Engine design for the environment

Aero-engine technology meeting the environmental challenge

RAeS - Hamburg

HAW Hamburg, 24th June 2010

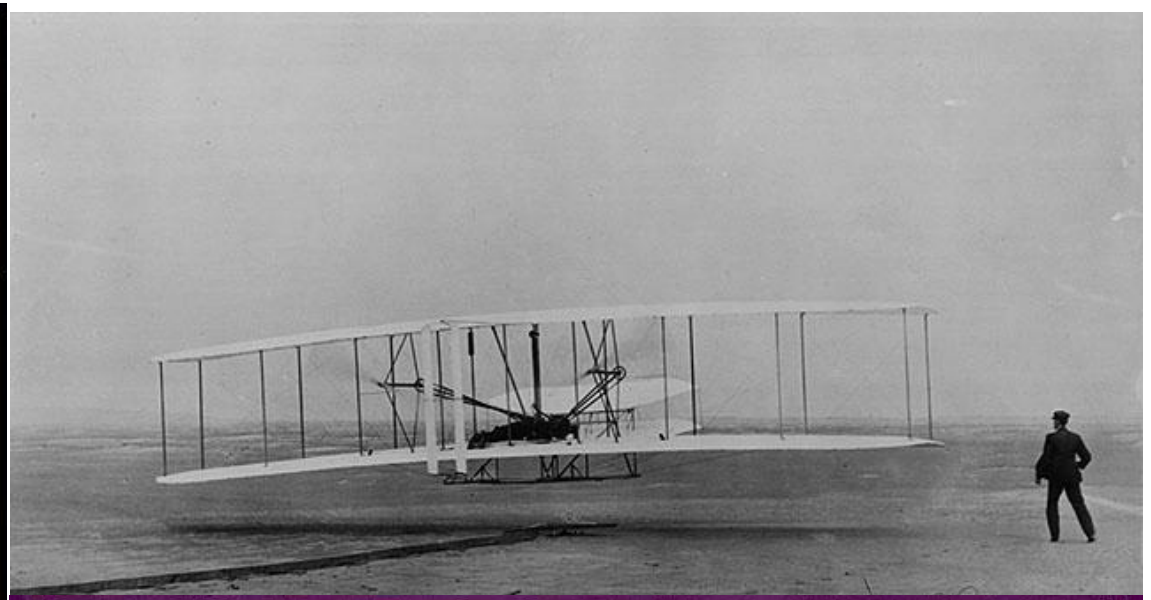
Andrew Bradley

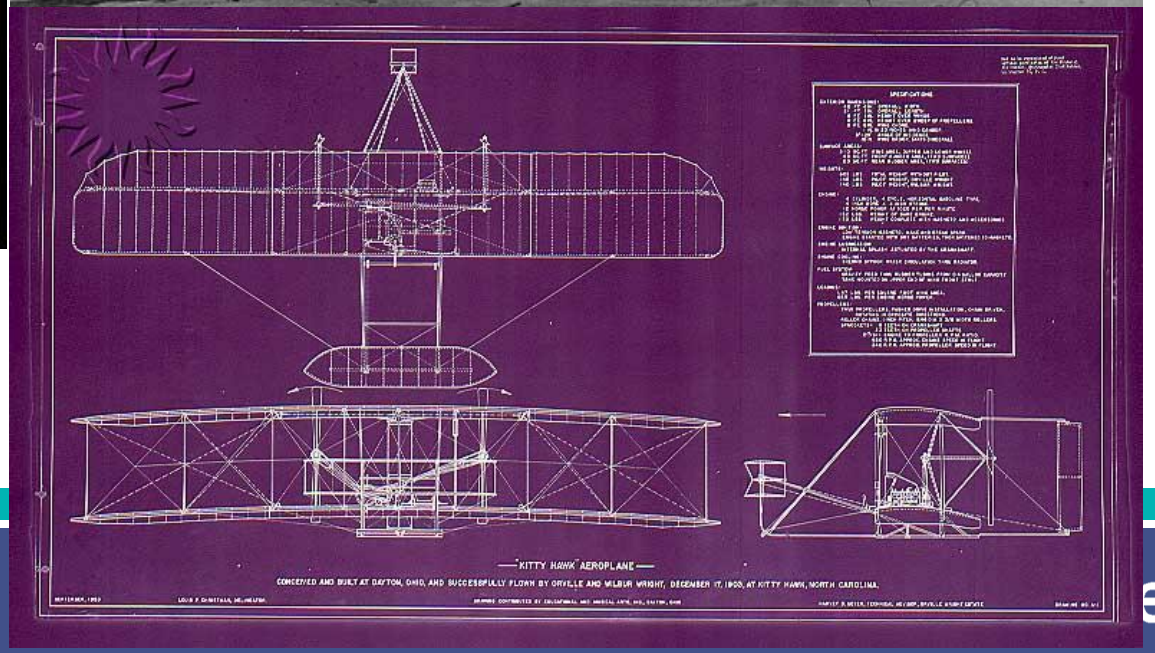
Chief Design Engineer – APSV

Agenda

- Changes in aero-engines
- Environmental impact
- Bringing technology to market
- Future engine technology
- Summary

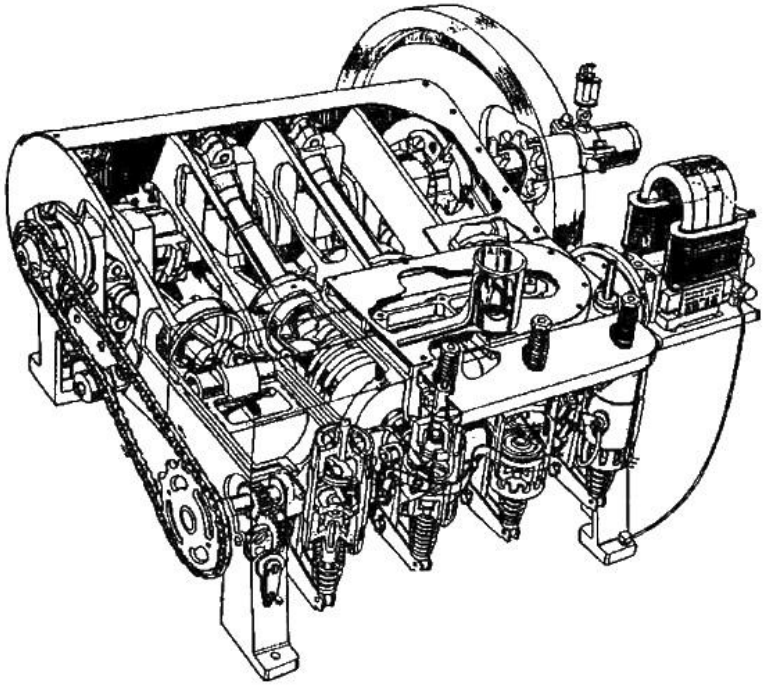
Over one hundred years of powered flight

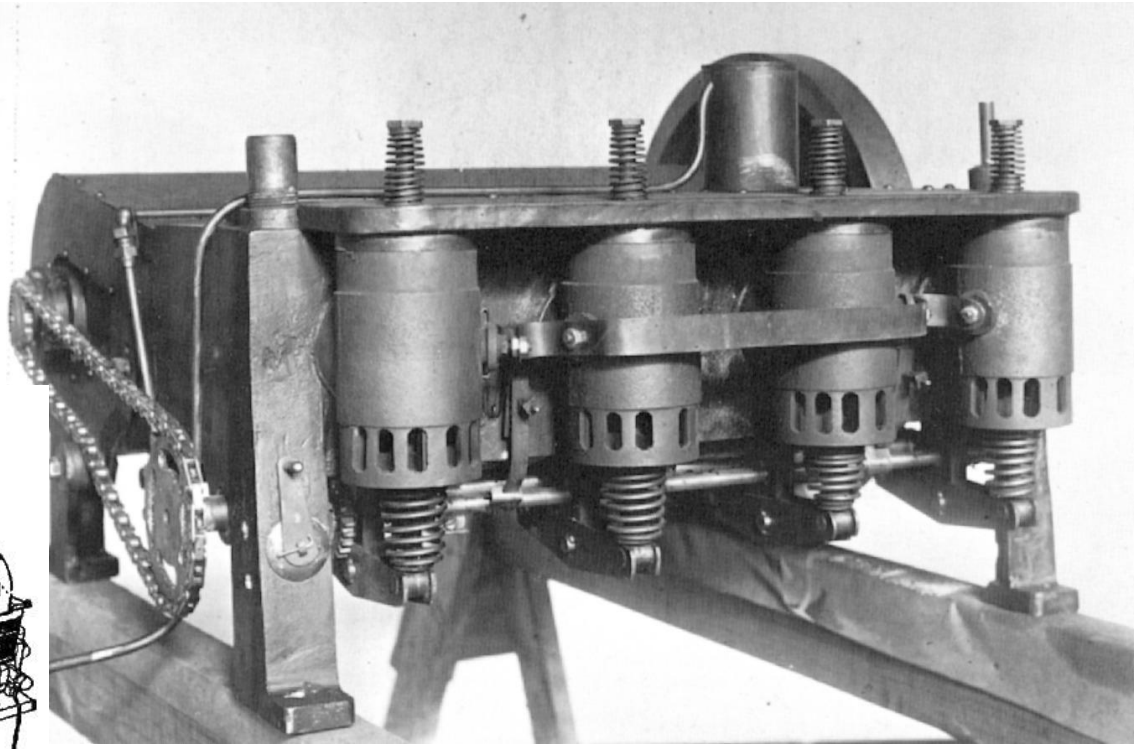




Wilber and Orville Wright
1st Flight December 1903
Kittyhawk, USA

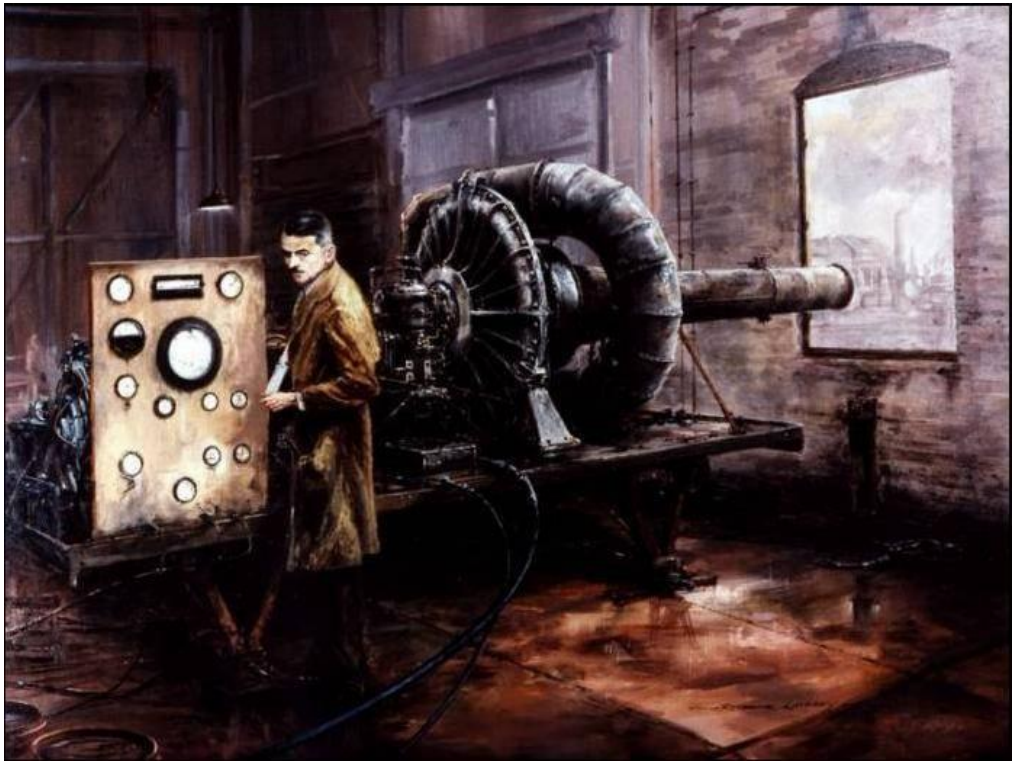
Over one hundred years of powered flight





The internal combustion engine from the Wright Flyer

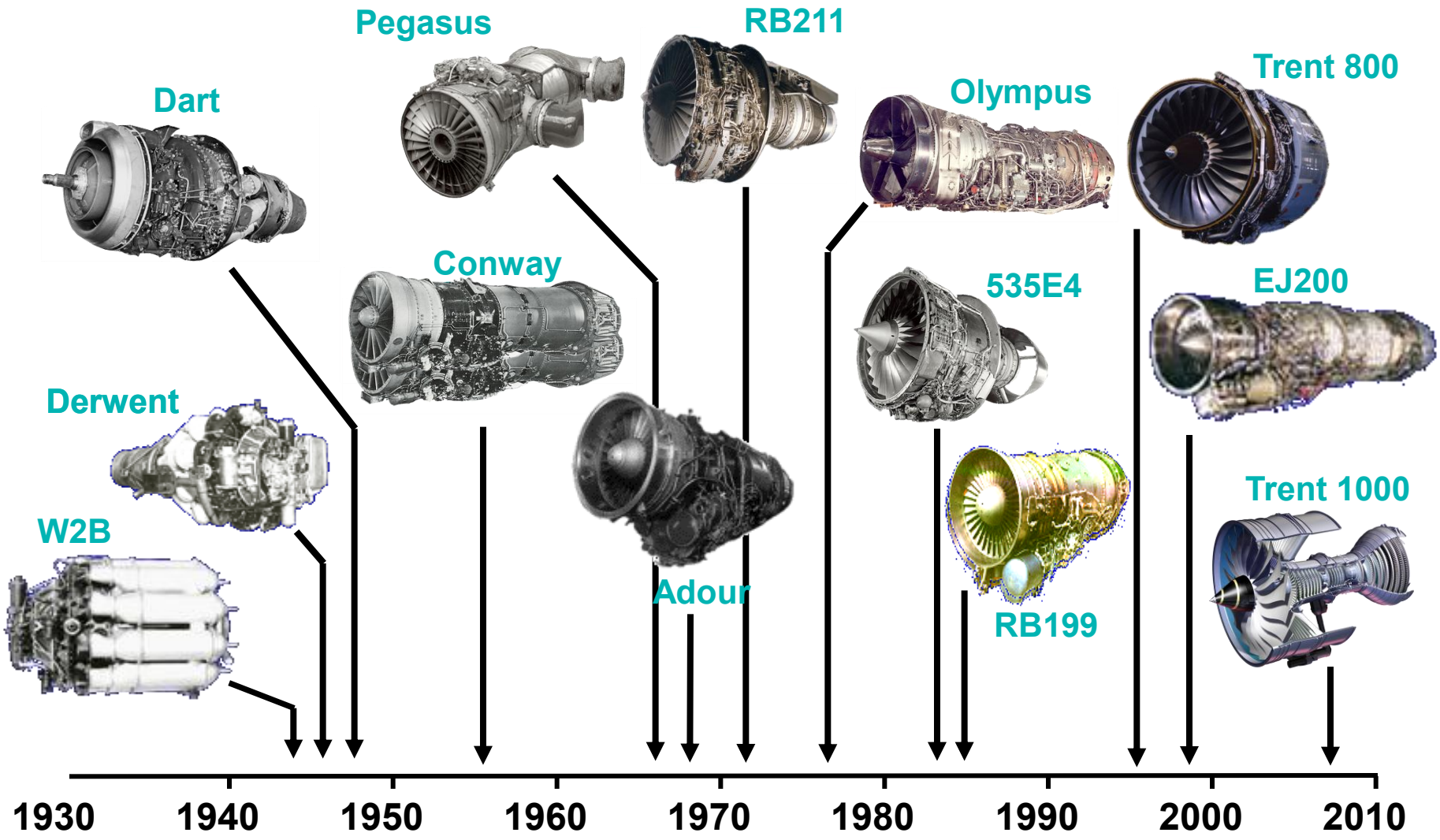
The Original Whittle Engine



"The invention was nothing.
The achievement was making the thing work"

