Environmental Constraints and Future Engine Architectures

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FUEL BURN REDUCTION

Fuel consumption improvement

B737-200 / JT8D

20 %

A320 / CFM56 -5A

6 %

A320 / CFM56 -5B

5 %

B737 CL / CFM56 -3B

B737 NG / CFM56 -7B

Y1 / LEAP56

A30X / LEAP56

20 to 30%

Year of Entry Into Service

1970 1980 1990 2000 2010 2020

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SILENCE IN PROGRESS

Annoyance lowered by a factor of 2

B737-200 / JT8D

8 dB

A320 / CFM56-5A

1.5 dB

A320 / CFM56-5B

Noise improvement

5 dB

B737 CL / CFM56-3B

B737 NG / CFM56-7B

6 to 8 dB

Y1 / LEAP56

A30X / LEAP56

Year of Entry Into Service

1970 1980 1990 2000 2010 2020

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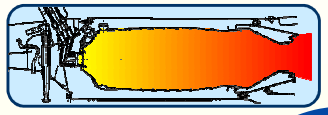
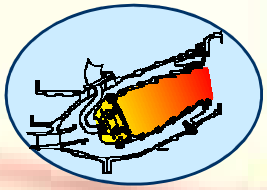
GREENER

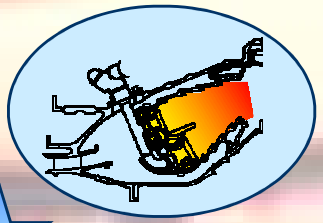


B737-200 / JT8D

First CFM offered 60% gain



Further 35% gain with DAC



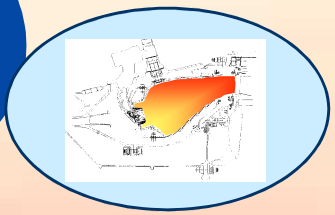
20%

A320 / CFM56-5A

CFM56-5B

737-800

LP multipoint show 50% benefits



LEAP56

Average gain in NOx level at ICAO point

Year of Entry Into Service

1970 1980 1990 2000 2010 2020

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Engine Contribution to Environmental Objectives

ACARE 2020 OBJECTIVES
(reference : 2000 aircraft)

- **To reduce perceived noise by half**
- **To reduce NOx by 80% and other emissions**
- **To reduce CO2 by 50%**

- *European Industry has committed on ACARE objectives for a drastic reduction of noise, Nox, and CO2*

ATM Contribution

Aircraft Contribution

Engine Contribution

- To reduce noise by 6dB per operation
- To reduce NOx by 60 to 80%
- To reduce specific fuel consumption by 20%

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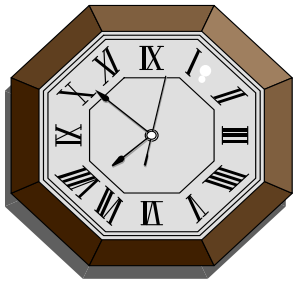
Design Decisions Must Balance Requirements

AIRCRAFT Requirements
- Thrust
- Weight
- Installation…..

Environment
- Noise,local rules included
- Emissions

FAA and EASA Regulation



TIMING
For Entry into service

Reliability – Maintenance
- Start and run
- “no surprise”
- D’s and C’s
- On wing life

ECONOMICS
- Market
- Cash EROC
- Maintenance cost
- Manufacturing cost
- Resale value…..

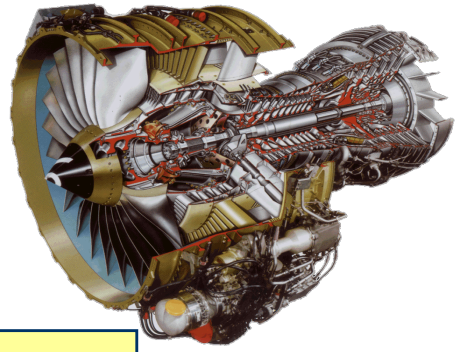
A market driven by « ownership cost »

and more and more Environmental Factors

Physical Principles Driving Environmental Tradeoffs

Increased Engine Pressure Ratio

- Reduced **Fuel Burn / CO_2** by improving thermal efficiency
- Reduces lower power emissions (**HC** and **CO**)
- Increases **NO_x** by increasing combustion temperature
- Increase Maintenance cost



