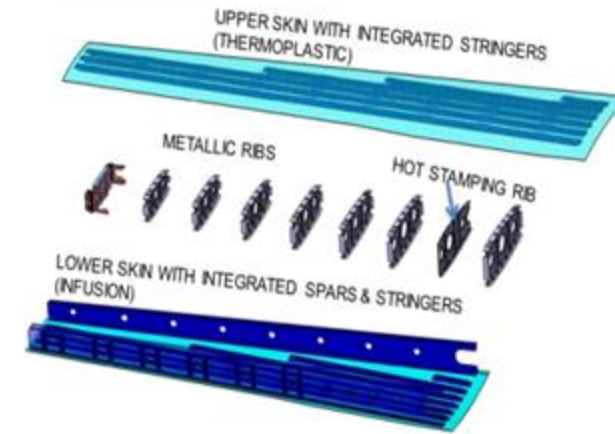
## Additive manufacturing



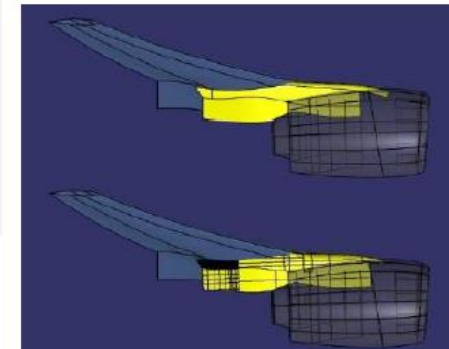
Flap track

	Build Option 1	Build Option 2	Build Option 3	Build Option 4	Build Option 5
Buy to Fly Ratio	1.2	1.3	1.2	2.0	1.1
WAAM Substrate Mass (kg)	5.0	6.5	5.0	20.7	1.1
Deposited Material Mass (kg)	15.1	14.7	15.0	11.8	16.0
Waste Material from Substrate (kg)	4.0	5.0	3.8	16.4	1.0
Number of Build Operations	5	3	4	2	4
No. of Double Sided Operations	1	1	1	1	2
Total Build Operations	6	4	5	3	6
Mass Above Substrate (kg)	15.9	4.1	11.2	8.1	11.9
Mass Below Substrate (kg)	0.1	9.4	5.0	8.1	4.3

## Compression molding



## Shape optimization



→ Pylon & nacelle geometry and wing shape optimization

subassembly into a single piece



Le premier caisson central de voilure monobloc en composite sera expédié à Broughton (Royaume-Uni) en août 2021.

+ alternative process (extrusion, flowforming,...)



1

POWERPLANT EFFICIENCY & INTEGRATION

2

WEIGHT REDUCTION

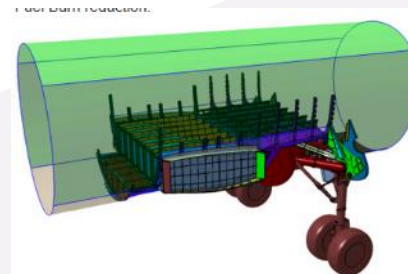
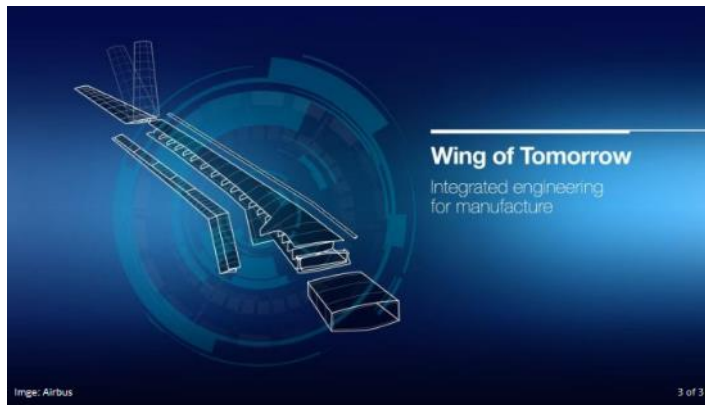
3

AERODYNAMICS

# Improving aerodynamics : Wing of tomorrow

## New wing design...

- › Hybrid laminar flow
- › Winglets, raked wingtips, riblets
- › Variable camber (morphing)
  - › New flap/slat configuration (tracks?)
- › Wing length and weight
  - › Transfer main landing gear below the fuselage

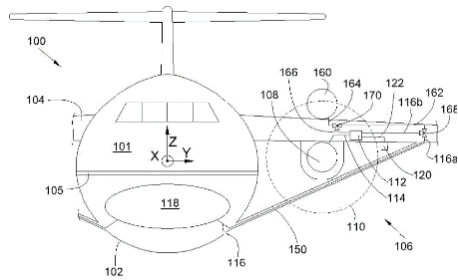


## ...Lot of other configurations



# Beyond 2050 : Disruptive architecture

## Strut-braced Wing



**AIRBUS**

## Blended Wing Body



Comparison between 787 and a BWB

### Strut-braced Wing

	Benefits	Challenges
<b>Environment</b>	Fuel burn	
<b>Ground operations</b>		Folding wing
<b>Flight performance</b>	High wings -> space for large engines (UHBR, open rotor)	