- Sir Frank Whittle

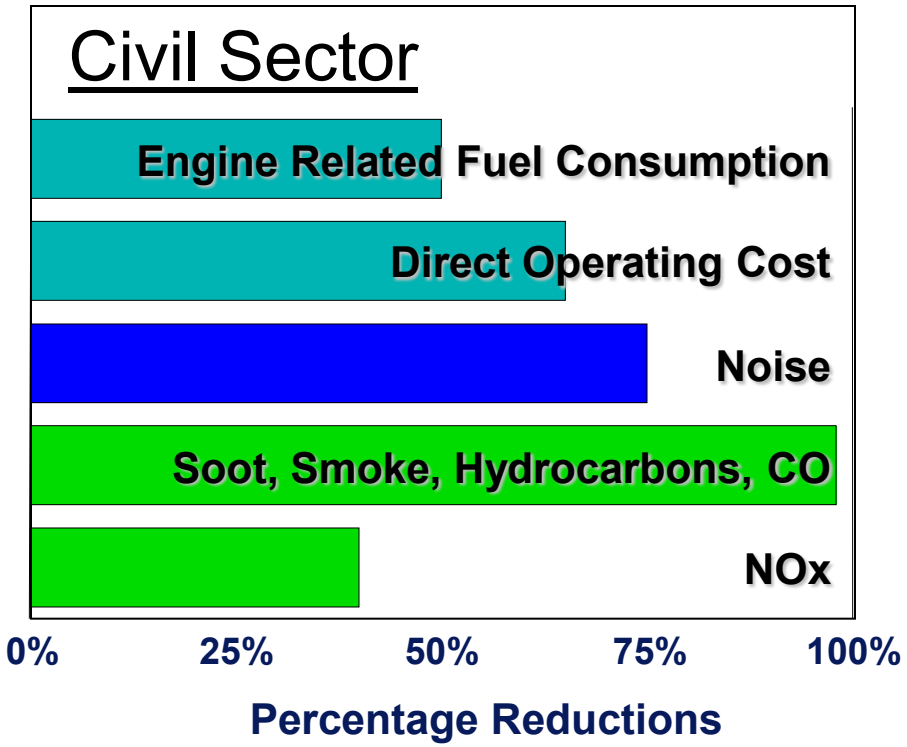
History of the gas turbine at Rolls-Royce



Rolls-Royce data – see front sheet

Aero engine evolution

- Significant performance improvements to date driven by advances in technology. Reductions since 1960 include:



- Product technology has been the principal driver to gain competitive advantage

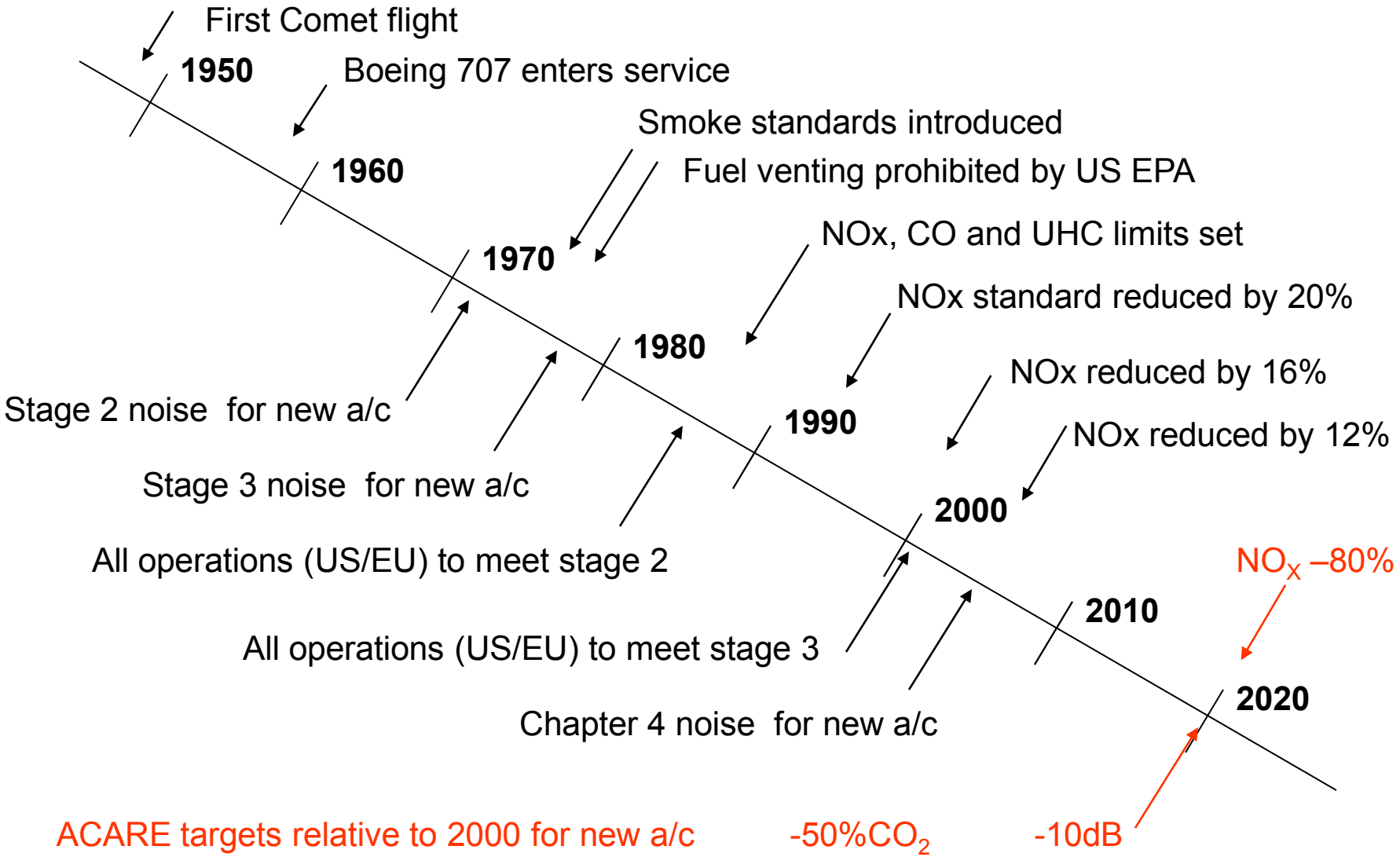
Rolls-Royce data – see front sheet

Aero engines and the impact on the environment

- Manufacture and maintenance
- Local to the airport
  - Noise
  - Air quality
    - Oxides of Nitrogen
    - Carbon monoxide
    - Sulphur dioxide
    - Unburnt hydrocarbons
    - Smoke
- Climate change
  - Carbon dioxide
  - Oxides of Nitrogen
  - Water

Rolls-Royce data – see front sheet

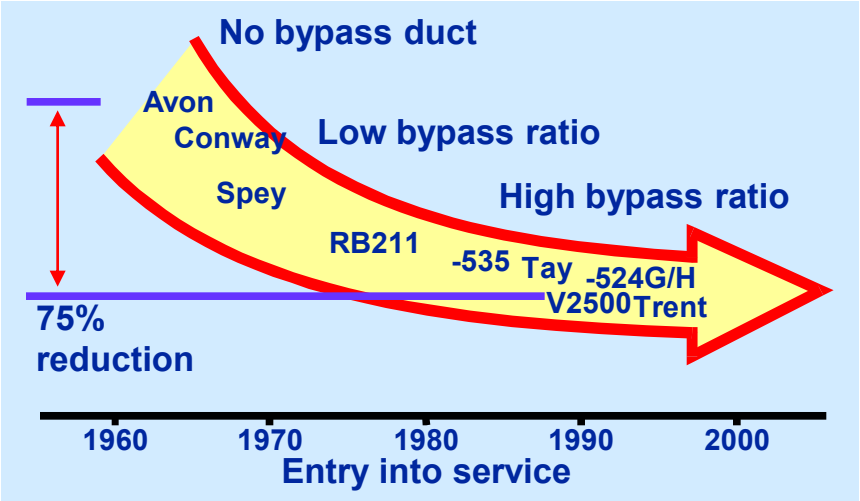
Aviation and the environment timeline



Rolls-Royce data – see front sheet

Aerospace power — Noise

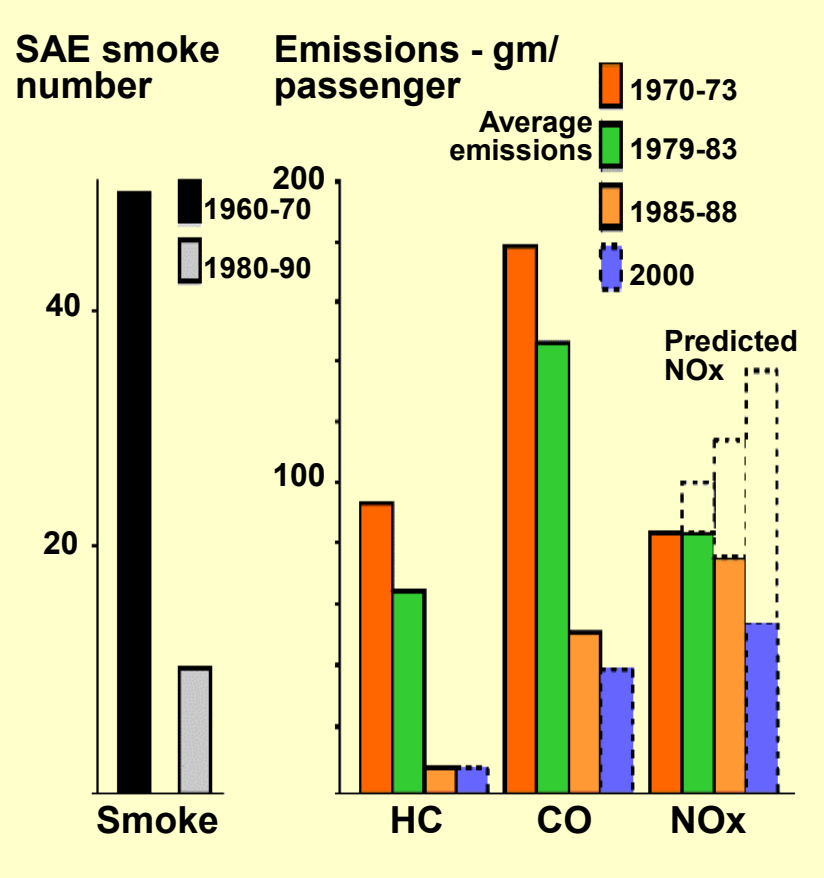
- Communities local to airports are worst affected due to take off and landing manoeuvres
- International and particularly local regulation impose very stringent limits
- Reductions in aircraft noise have been largely offset by increased traffic and aircraft size



Total aircraft noise - Rolls-Royce engines

Rolls-Royce data – see front sheet

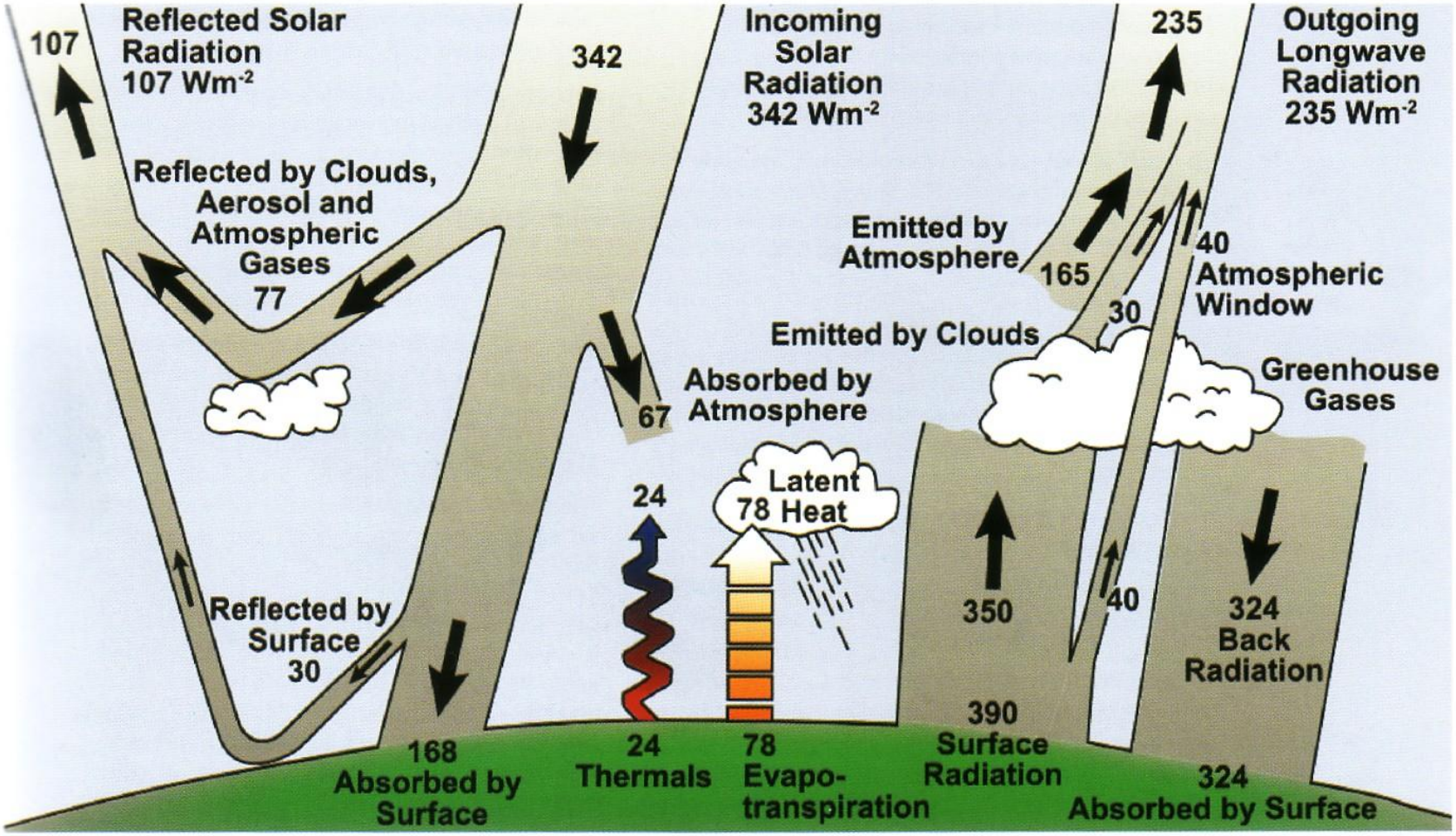
Aerospace power — Emissions legislation



- Legislation is focused on the landing/take-off cycle and limit UHCs, CO and NOx
  - local impact often provokes localised legislation
  - modern engines have acceptable UHC, CO and smoke emission
  - Current legislation required a 36% reduction of NOx relative to 1986 limit
    (16% at 1996 limit)
- More advanced cycles improve CO_2 (fuel burn) but deteriorate NOx