Increased engine bypass ratio at current architecture

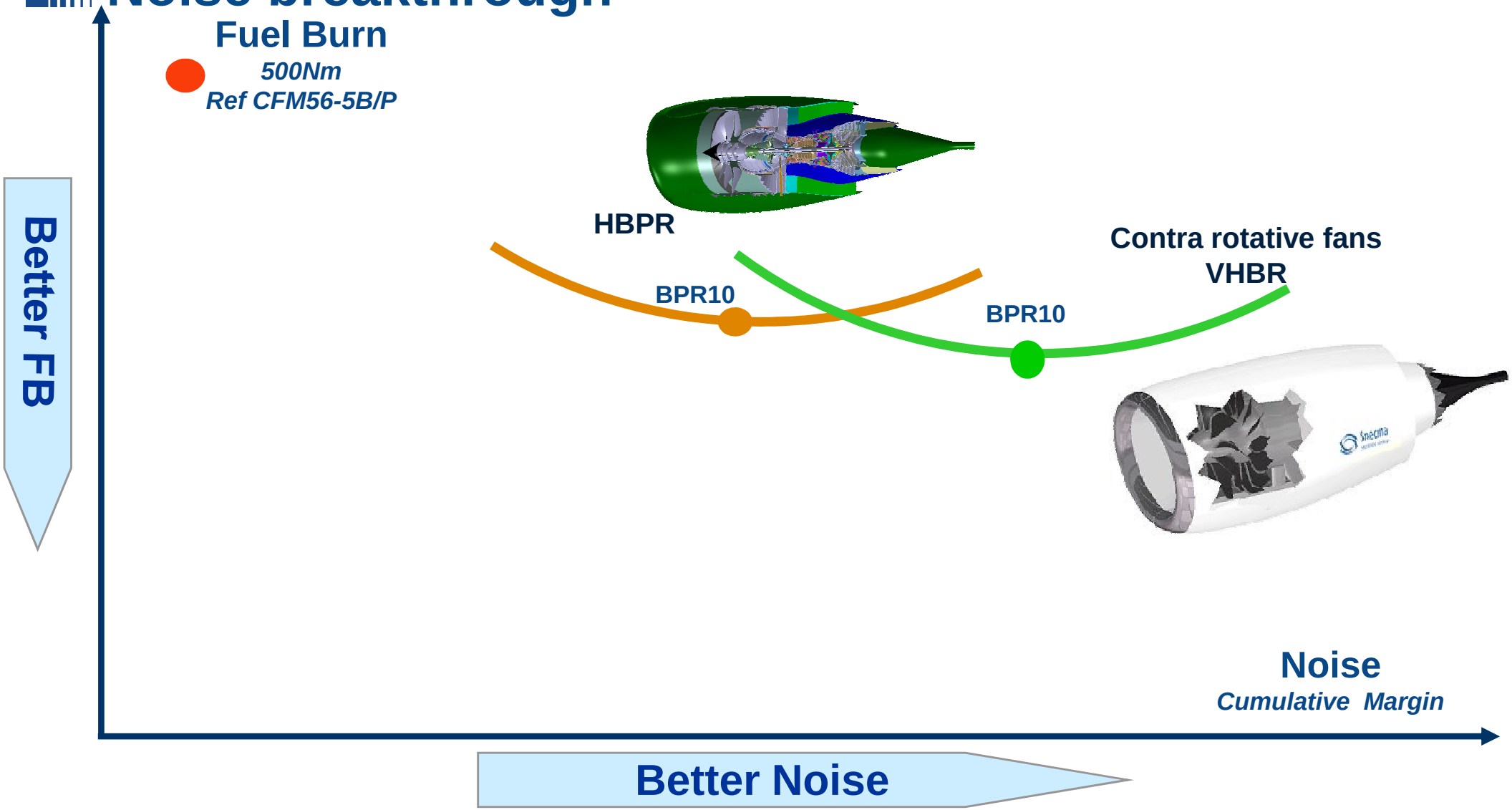
- Reduced **Fuel Burn / CO_2** by improving propulsive efficiency
- Reduces **Noise** by reducing fan Tip speed, pressure ratio and exhaust velocity
- Increase Maintenance cost
- Increase powerplant weight, Drag