### Blended Wing Body

	Benefits	Challenges
<b>Environment</b>	Lower fuel burn Less noise (engine shielding)	
<b>Ground operations &amp; infrastructure</b>	Easier boarding & disembarking – shorter turnaround time, more comfortable	Ground service infrastructure may need adaptation*
<b>Passenger / Cargo</b>	Large available cargo volume	Passenger acceptance for very large cabin*
<b>Industrial</b>	With the small BWB design, the concept is now scalable	Unconventional design processes needed, with high uncertainties Family concepts more complex to implement* High investments
<b>Certification</b>		Emergency evacuation*

\* Challenge applies essentially or only to large BWBs, not to small ones



**CONSUME BETTER**



1

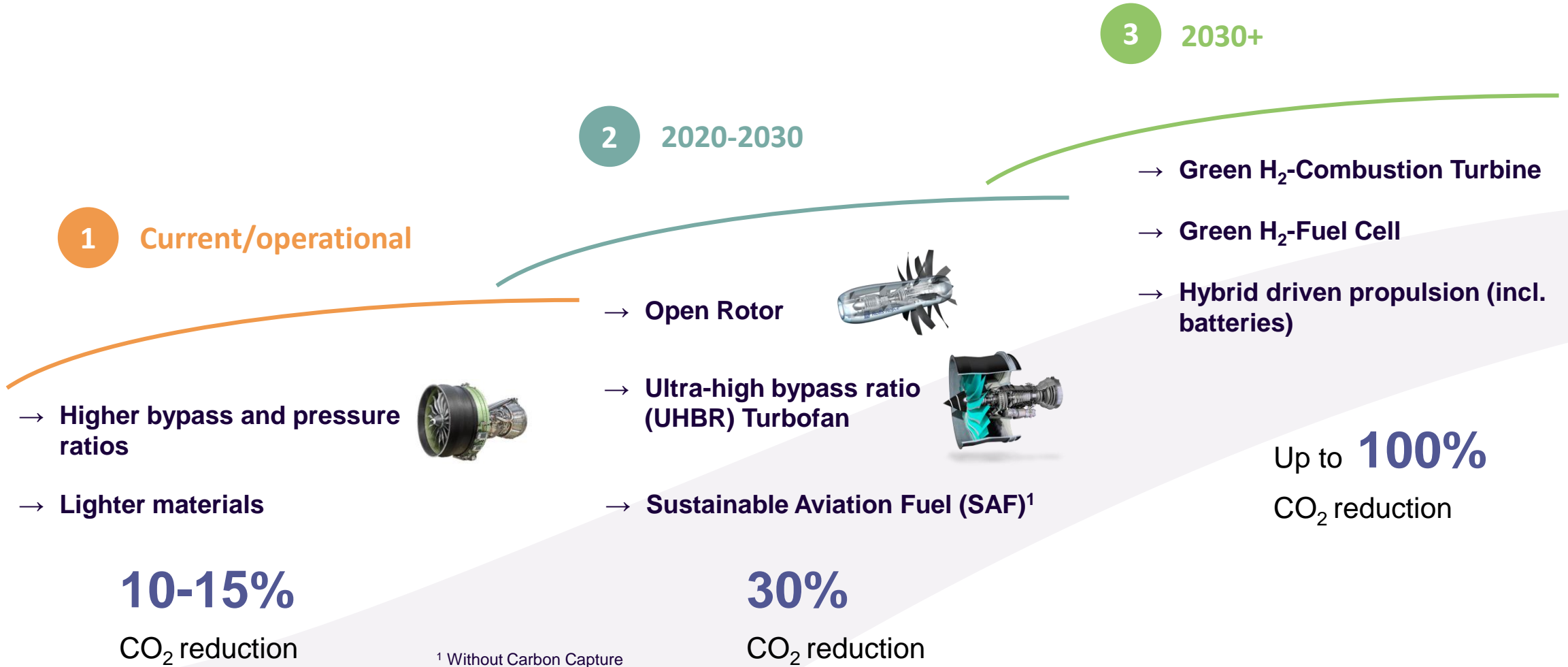
HYDROGEN

2

SUSTAINABLE FUELS & ELECTRIFICATION

# Contribution of new engine technologies to CO<sub>2</sub> reduction

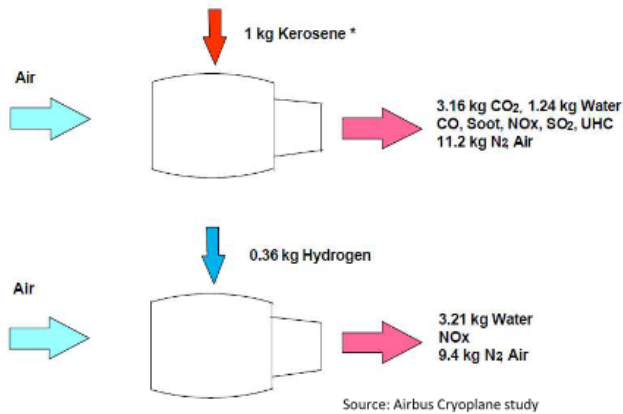
## OPERATIVE TIMEFRAME OF NEXT PROPULSION TECHNOLOGIES



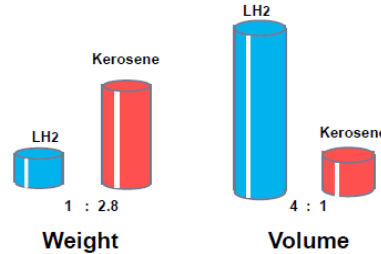
<sup>1</sup> Without Carbon Capture

# Why Hydrogen ?

Emissions (\*Fuel masses of equal energy content)