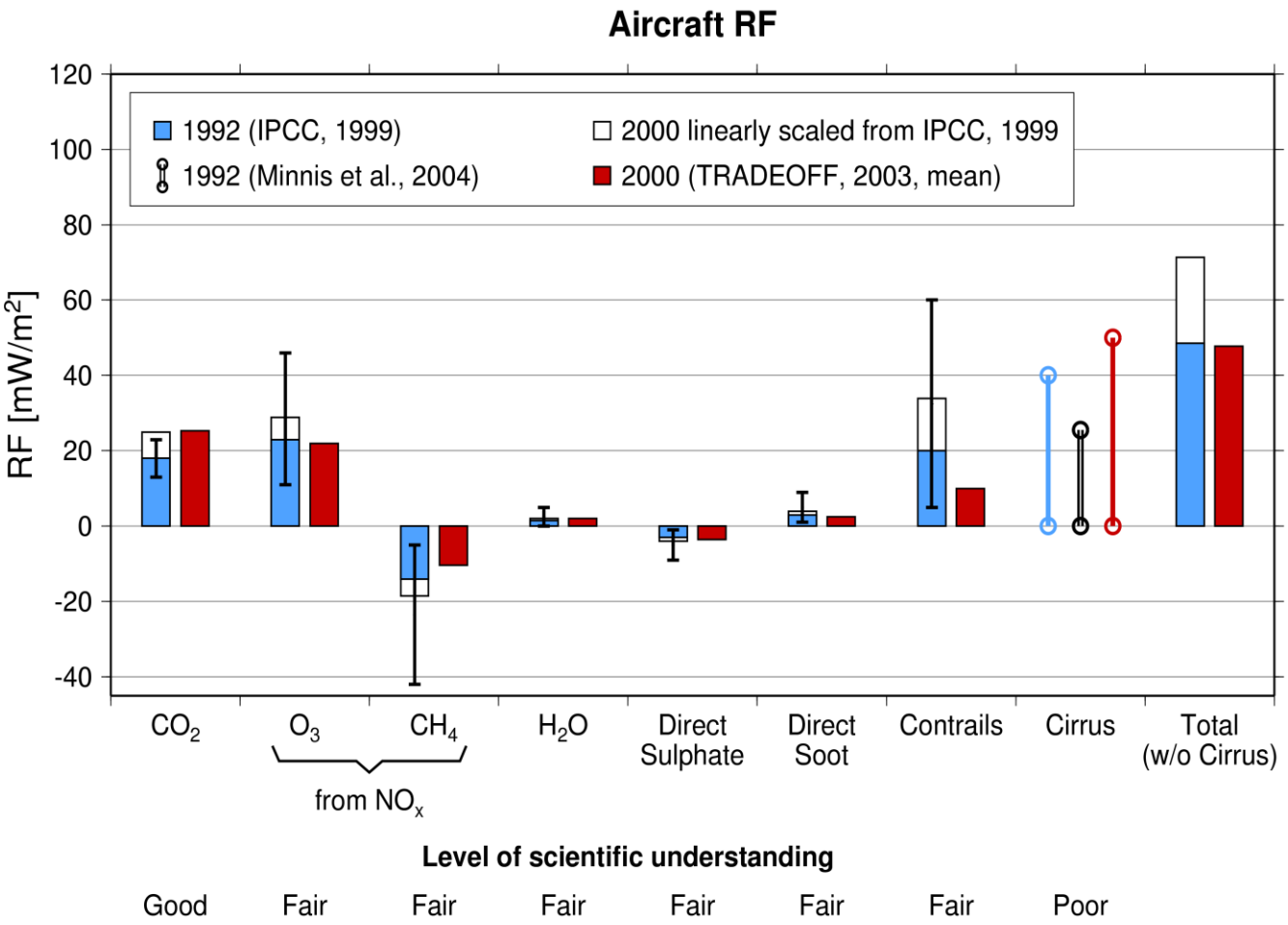
Rolls-Royce data – see front sheet

Climate change?



Rolls-Royce data – see front sheet

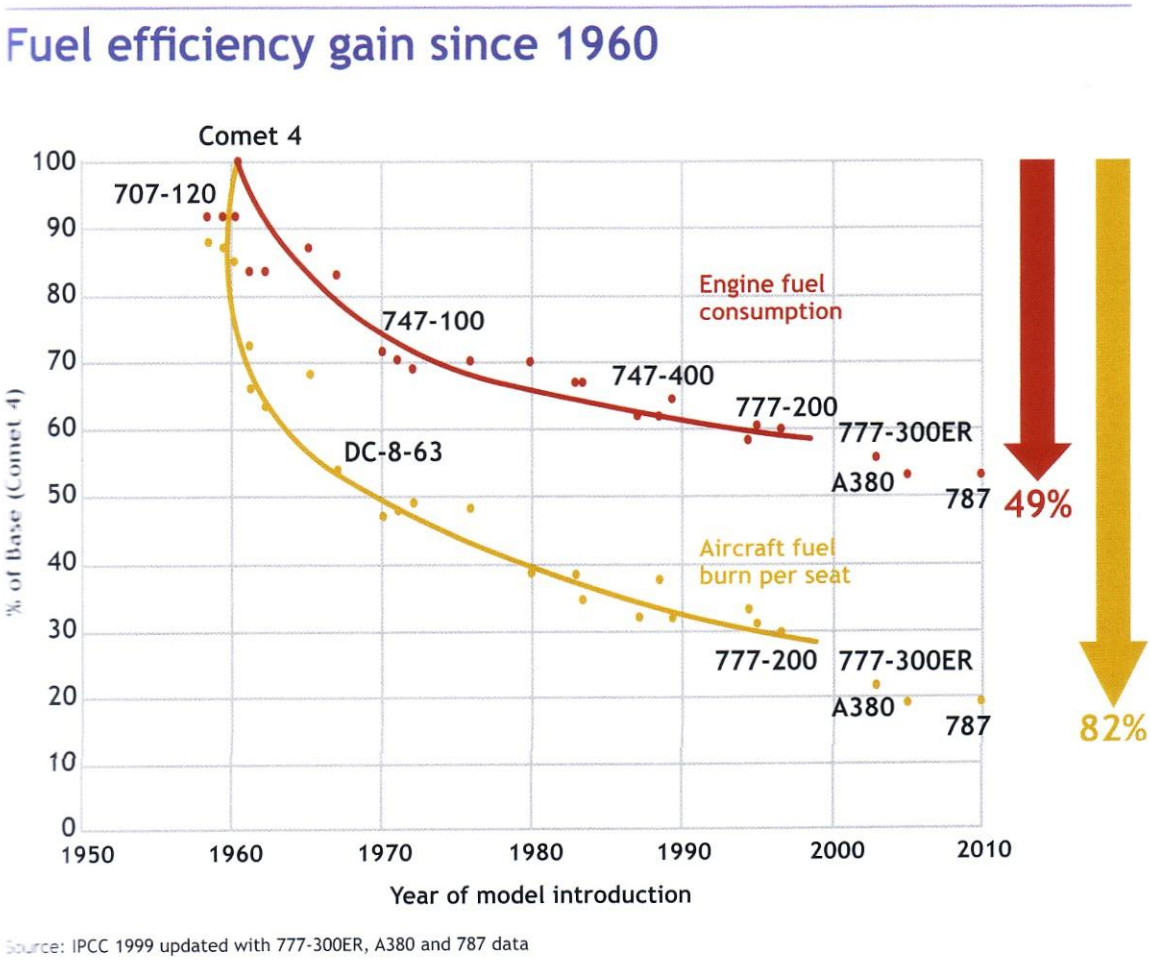
Radiative forcing from aviation for 1992 and 2000, based on IPCC (1999) and TRADEOFF results



Source Sausen, R et al., Aviation Radiative Forcing in 2000: an Update on IPCC (1999). Meteorologische Zeitschrift, submitted for publication.