Improved efficiency

- Already high level efficiency achieved
- Reduces **CO_2** by improving fuel efficiency and reducing required thrust
- Reduces **NO_x** by reducing combustion temperature
- Increase **maintenance** cost

Requires Optimization of Multiple and Sometimes Conflicting Factors
Priorities must be right for the entire life of the Product

Noise breakthrough



Break through technology required to meet ACARE Goals

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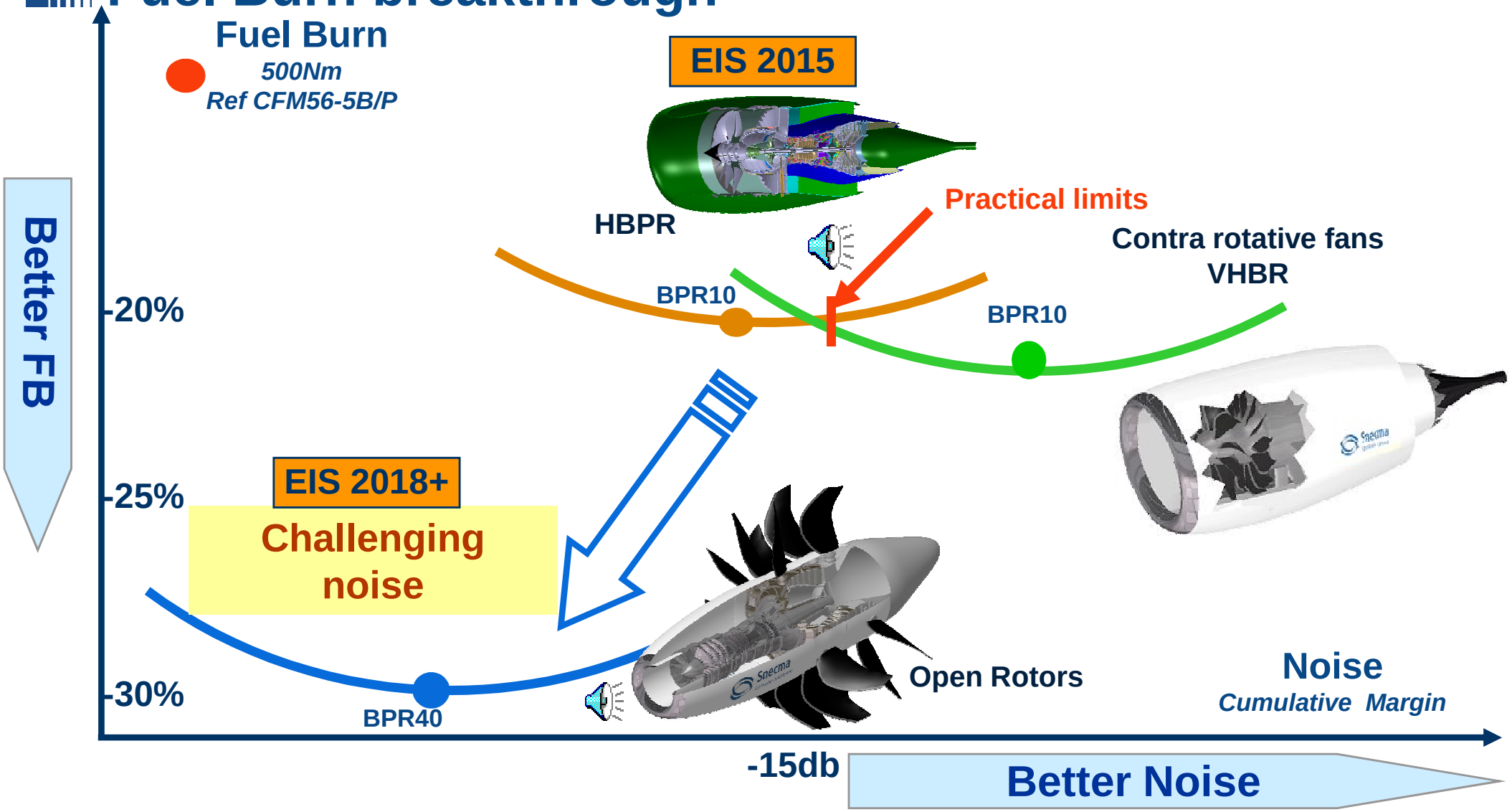
Fuel Burn breakthrough