Comparison of properties  
Liquid Hydrogen vs. Kerosene  
@ same energy content



## Lot of advantages:

- High availability (everywhere in solar system, on Earth, natural hydrogen is bonded to other elements, mainly as water and hydrocarbons.)
- Ability to carry/store energy (highest energy density of all chemical fuels)
- CO<sub>2</sub> neutral (during chemical reactions)
- Circular economy in Power-to-Gas : H<sub>2</sub> produced from water by electrolysis, is chemically combined with CO<sub>2</sub> in biogas to produce methane (4H<sub>2</sub> + CO<sub>2</sub> = CH<sub>4</sub> + 2H<sub>2</sub>), and water (H<sub>2</sub>O)

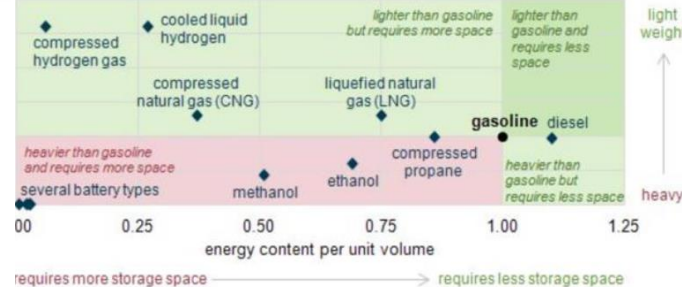


## But some challenges:

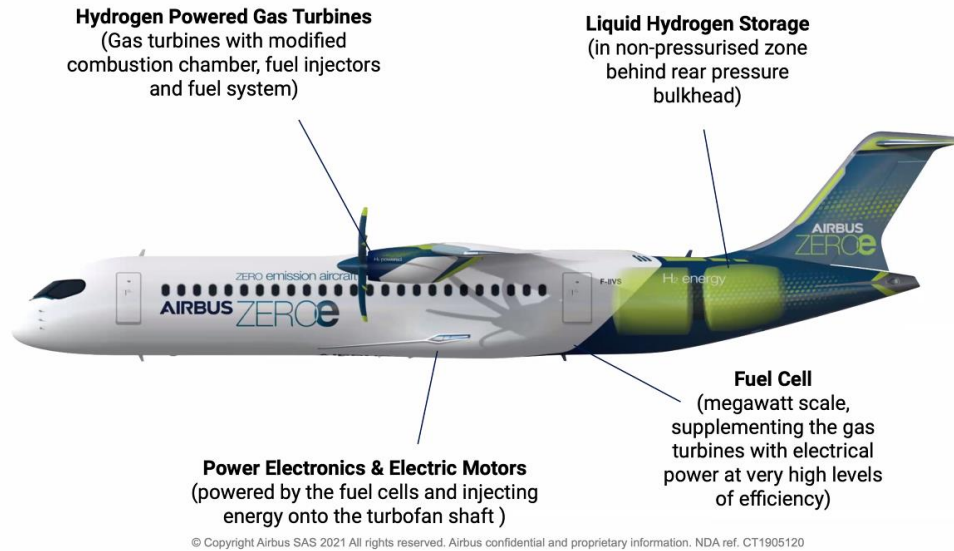
- Volume → liquefaction
- Hydrogen loss due to boil-off
- High energy consumption for liquefying hydrogen
- Thermal management system
- Embrittlement

Overview of H<sub>2</sub> states

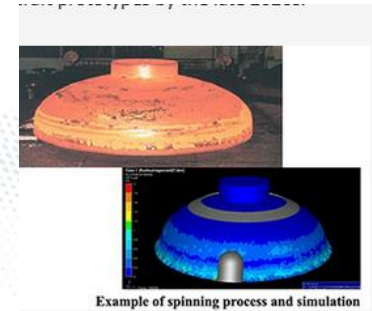
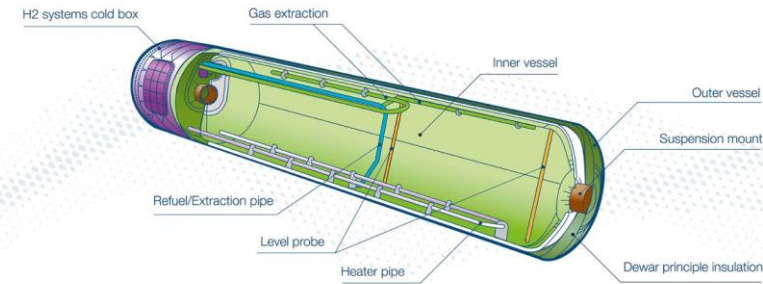
LH<sub>2</sub> Liquid Hydrogen  
CcH<sub>2</sub> Cryo-compressed Hydrogen  
CGH<sub>2</sub> Compressed Gaseous Hydrogen