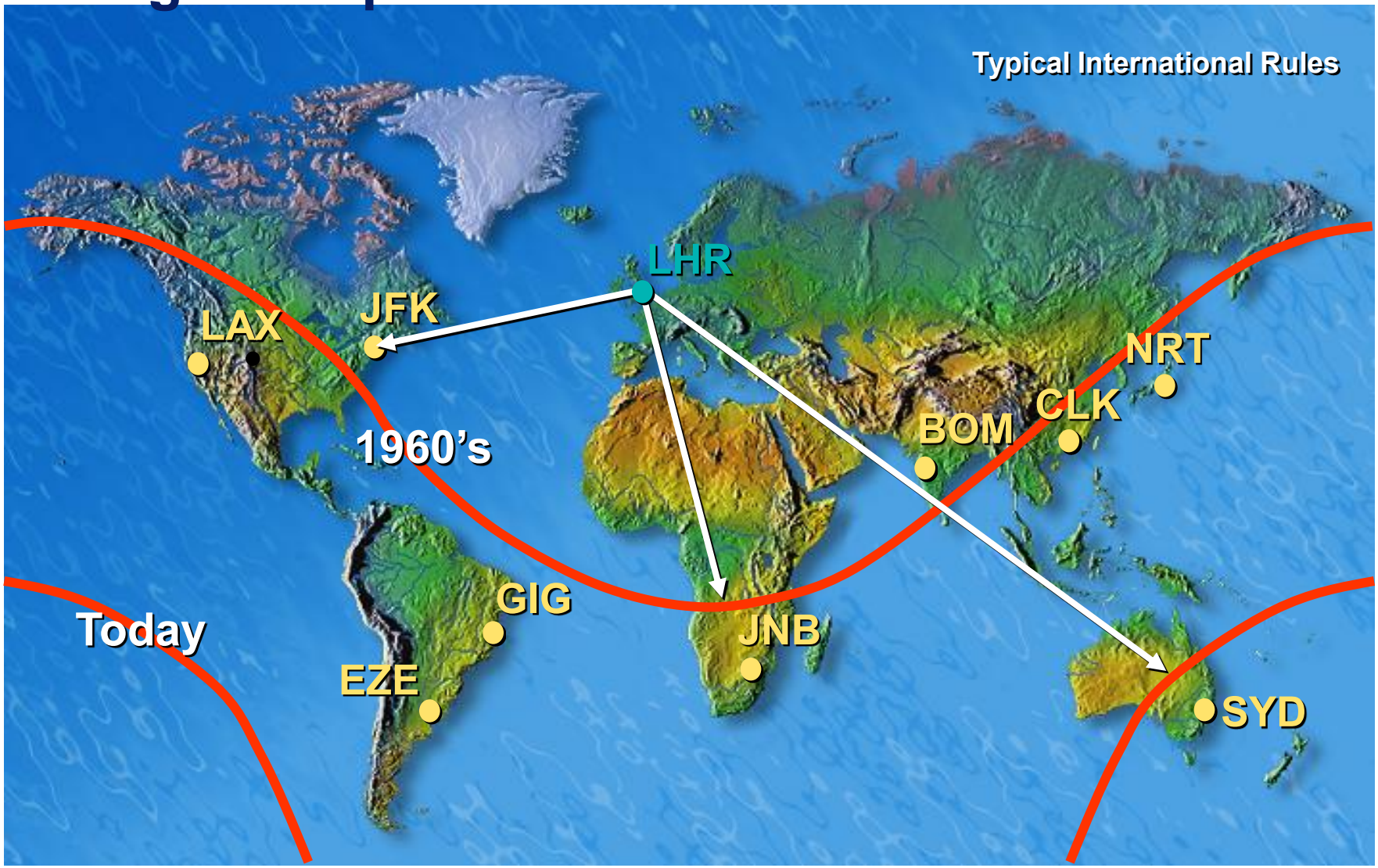
Rolls-Royce data – see front sheet

Fuel consumption



Rolls-Royce data – see front sheet

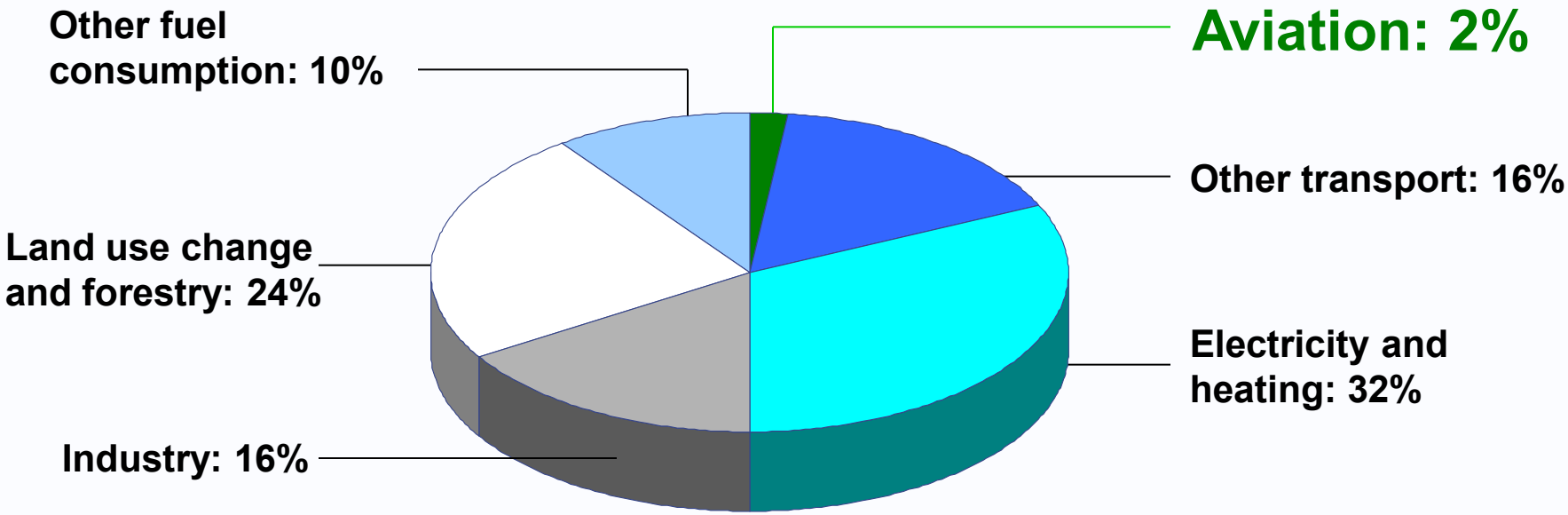
Range Comparisons - 1960's to Present



Rolls-Royce data – see front sheet

Rolls-Royce

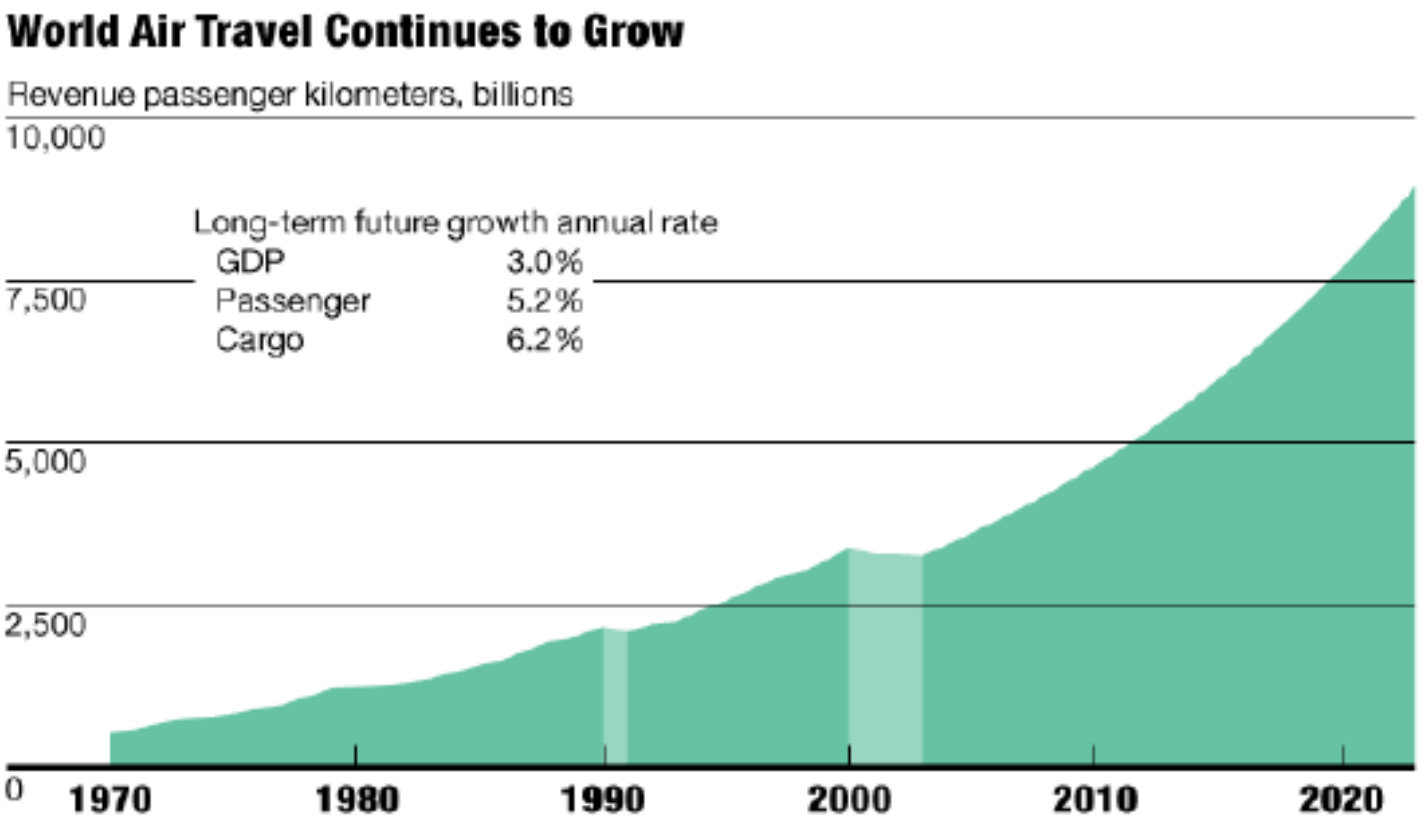
Global man-made CO_2 emissions



Source: World Resource Institute

Rolls-Royce data – see front sheet

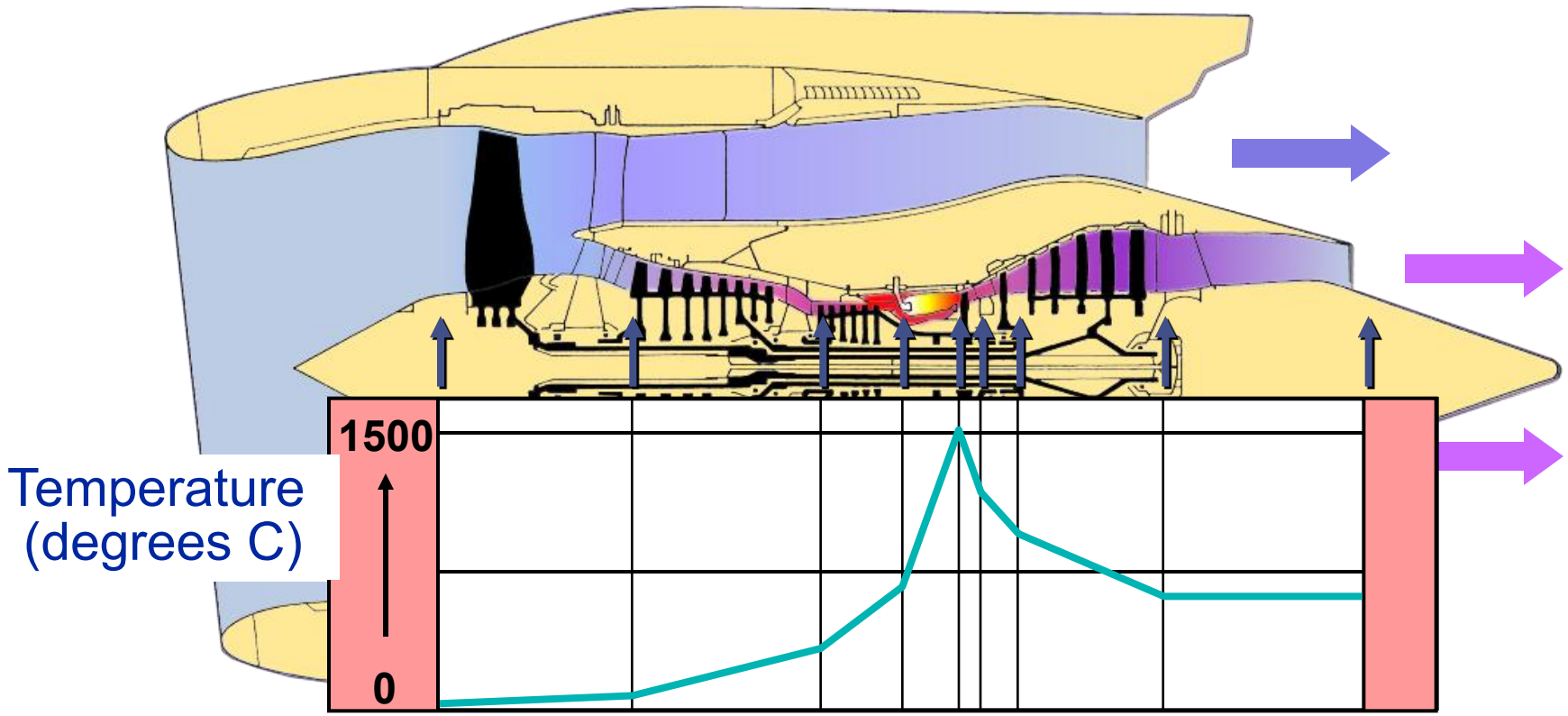
Growth in air travel



Boeing Current Market Outlook *2004,*
Demand for Air Travel

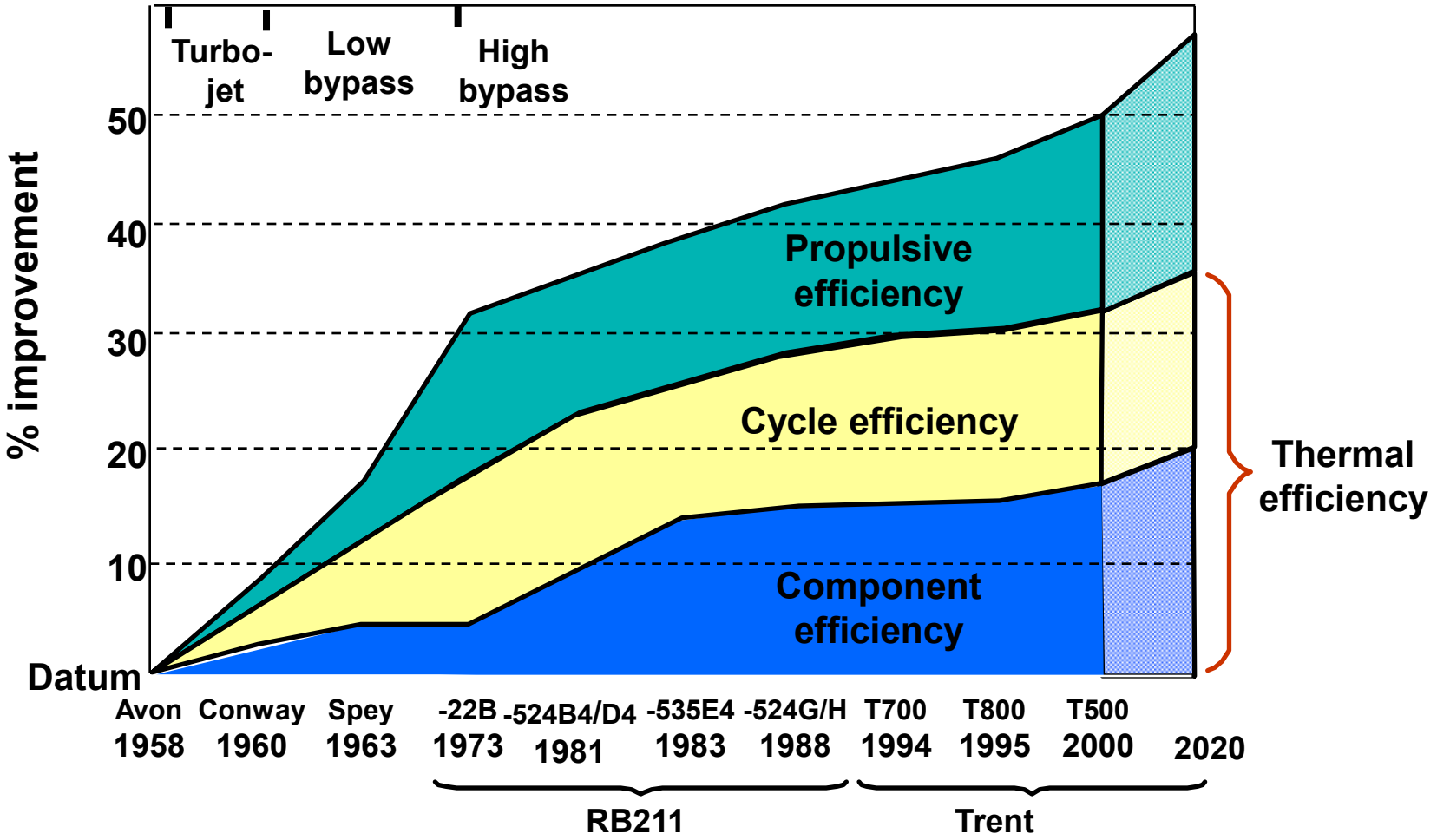
Rolls-Royce data – see front sheet

Turbofan Engine



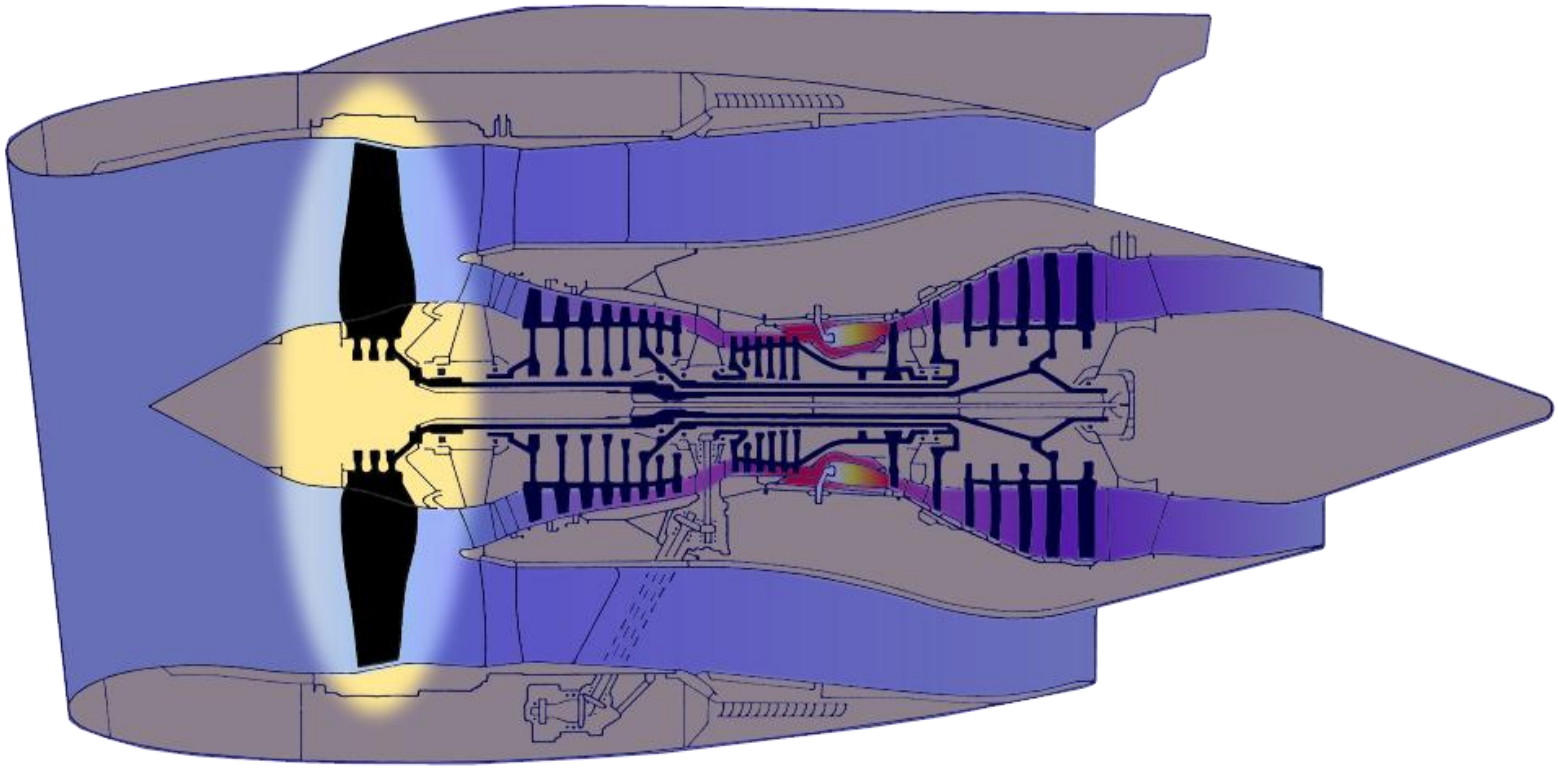
Rolls-Royce data – see front sheet

Jet-engine fuel consumption improvement