Break through technology required to meet ACARE Goals

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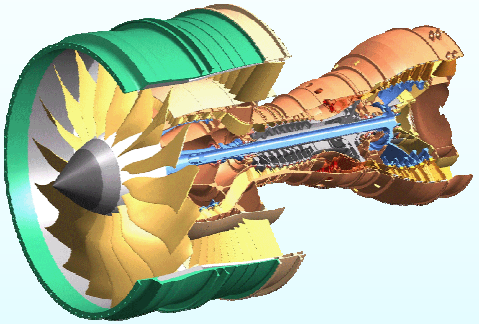
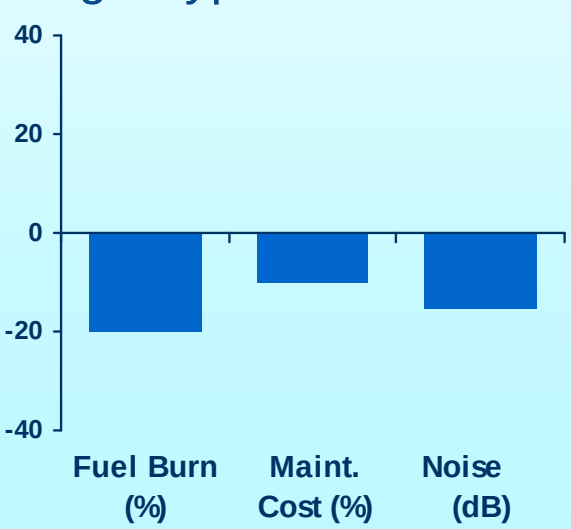
Narrow body engine architectures vs. Current engines