# 1<sup>st</sup> challenge: LH2 cryogenic storage



## Liquid H<sub>2</sub> tank



AIRBUS

## LH<sub>2</sub> cryogenic storage requires:

- High Insulation to minimize heat transfer into the tank and maintaining the internal temperature
- Fatigue life: Fueling cycles are potential sources of fatigue failure in a LH<sub>2</sub> fuel tank. Embrittlement due to low temperatures increases the yield strength of the material and its endurance limit
- Empty weight: Increase in the airplane OEW due to structural reinforcement, insulation and maintenance facilities required in a LH<sub>2</sub> fuel tank



## Tanks may be fabricated from:

- Aluminum tank wall (liner) + composite layer
- Polymer liner + composite (carbon fiber) layer
- Thermoplastic liner

# 2nd challenge : integration of H2 tanks

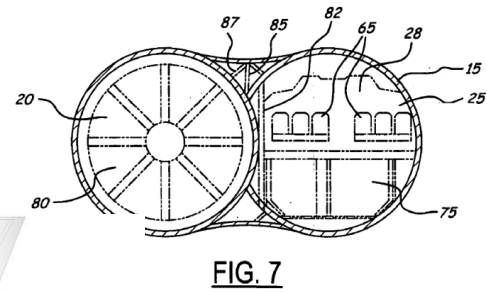
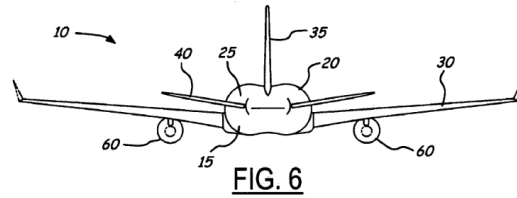
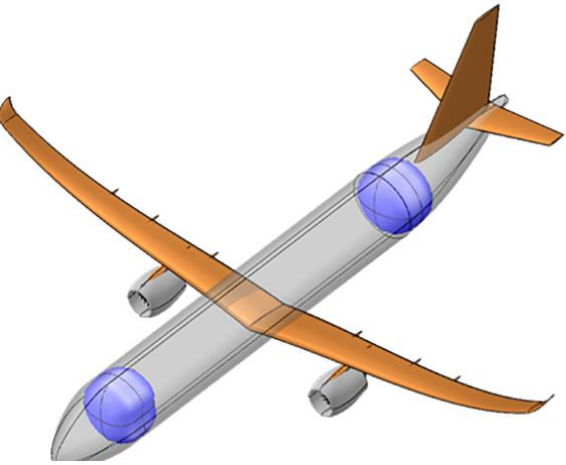


Figure 21 : H<sub>2</sub> tank layout for A330 aircraft.



rates, as well as elevated risk of ice formation on the wings.

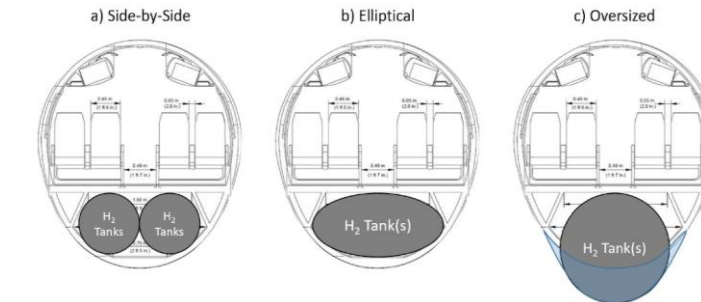


Figure 20: Potential H<sub>2</sub> tank layouts include a) side-by-side, b) elliptical, and c) oversized tanks.