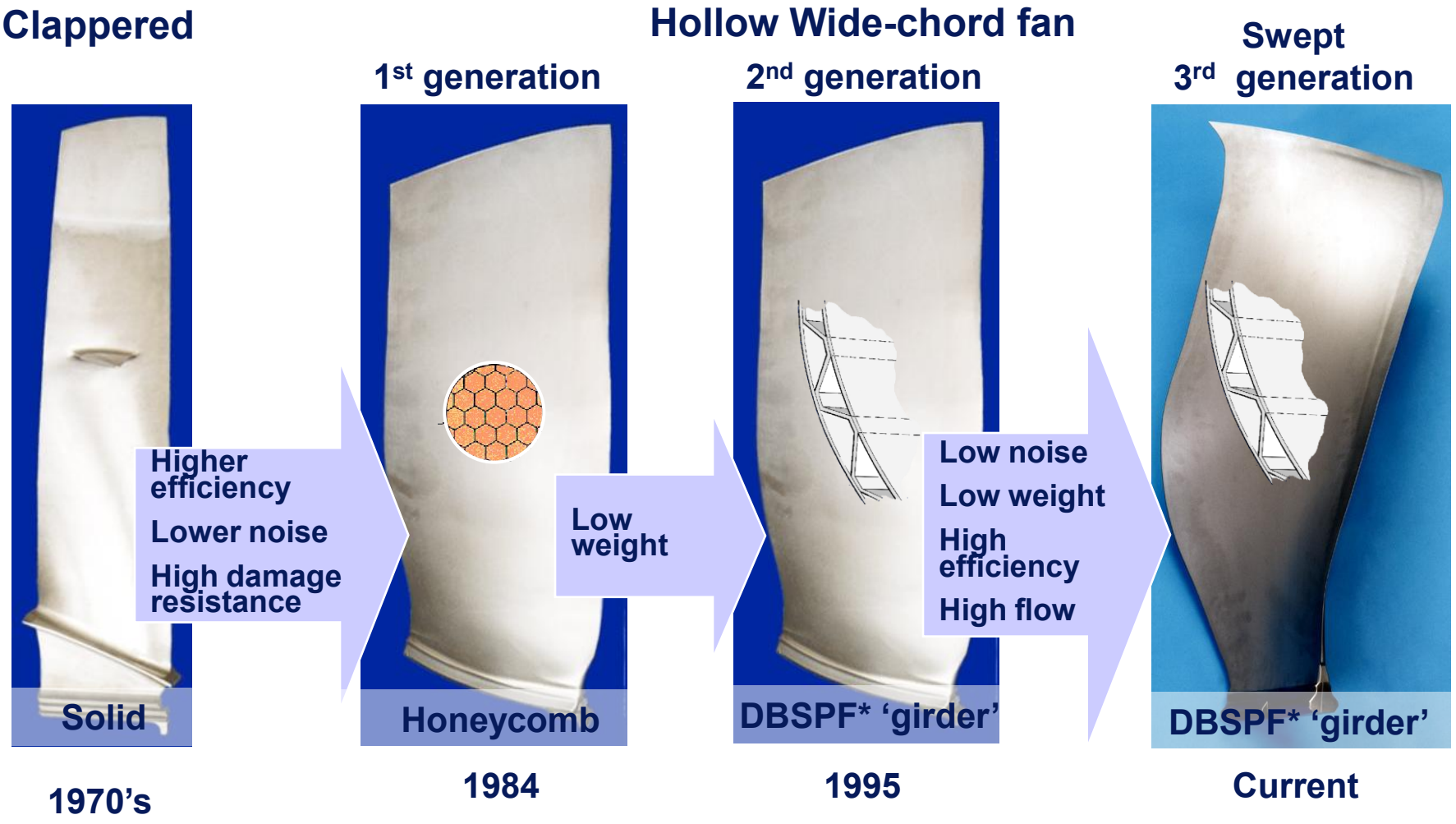
Rolls-Royce data – see front sheet

Fan Technology



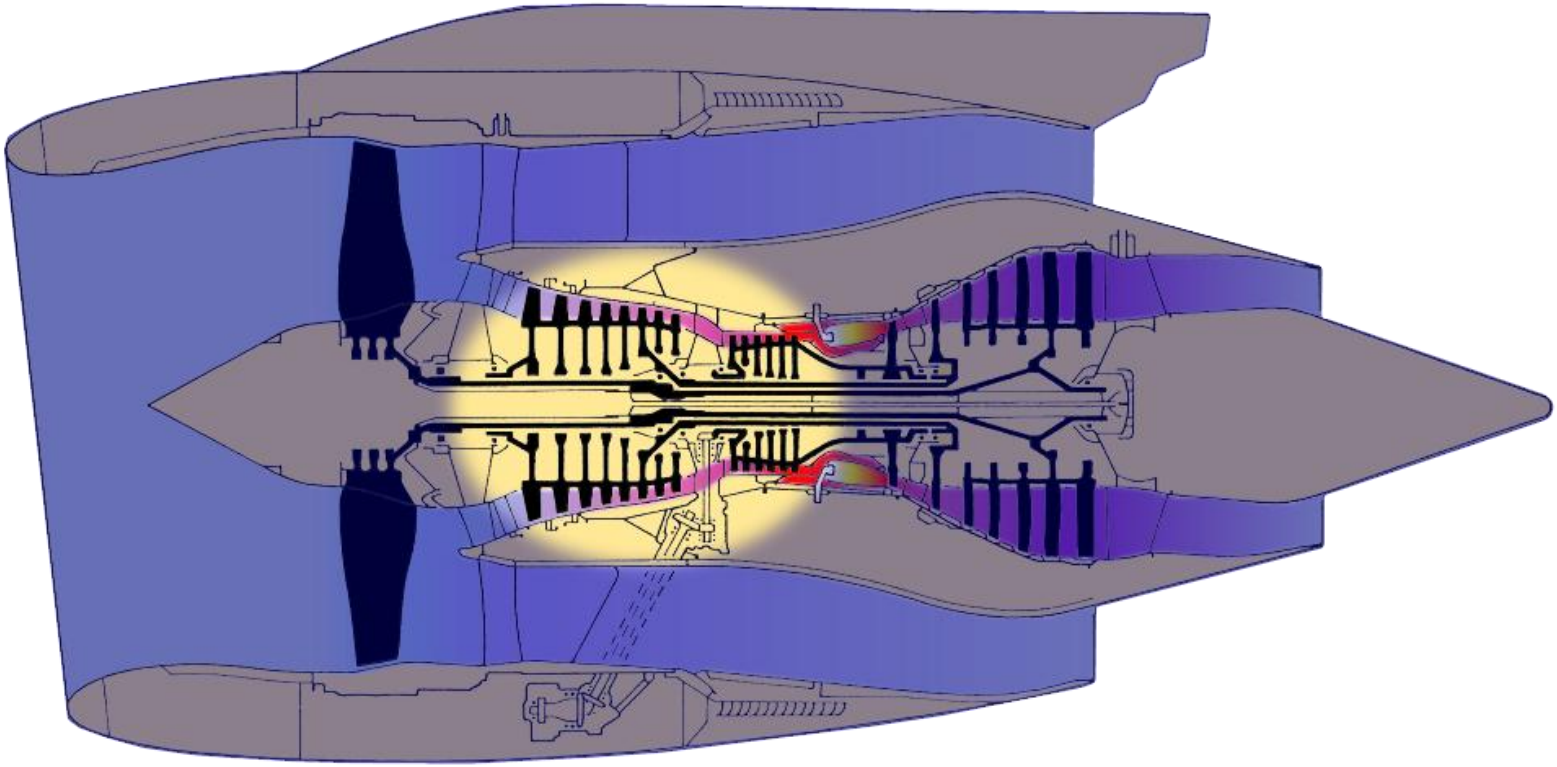
Rolls-Royce data – see front sheet

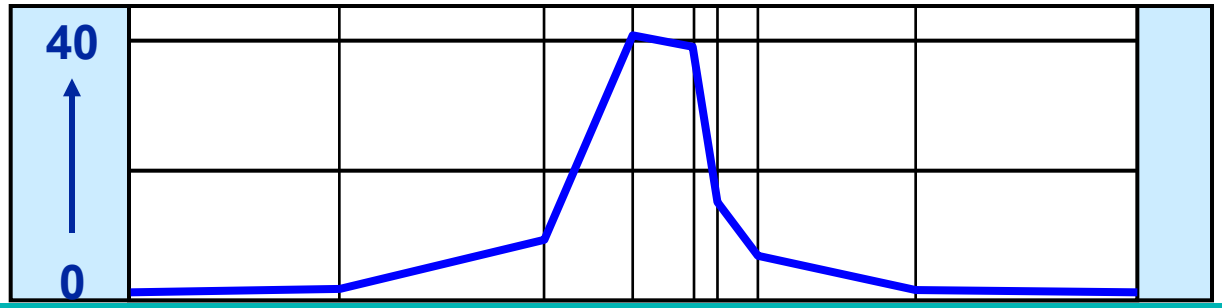
Rolls-Royce
Wide Chord Fan Technology



Rolls-Royce data – see front sheet

Compressor Technology

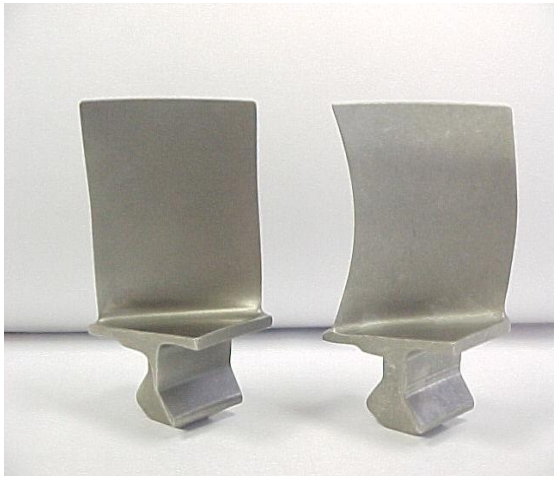




Rolls-Royce data – see front sheet

Rolls-Royce

Trent 900 & Trent 1000
Compressor 3-D Aerodynamics

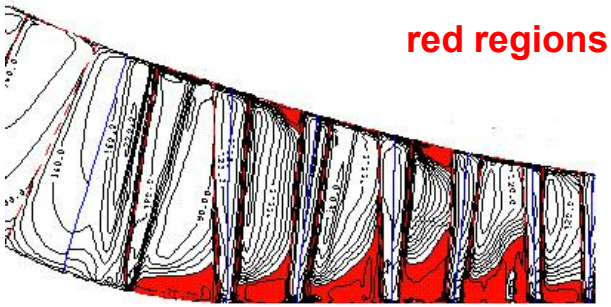


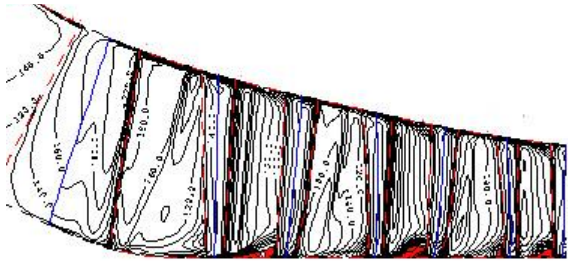
- 3-D aerofoils are used in the IP and HP compressor stages and all the turbine stages
- Allows optimal blade design to give optimum flow field, reduced flow separation and reduced reverse flow