50% lower Nox emission

LEAP56
Balanced solution

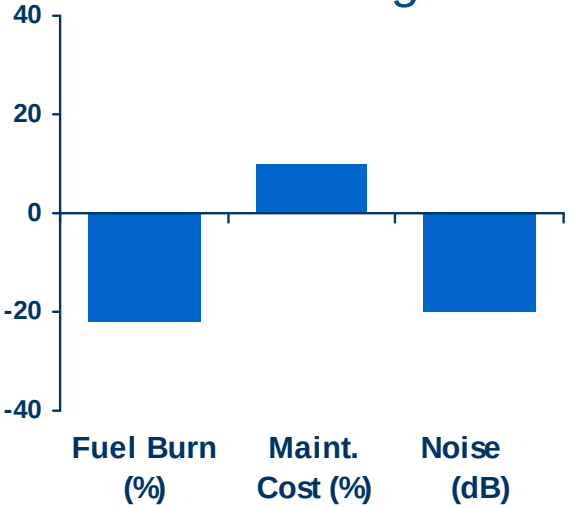


High Bypass Ratio

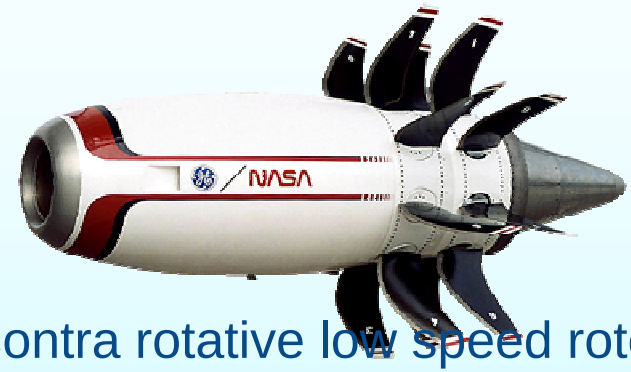


LEAP56
Noise solution

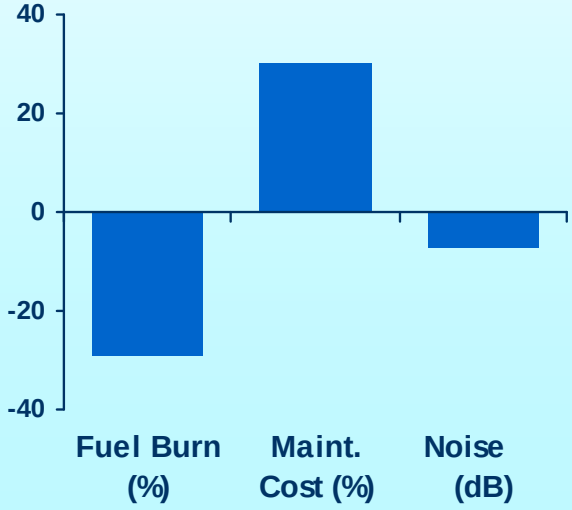
Contra rotative 2 stages fan



Open Rotor
Fuel burn optimized



Contra rotative low speed rotors



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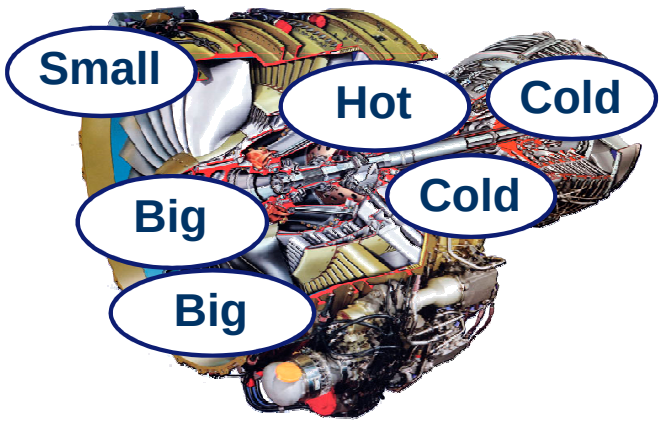
Not so easy to make it simple



LOW NOISE

BIG

SMALL

LIGHT

LOW CO_2

LOW FUEL BURN

BIG

LOW SPECIFIC FUEL CONSUMPTION
Low CO, unburn HC

COLD

LOW MAINTENANCE COST
HIGH ON WING LIFE

HOT

LOW NOx

COLD

Optimization … and … compromise
Technology required for overall optimization

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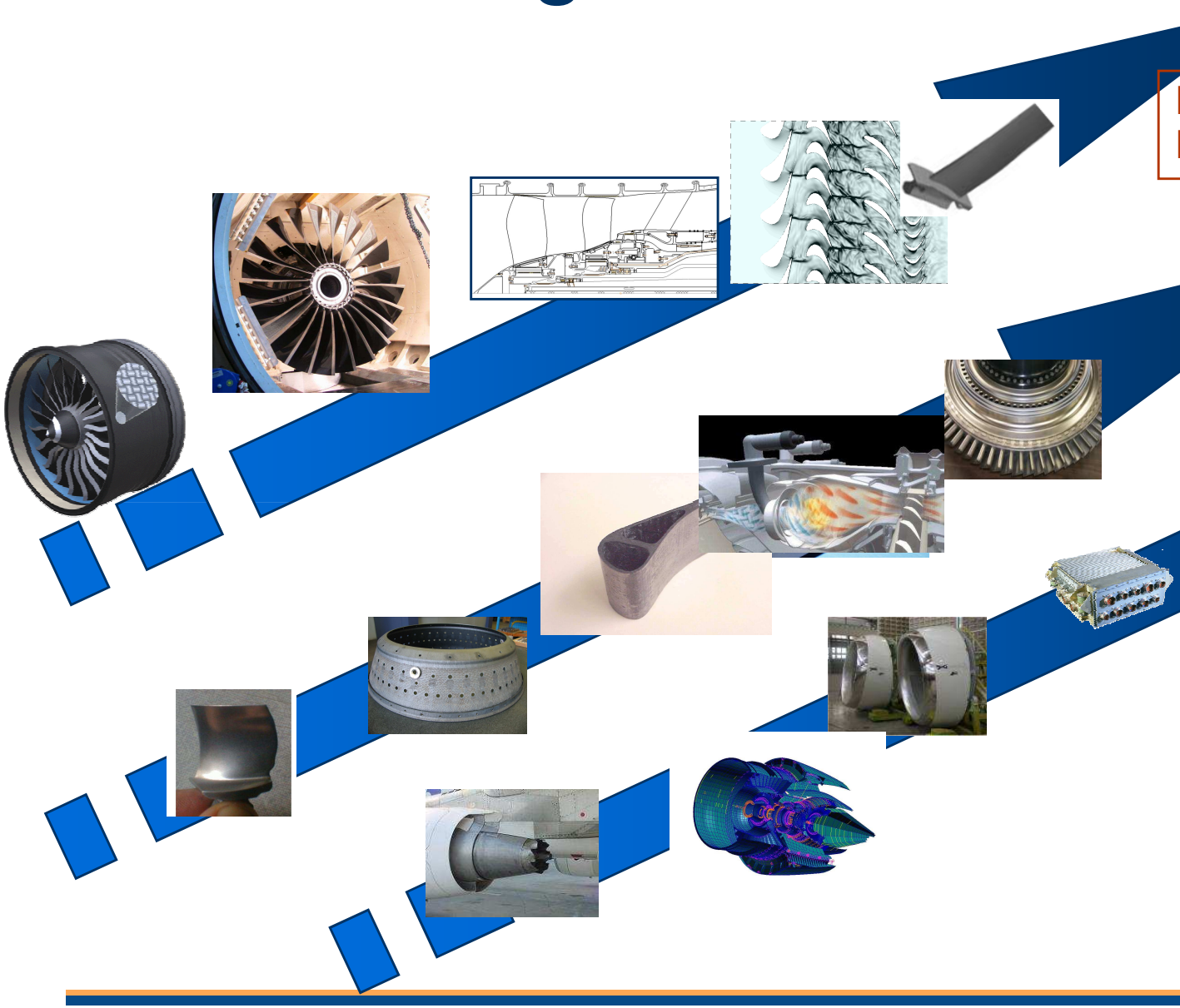
Technologies for tomorrow …