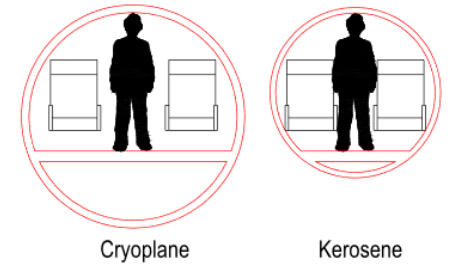


Fig. 3 Change in fuselage diameter for the CRYO business jet

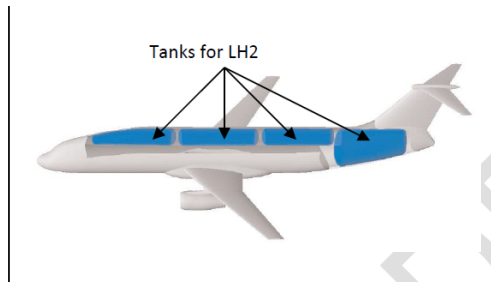


Figure 1.3. LH<sub>2</sub> tanks storage scheme of "Cryoplane" project

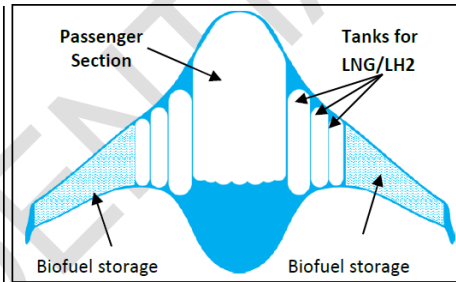


Figure 1.4. A futuristic BWB aircraft layout with cryogenic tanks & biofuels

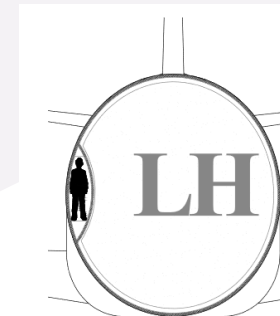


Fig. 2 Cross-section front tank 380 pax aircraft

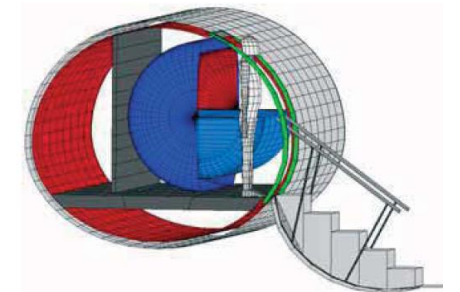


FIG 6. Integration of Forward Hydrogen Tank and Entrance Area

# 3rd challenge: Thermomechanical impacts on turbofan engines

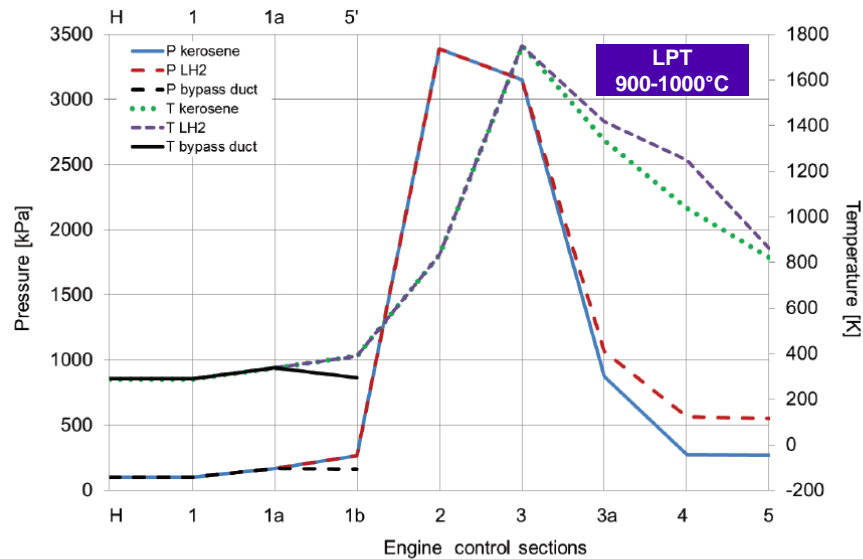
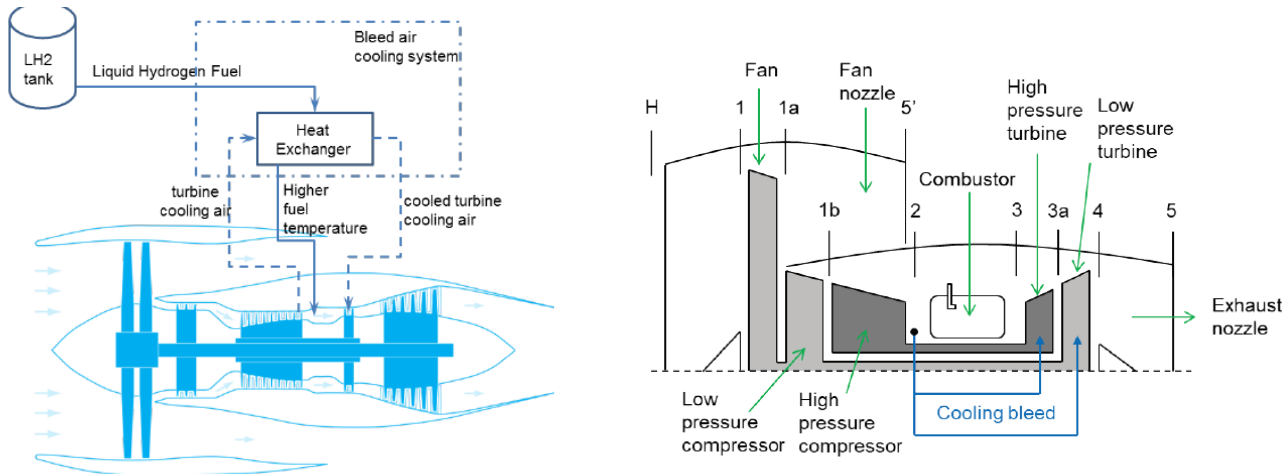


Fig. 3. Pressure and temperature distribution – take off conditions

## Better performance and efficiency...

- Increasing engine thrust during take-off by 14.5%, with simultaneous reduction of specific fuel consumption by 62.7%.
- During take-off, the velocity of exhaust gases is by 53.6% higher for hydrogen-fuelled aircraft, than for aircraft supplied by kerosene, as well for cruise condition, where engine thrust increased by 18.9% for hydrogen fuel

## ... thanks to higher gas temperature and pressure at the outlet of LPT

- High temperature and pressure in LPT but too large speed of exhaust gases may be undesirable from environmental point of view, as it affects the increase of noise emitted by turbine engines.
- Necessity to add heat exchanger to cooling the delivered compressor bleed air