Trent 900 2-D design iteration compressor

Trent 900 3-D design

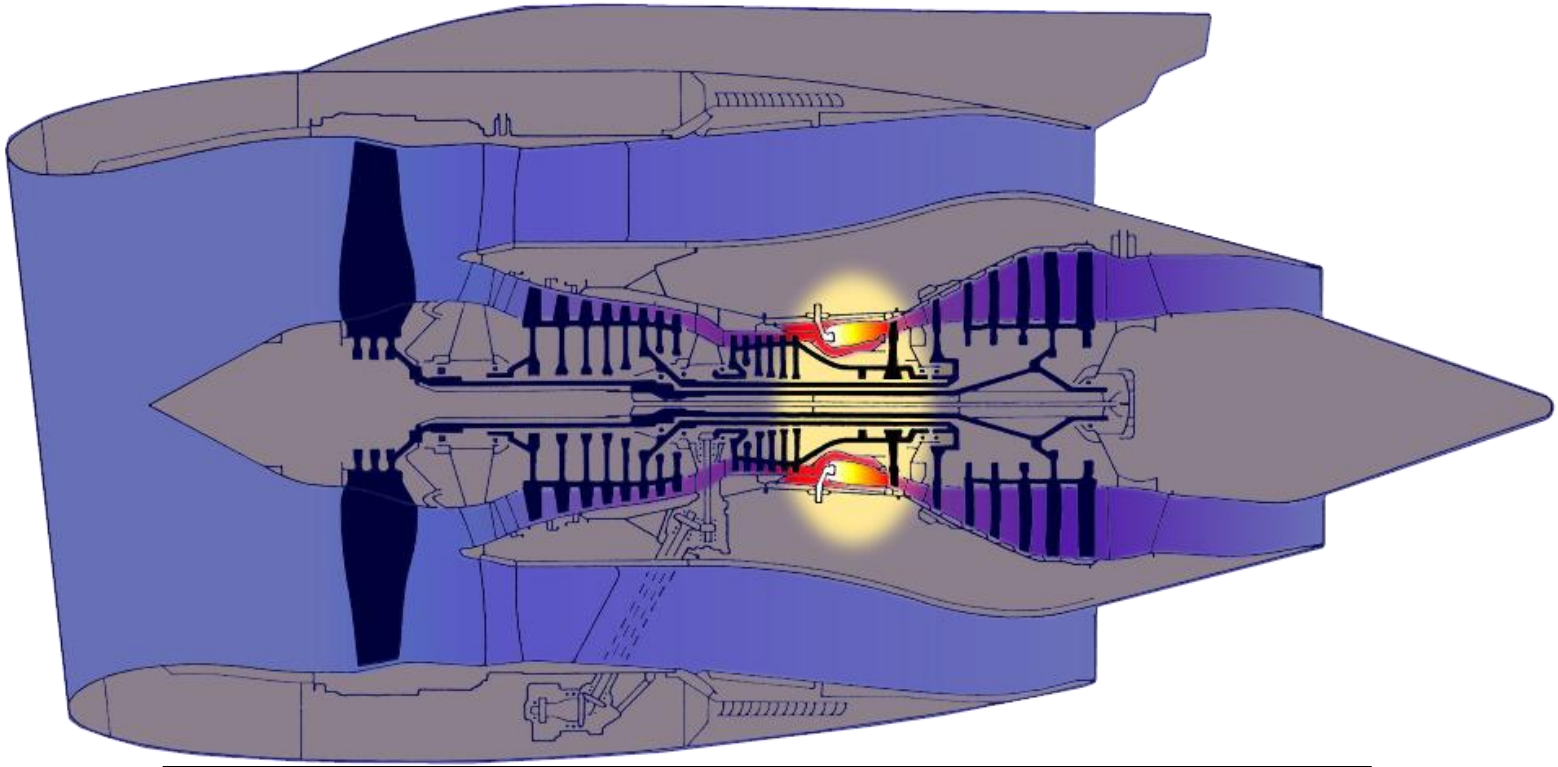
red regions indicate flow separation

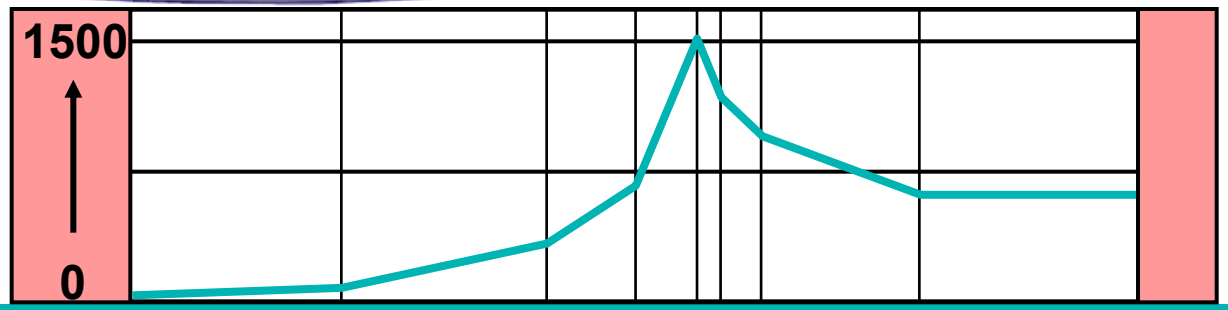




Rolls-Royce data – see front sheet

Efficient Burning

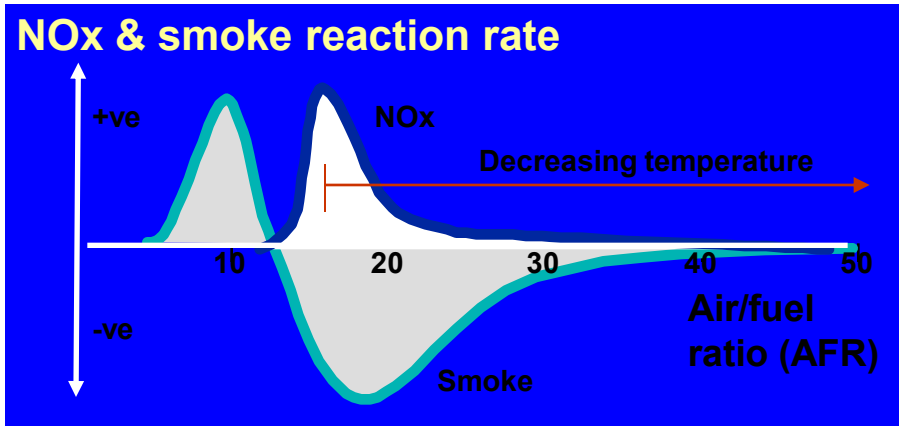


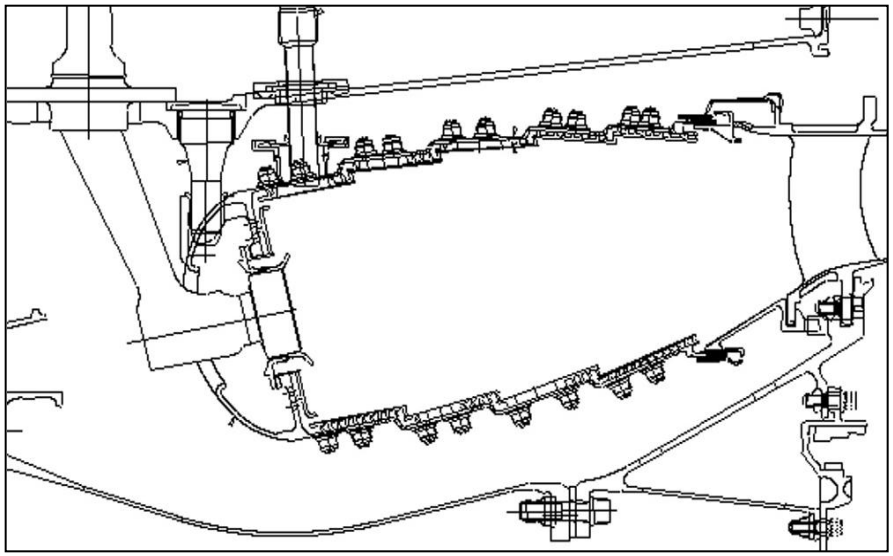


Temperature (degrees C)

Rolls-Royce data – see front sheet

Emissions constraints





At idle:

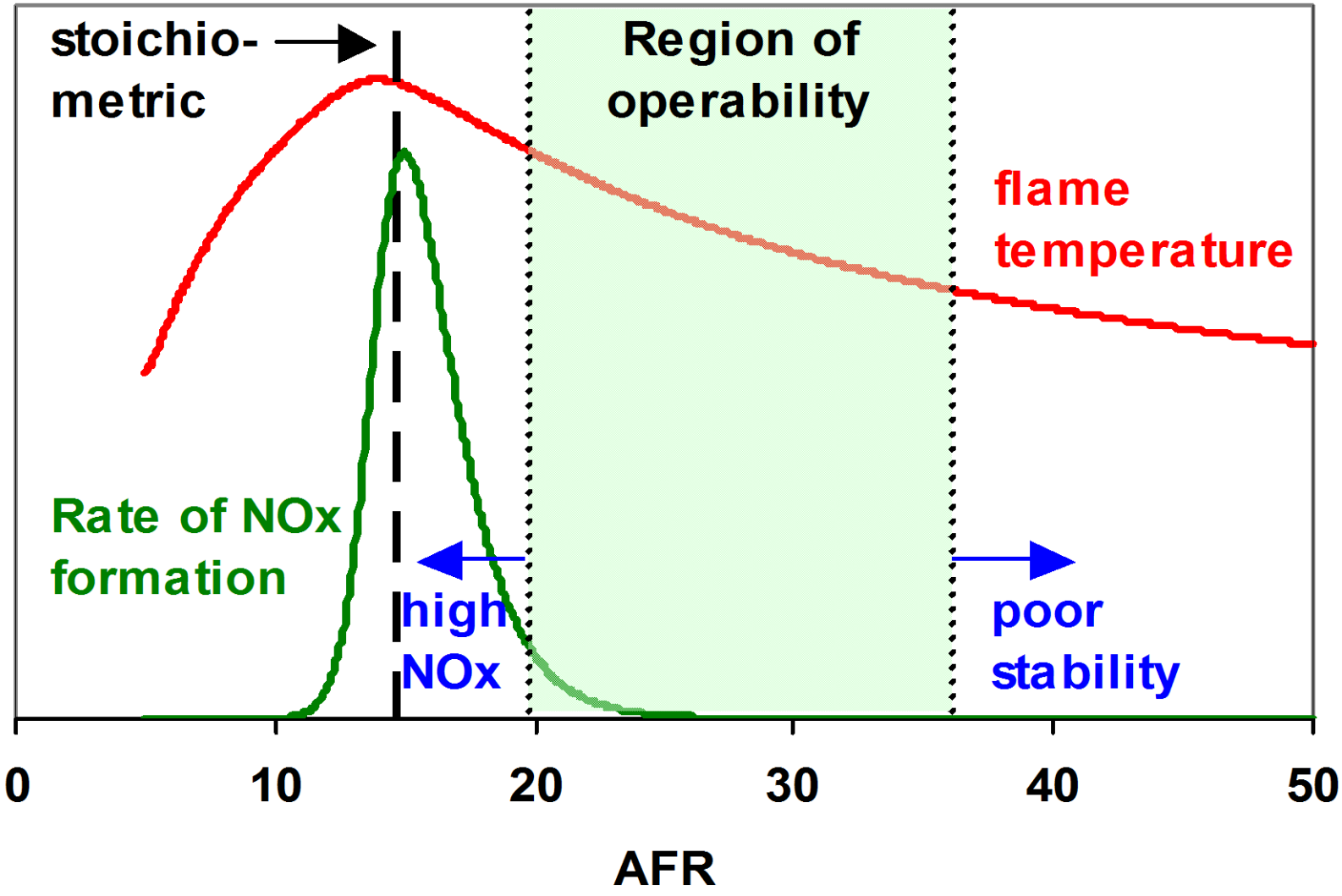
- Combustor pressure and temperature are low, and primary zone is weak (high AFR (Air/Fuel Ratio))
  - inhibits chemical reaction which creates CO and UHCs

At high power:

- Combustor temperature and pressure are high and primary zone is rich (low AFR)
  - a fuel-rich mixture creates smoke which is burned off in secondary zone
  - secondary combustion creates NOx establishing a trade with smoke