LP spool technologies
Performances/noise/Eroc/Weight

HP spool technologies
Performances/emission/Eroc

System technologies
Integrated powerplant
Intelligent engine

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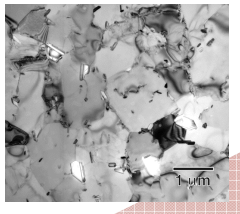
Fuel burn technologies
Weight reduction & aerodynamic improvement

Highly loaded compressor

Next-gen RTM composite fan

Novel alloys

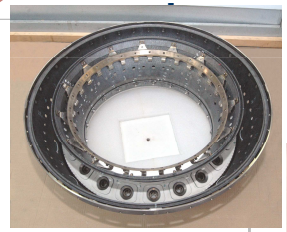
EIS 2020

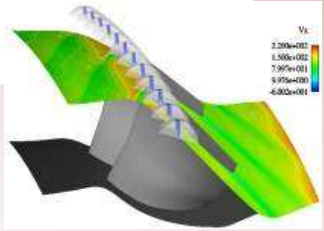


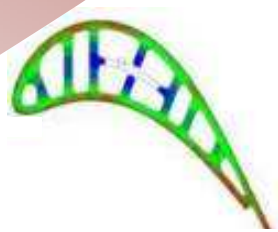
Composite fan case

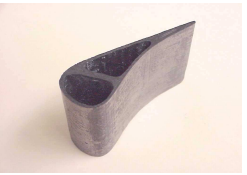
Light weight Composite mixer

Ceramic-matrix









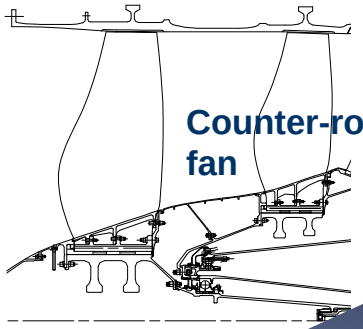
Highly loaded Contra rotative turbines

Bling

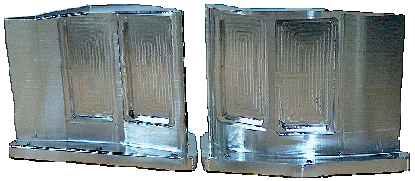
Ceramic matrix composites have 1/3 the density of nickel-based alloys