# Airbus ZeroE program

Introducing Airbus **ZEROe**

Turboprop		 <b>&lt;100</b> Passengers	 <b>1,000+nm</b> Range
		 Hydrogen Hybrid Turboprop Engines (x 2)	 Liquid Hydrogen Storage & Distribution System
Blended-Wing Body		 <b>&lt;200</b> Passengers	 <b>2,000+nm</b> Range
Turbofan		 Hydrogen Hybrid Turbofan Engines (x 2)	 Liquid Hydrogen Storage & Distribution System

**AIRBUS**



## Hybrid-hydrogen aircrafts

- Hydrogen direct combustion + fuel cells
- 2021-2024 : pre-study for storage

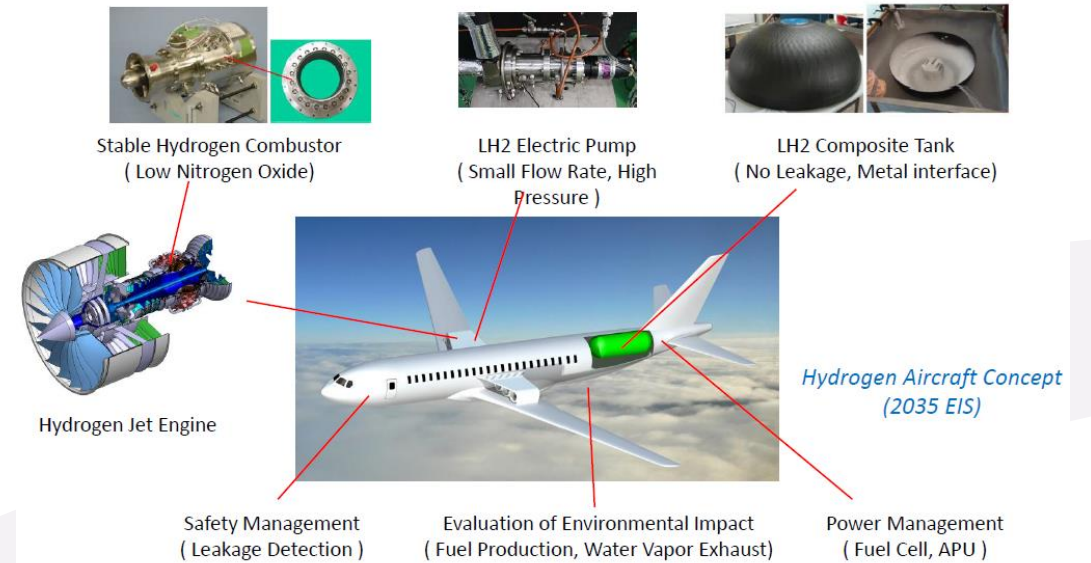
**Entry in service in 2035**

# Other projects are emerging

## FlyZero - Aerospace Technology Institute (ATI) - UK



## JAXA - Japan



# Safran H2 roadmap

## Maturing hydrogen aircraft technologies

### 1. Support Airbus in-flight “EarlyDemo” to acquire knowledge about operation and emissions of a liquid H<sub>2</sub> aircraft

- Adaptation of an existing engine



TO PREPARE FOR LARGER SCALE DEMONSTRATOR

### 2. Mature H<sub>2</sub> technologies for aircraft equipment

- Materials and processes for H<sub>2</sub> burn
- Fuel system technologies (valves, heat exchangers, compressors)
- Injection/combustion



 AIRBUS



### 3. Mature fuel cell technologies @1MWe

- Proton Exchange Membrane stacks already demonstrated
- Next steps: multi-stack operations, increased power density