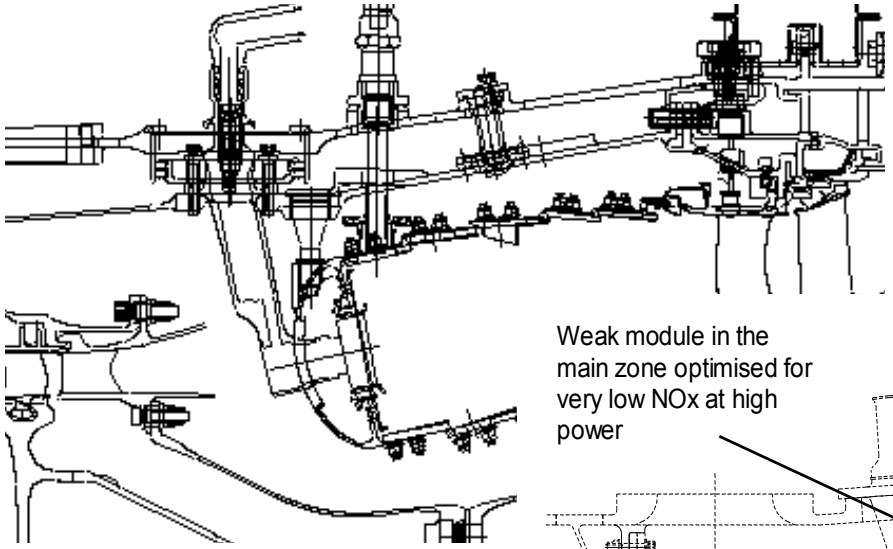
Rolls-Royce data – see front sheet

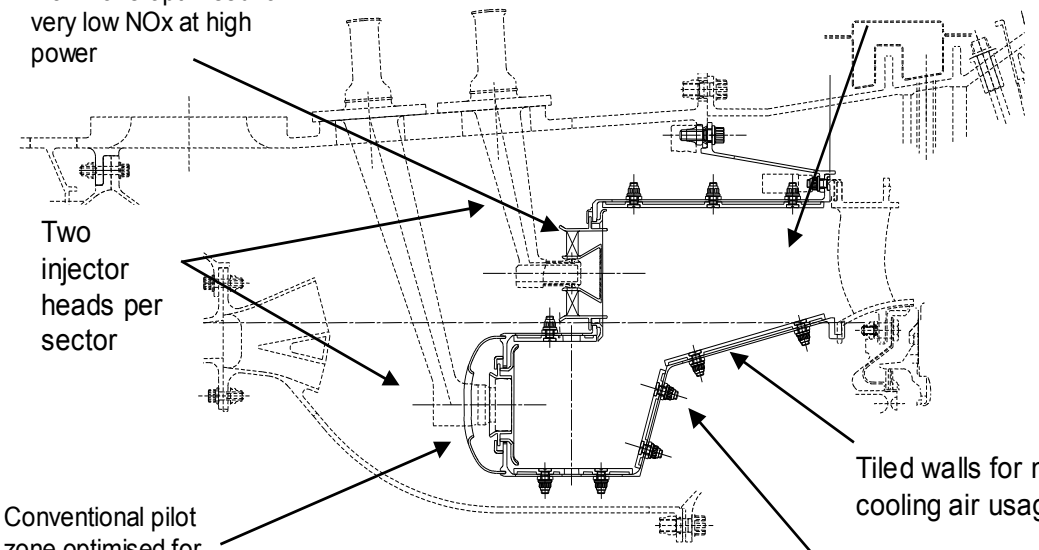
Design for low NOx: lean burn strategy



Rolls-Royce data – see front sheet

Improving Emissions - staging





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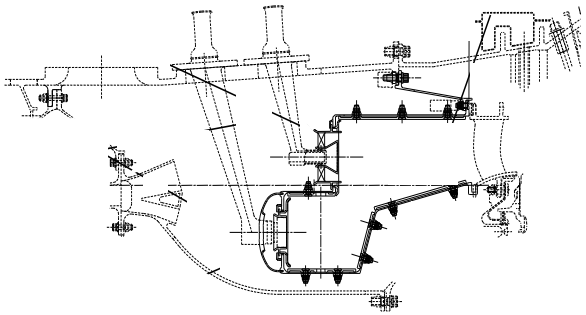
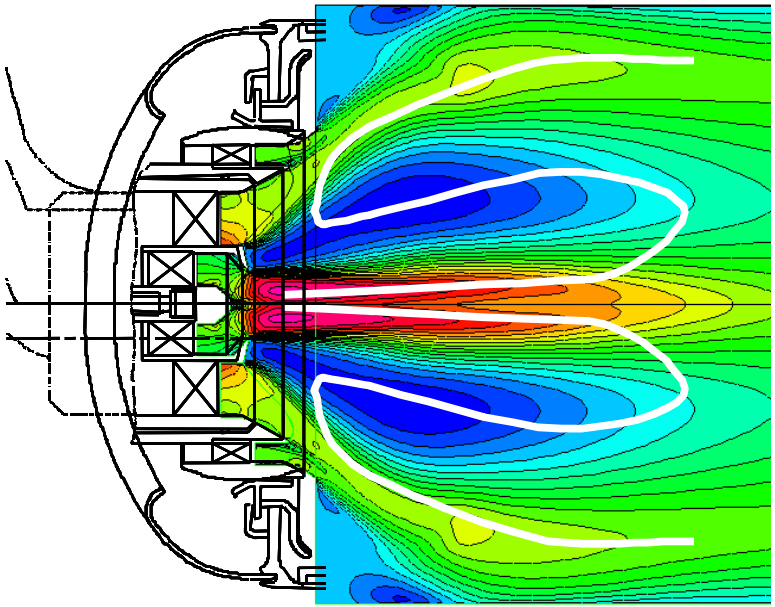
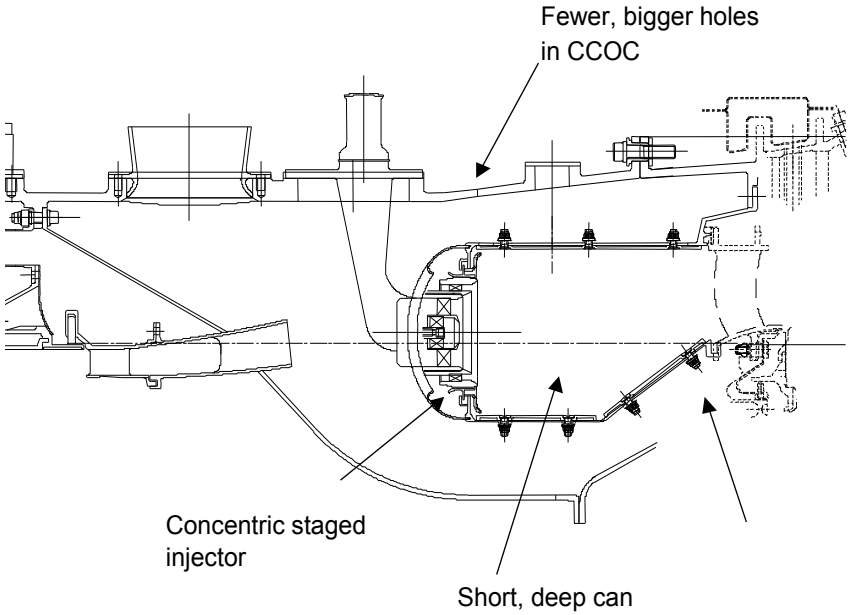
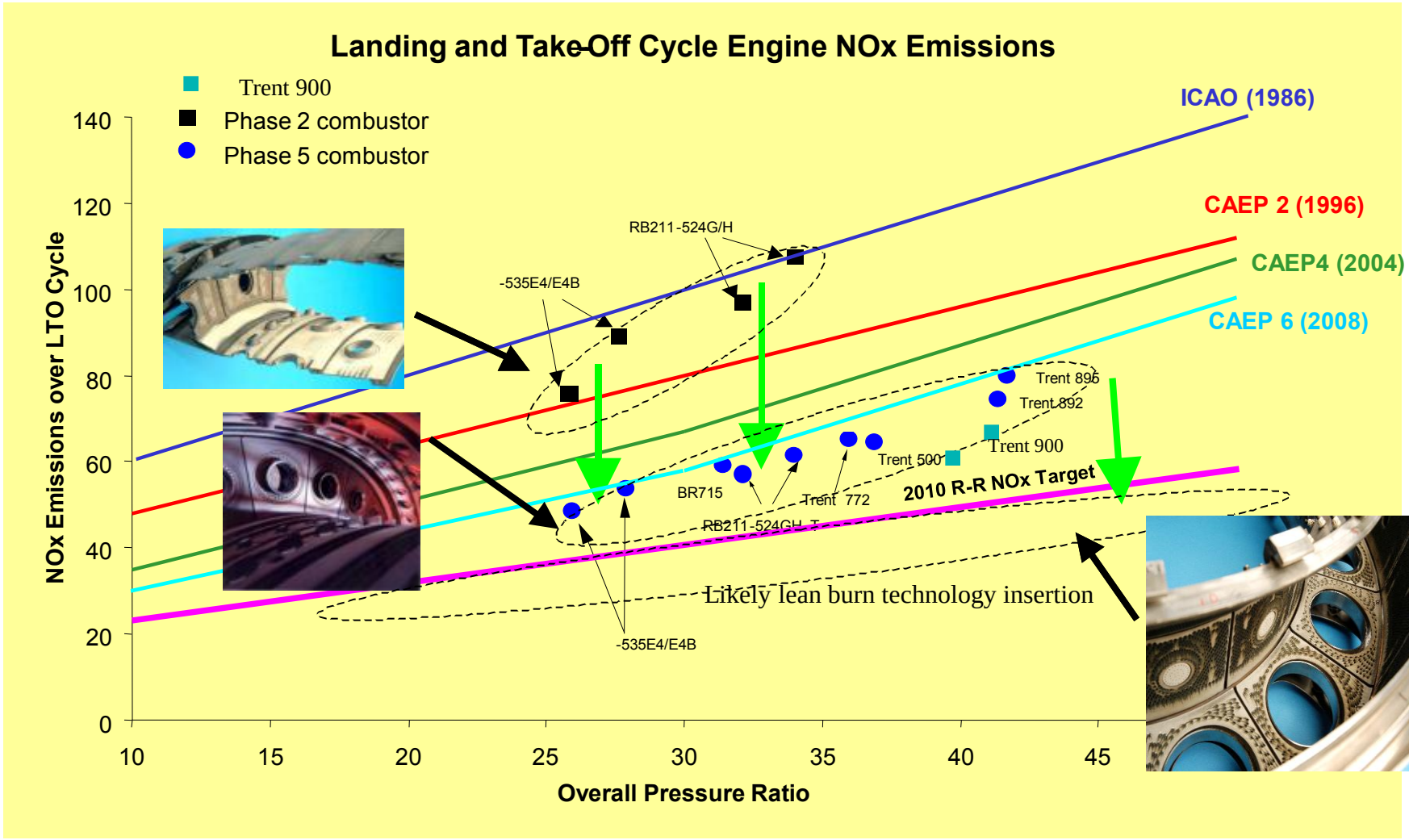






Rolls-Royce data – see front sheet

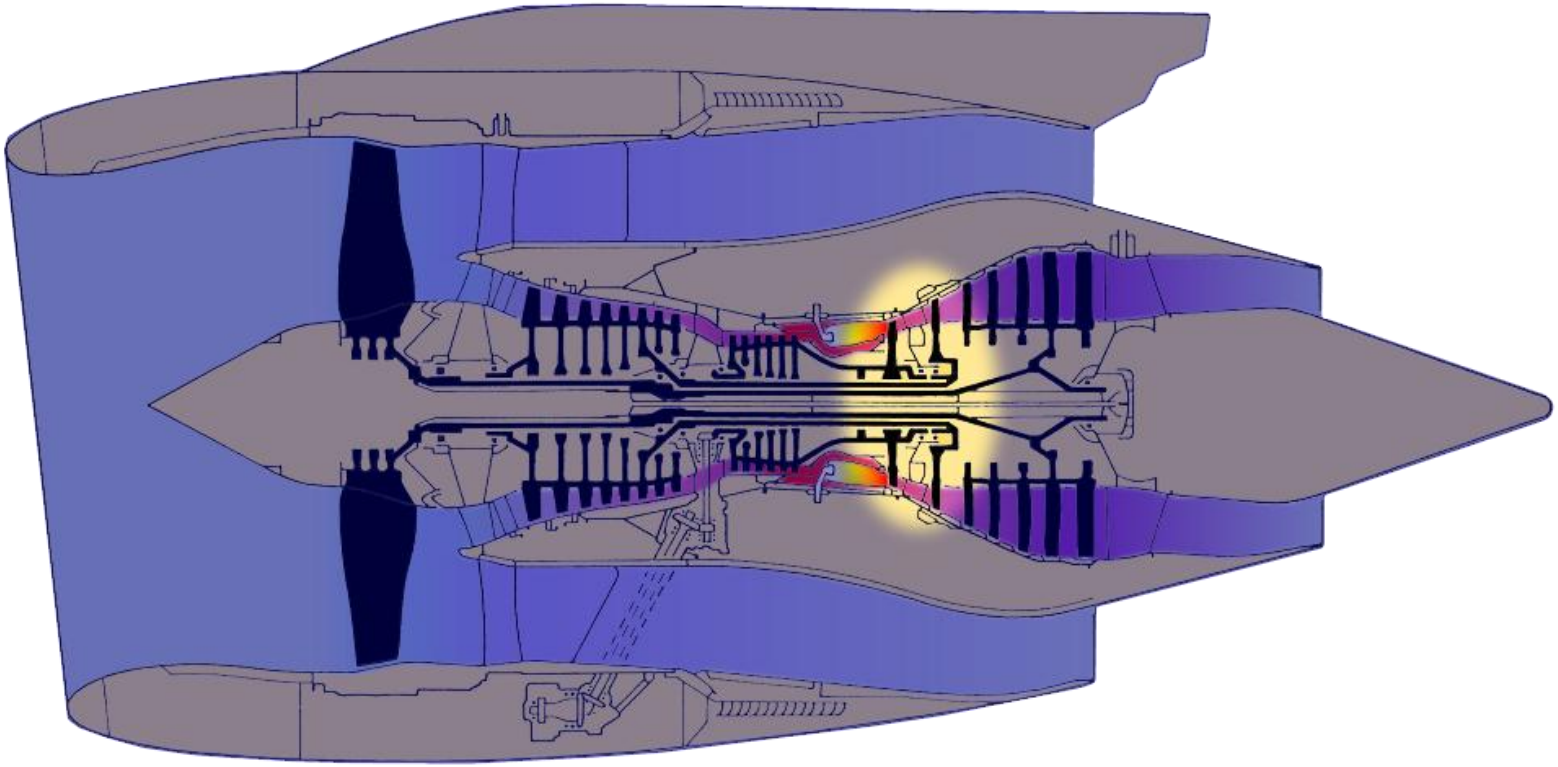
Emissions Compliance with Legislation

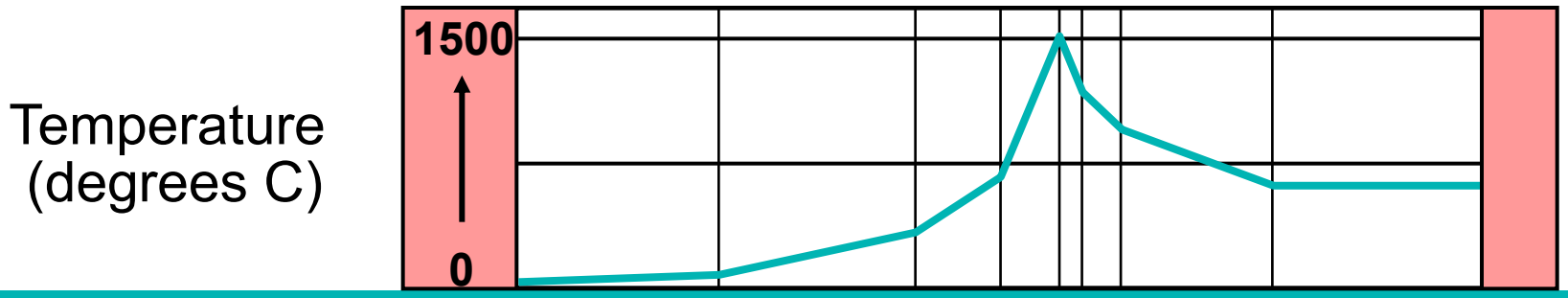


Rolls-Royce data – see front sheet

Rolls-Royce

Turbine Technology

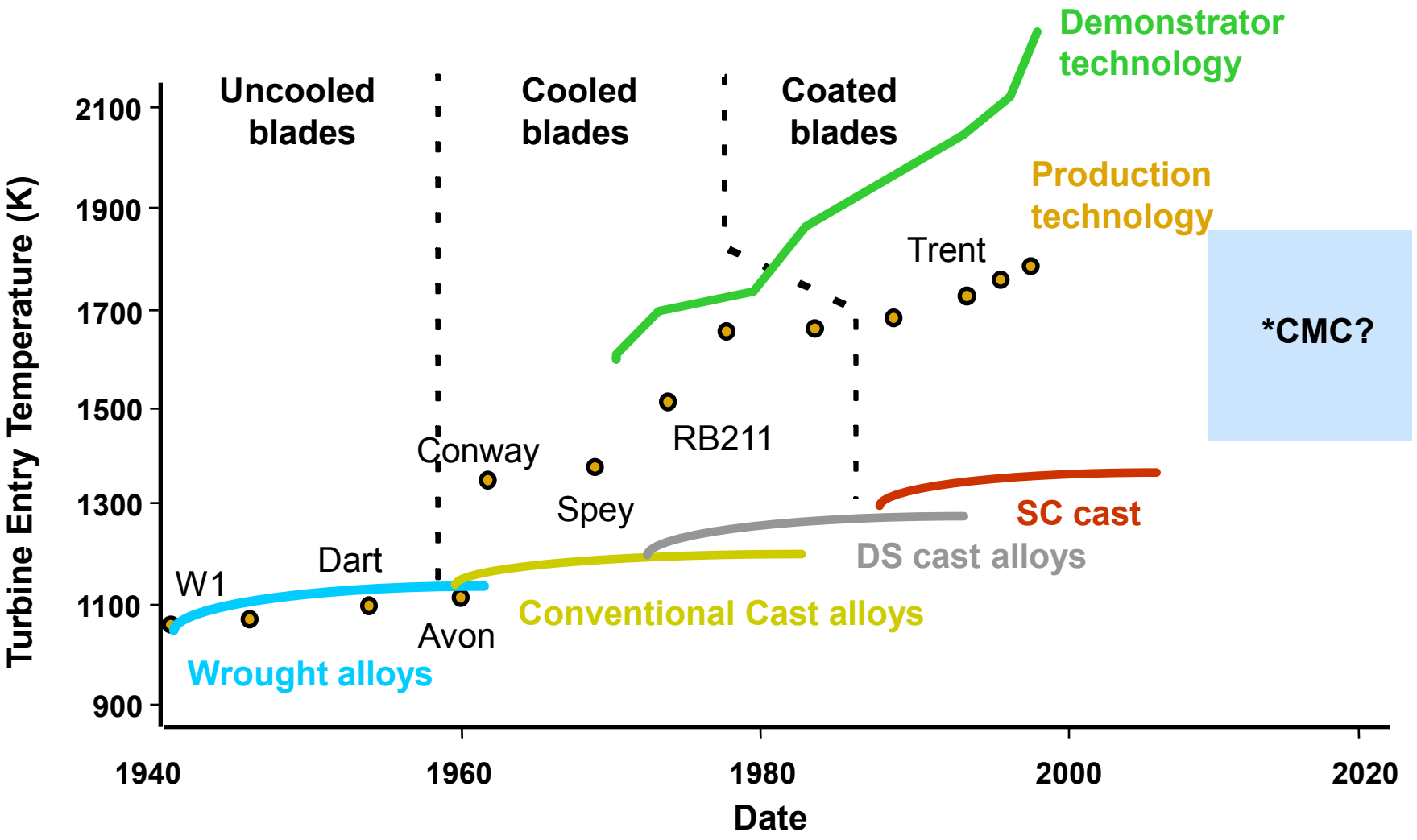




Rolls-Royce data – see front sheet

Rolls-Royce

Progress in Turbine Materials and Technology



*Ceramic Matrix Composites

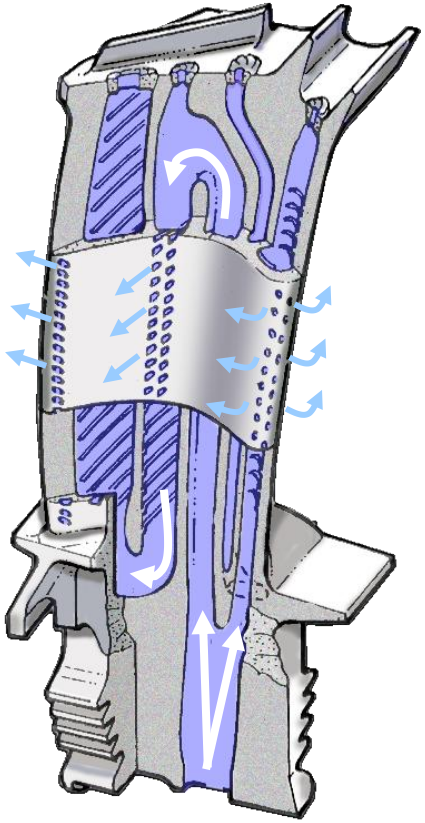
Rolls-Royce data – see front sheet

Turbine Cooling

Gas Temp: 825°C

Uncooled

Gas Temp: 1425°C



Cooling air

Multipass

Gas Temp: >1550°C

Thermal Barrier Coating

Rolls-Royce data – see front sheet

Rolls-Royce

Trent turbine blade

Overall ACARE* Environmental Targets for 2020

Targets are for new aircraft and whole industry relative to 2000

Reduce perceived external noise by 50%

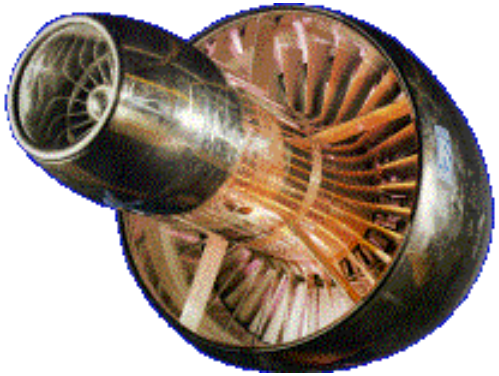
Reduce fuel consumption and CO_2 emissions by 50%