Acoustics technologies
Quieter engines

Splice-less inlet

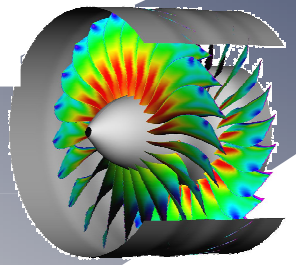


Counter-rotating fan



2018

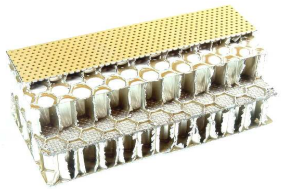
Chevron Nozzles

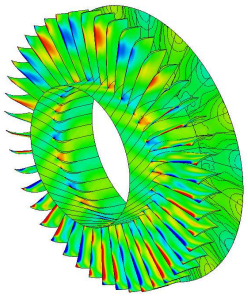


Fluidic / variable geometry chevrons

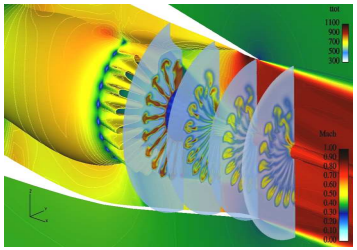
Quiet Technology Demonstrator

2008





Turbomachinery source noise reduction



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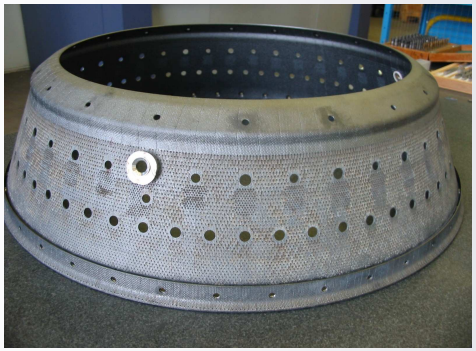
WIN EMISSION CHALLENGE

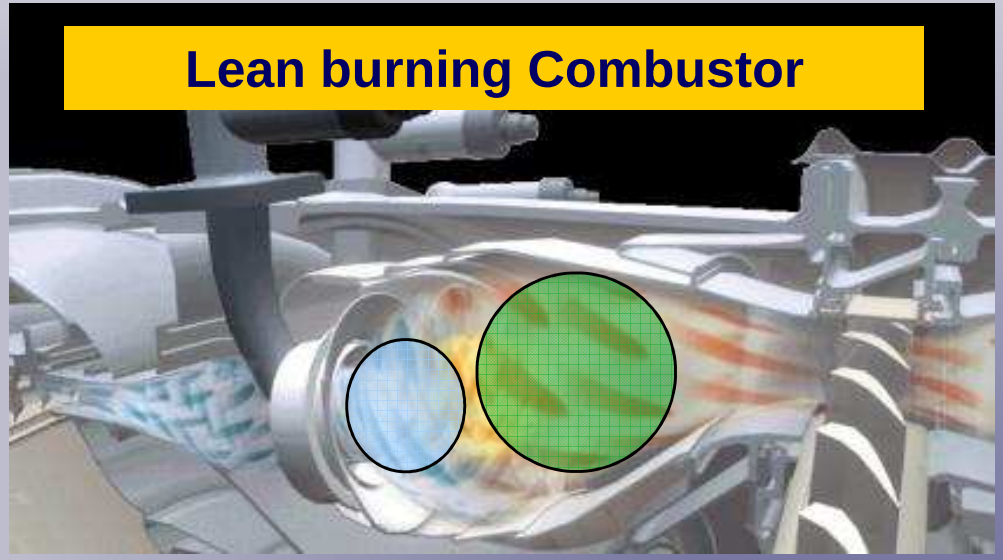
Traditional Combustor

(More fuel, less air … hotter temperatures … more NOx)

- **Twin-Annular, Pre-Swirl Combustor**
  - Shortened design
  - NOx reduced 50%
- **CMC combustor**
  - Higher temperature capability
  - Optimize cooling flow to reduce NOx



Lean burning Combustor



(Less fuel, more air … cooler temperatures … less NOx)

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… Laying the foundation for the future

Evaluating the requirements

- Environment : noise, emissions
- Engine performance :fuel, CO2 high priority
- Maintenance costs and reliability: start and run, on wing life, no surprise….
- Health monitoring, intelligent engine, prognostic, diagnostic

Assessing game-changing architectures

- Noise, aircraft integration, technology to develop….

Maturing the technology to unlock the future

- System optimization
- Pioneer and mature new technologies

Heavy Technology Programs required … laying the technology foundation for the future.

As for the future,
our task is not to foresee it,
but to enable it.

Antoine de Saint Exupery