 arianeGROUP



**H<sub>2</sub> TECHNOLOGY ASSESSMENT** will be ready to support the launch of a new aircraft program



1

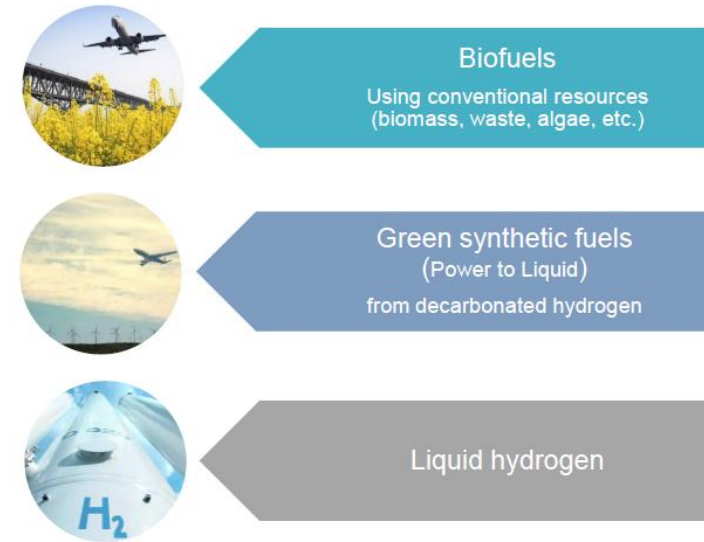
HYDROGEN

2

**SUSTAINABLE FUELS & ELECTRIFICATION**

# Consume better : Sustainable Fuels and Electrification

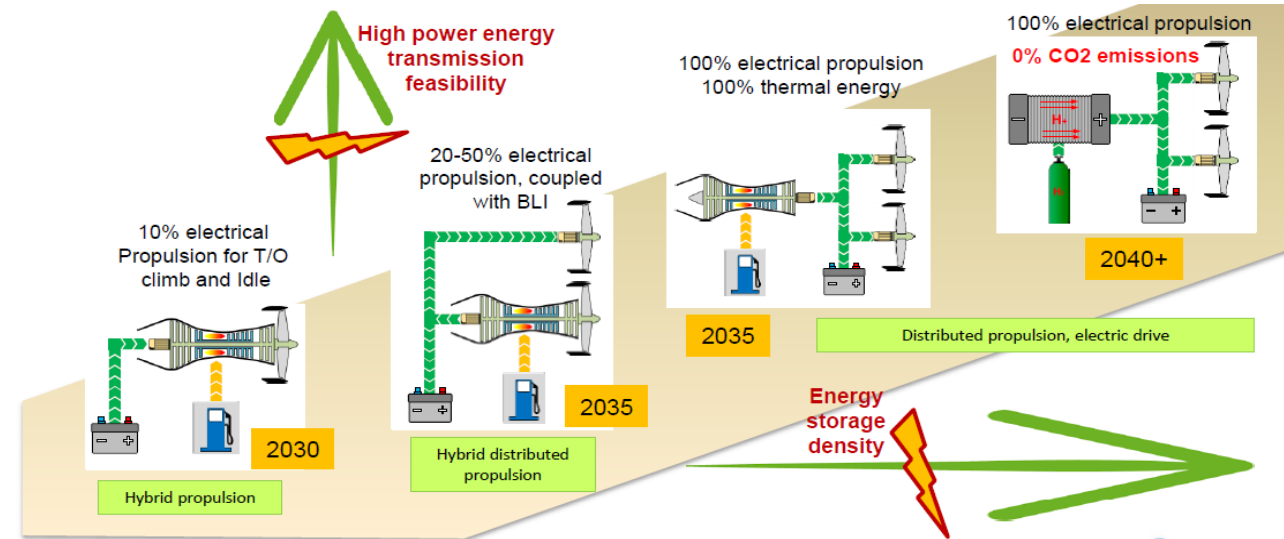
## Sustainable Alternative Fuels



Existing aircraft and infrastructures

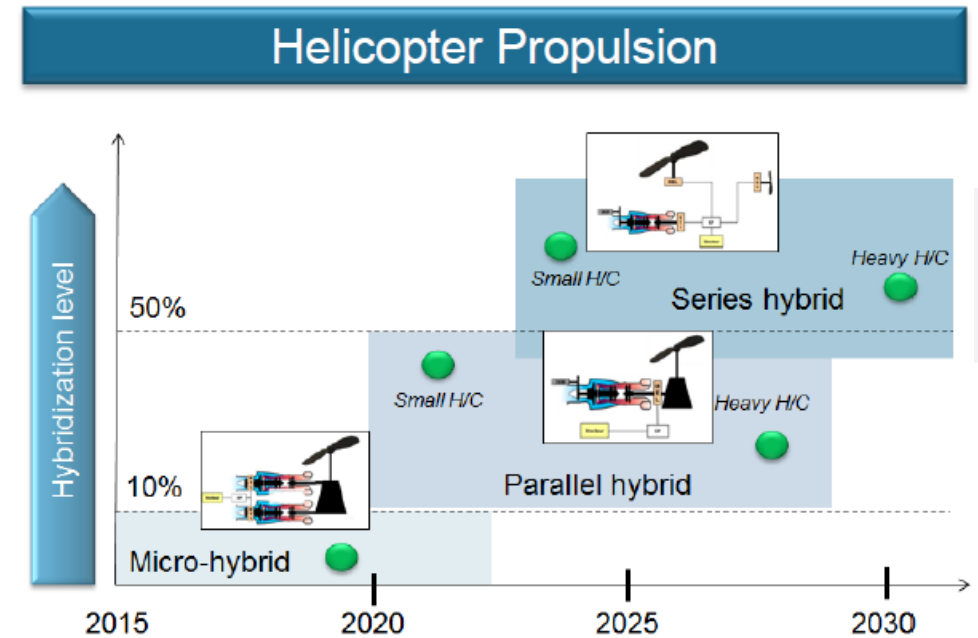
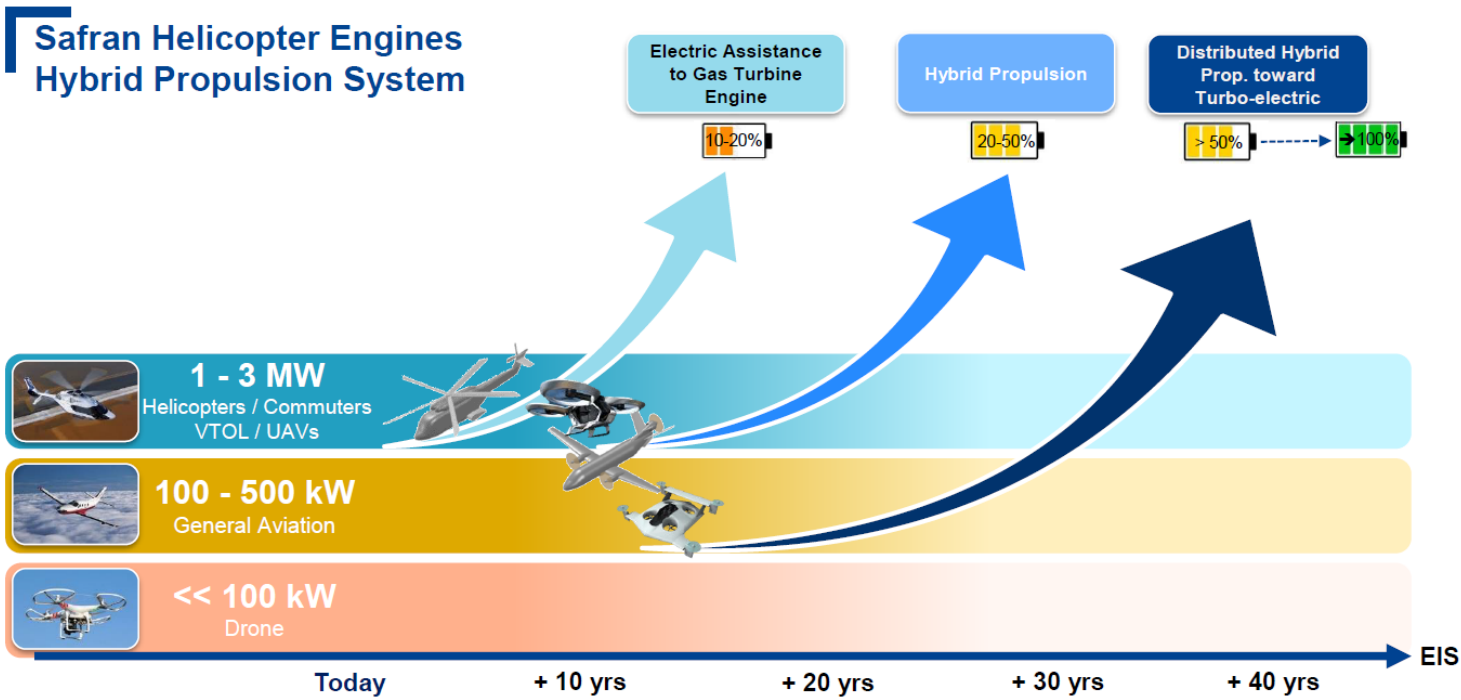
Disruptive aircraft, new infrastructures  
→ Higher risk and longer term option

## Electrification



Vehicle	nm	2015	2020	2025	2030	2035	2040
Large widebody	4000						Pure engine
Middle of market	1500						Engine / battery hybrid
Regional aircraft	500						Pure battery
Air taxi	200						Pure battery
GA aircraft	100						Pure battery
Air taxi	25		200 Wh/kg		500 Wh/kg		Pure battery

# Helicopter hybrid propulsion system



# Helicopter hybrid propulsion system

## Safran View On Helicopter Engine Business

### Growth strategy

Pulled by new means of mobility...

...and by conventional architectures that will remain for a long time

EIS Hybrid Propulsion Systems  
Payload >150kg

2025 2030 2035 2040 2045

Hybrid systems opportunities

On Demand Mobility

Logistic

Cannibalization

Replacement acceleration

Sustainable need

NEW

CURRENT



# PLAN D' ACTIONS

# Plan d'actions Stratégie / DMPI / Commerce

Thématique	Actions	Commentaires	Parties prenantes
Réservoir H2	Mise en place copil ISS projet à structurer	Focus sur Matériaux, process (forgeage/matriçage/fluotournage), simulation Poursuite des échanges avec Airbus St Nazaire	Laurent F/L. Bourgeon / A. Blanckaert
UHBR	Réunion de travail (28/01)	Evaluation des impacts (fan / turbine BP / Arbre)	E.Pons, E. Jullian, S. Tierce, B. Picqué, B. Flageolet, A. Benbahmed, C. Declairieux, Sandrine B, Sandrine P, L. Foucher
	Techday SAE	Relancer le sujet auprès de Safran	L. Foucher
Mât réacteur	Echanges avec Airbus St Eloi	Programmer réunion avec Airbus St Eloi	L. Foucher / A. Ragain / G. Philippe
Nacelles	Echange avec SN	Prendre contact avec SN (management)	L. Foucher
Train	Techday SLS	Mettre le sujet à l'ordre du jour (31 mars, Ancizes)	S. Bozzi
Ailes	Echanges avec Airbus UK	Aller à la pêche aux infos côté Airbus UK	A. Ragain
	Projet Aile du Futur	Questionner notre partenaire TAI sur ce projet	Sandrine B
	Echanges avec Asco	Questionner sur l'avenir des rails de volet vs krügers	L. Mourgues, M. Legros
Fan drive gear system (gearbox)	Mise en place copil Technique/Commercial	Rencontrer les roulementiers / fabricant d'engrenages / Transmissions Identifier les nuances répondant aux sollicitations Etudier si opportunités d'offrir une solution intégrée PL + PM sur certaines pièces de la gearbox	Sandrine P / L. Bilang / A. Benbahmed
Matériaux H2	Impacts matériaux	Essais cryo sur un panel de nuances + biblio Contact avec Airbus sur les attentes matériaux pour la tuyauterie/échangeur thermique.pompes	S. Bozzi
Sensibilisation/Présentation	Présentation à équipe DMPI-DA	Date à définir (séminaire)	S. Bozzi/S. Provenchère