Reduce NO_X emissions by 80%

The ACARE targets represent a doubling of the historical rate of improvement…

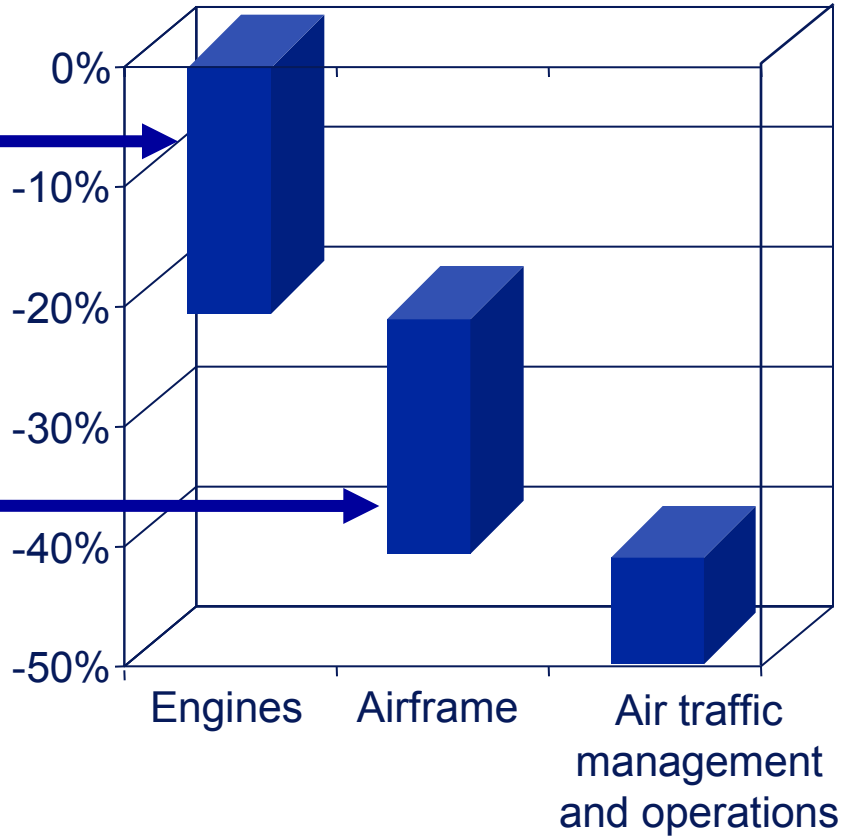
* Advisory Council for Aerospace Research in Europe

Meeting 50% fuel burn needs changes in all areas



Possible design solutions

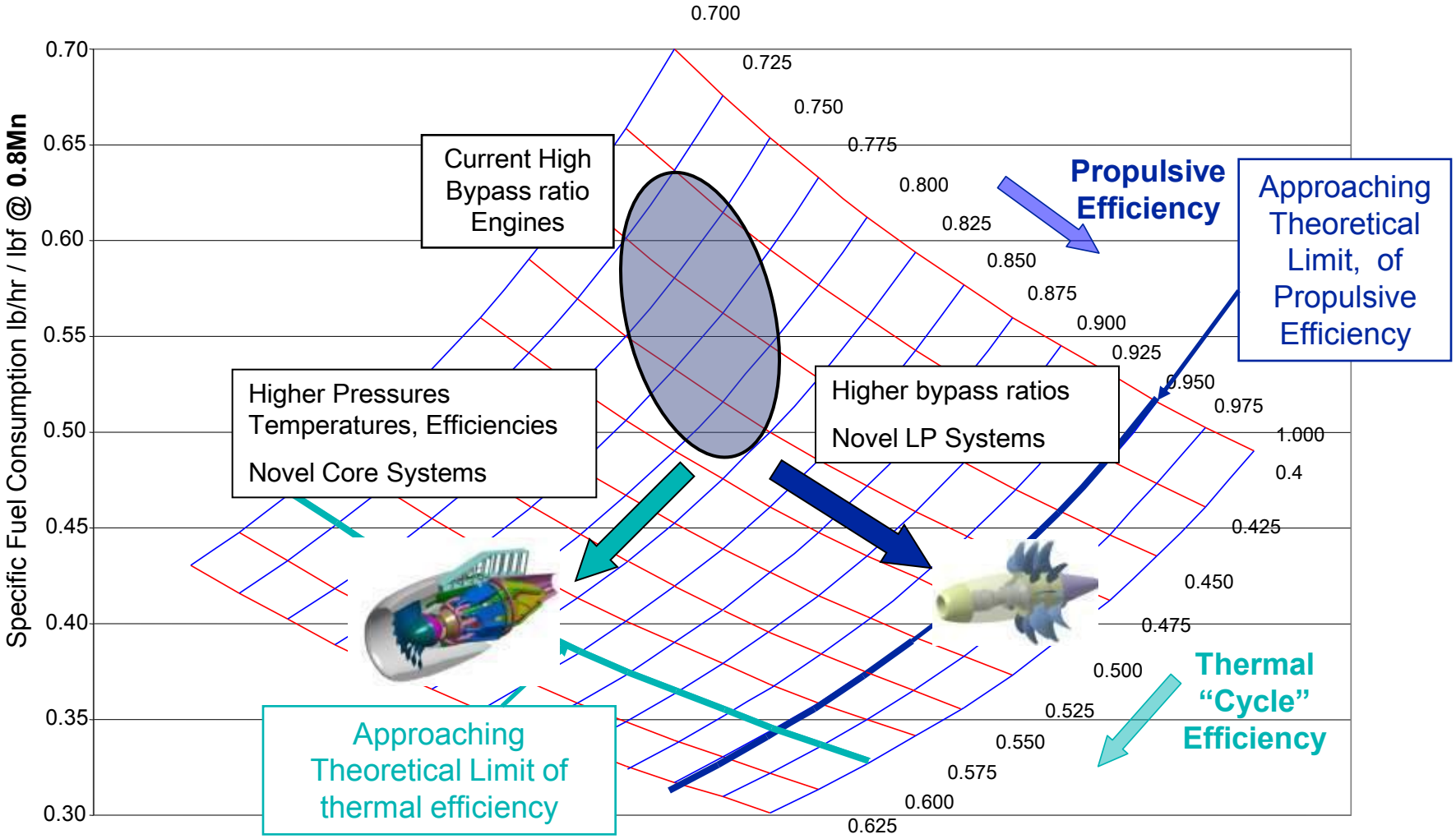
Contributions to CO_2 reduction



Rolls-Royce data – see front sheet

Rolls-Royce

Theoretical sfc improvements



Rolls-Royce data – see front sheet

Rolls-Royce

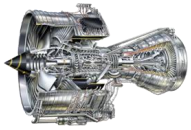
European Engine Technology Roadmap

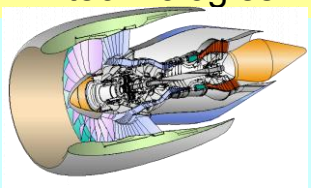
SILENCER
Noise reduction technologies

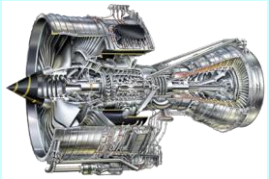
VITAL
Low spool components for DDTF, GTF and CRTF

SEVENTH FRAMEWORK PROGRAMME

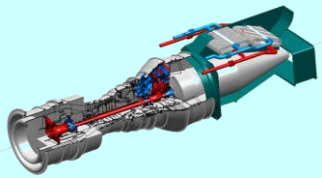
year 2000 in service engine

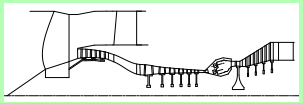


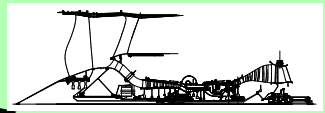


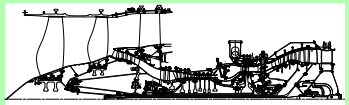


ANTLE&CLEAN
Component improvements, New components



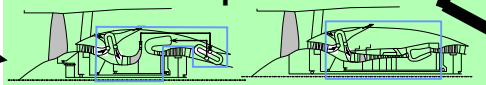


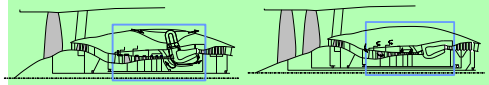




LP component impr.
New LP components

HP component impr.
New components





Engine Validation Concept 1

Engine Validation Concept x

ACARE Reference

EEFAE
Validation at engine level

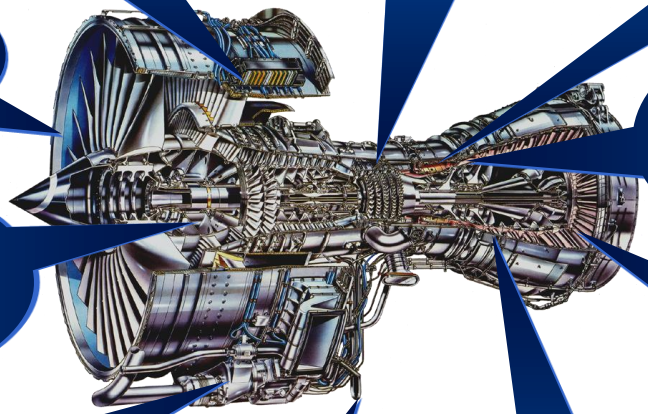
NEWAC
High spool components, Intercooler, Recuperator

Rolls-Royce data – see front sheet

Rolls-Royce

ANTLE

Trent 500 baseline engine with new technologies incorporated



Controls
• Distributed systems

HP compressor
• 5 stages
• Blisks

Combustor
• Lean burn
• Staged combustor

Whole engine
• Increased temperatures and pressures

HP turbine
• Reduced blade numbers
• Increased temperatures
•Contra-rotating

Oil system
• Oil pump
• Air riding carbon seals
• Brush seals

LP turbine
• 4 stages
• Novel construction

Accessory gearbox
• Bearings
• Seals

IP turbine
• Cooled
• Variable capacity

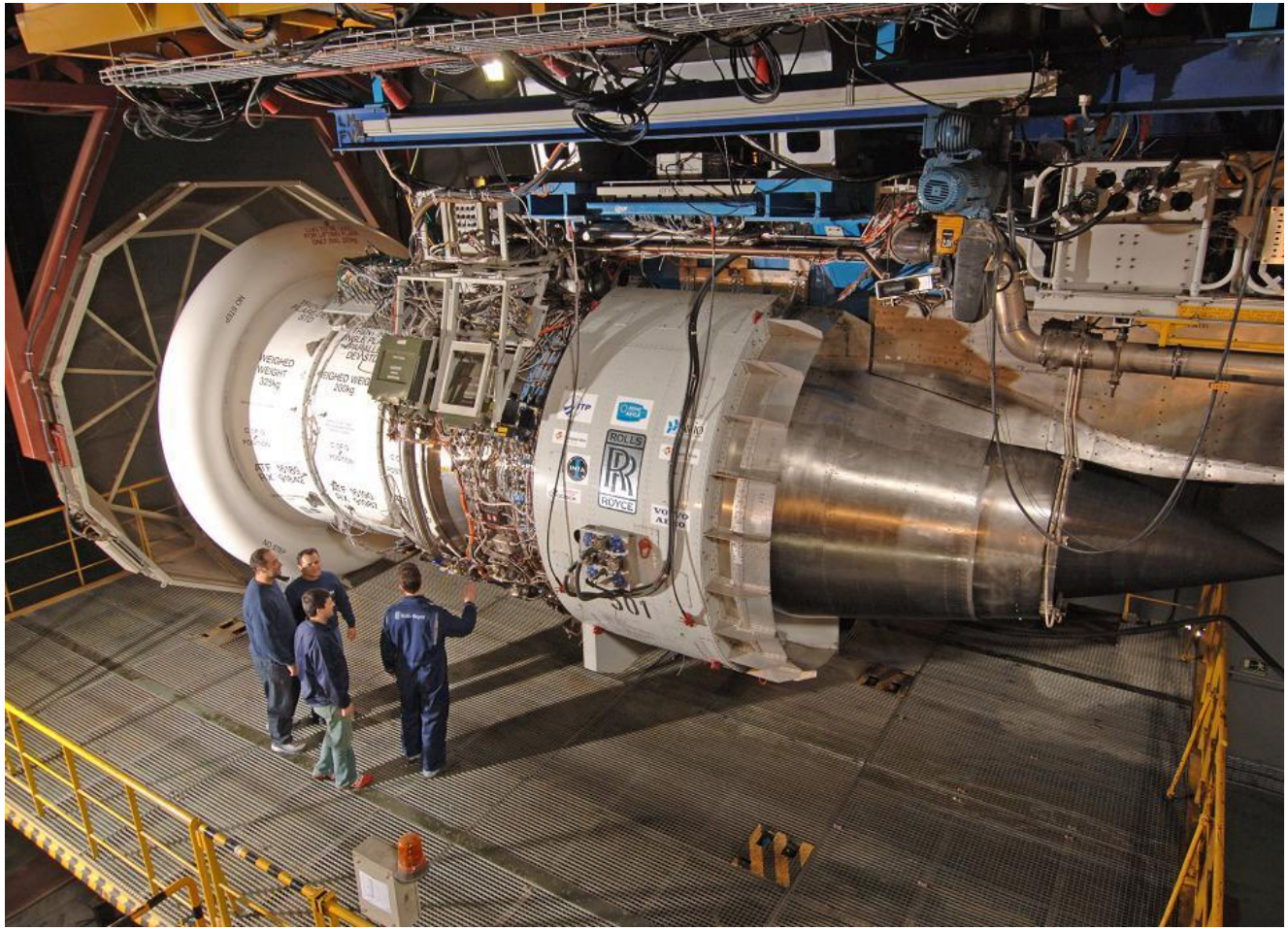
Health monitoring
• Intelligent sensors
•Advanced EHM

ANTLE =
Advanced Near-Term Low Emissions

EU, UK govt. & Spanish govt. funded

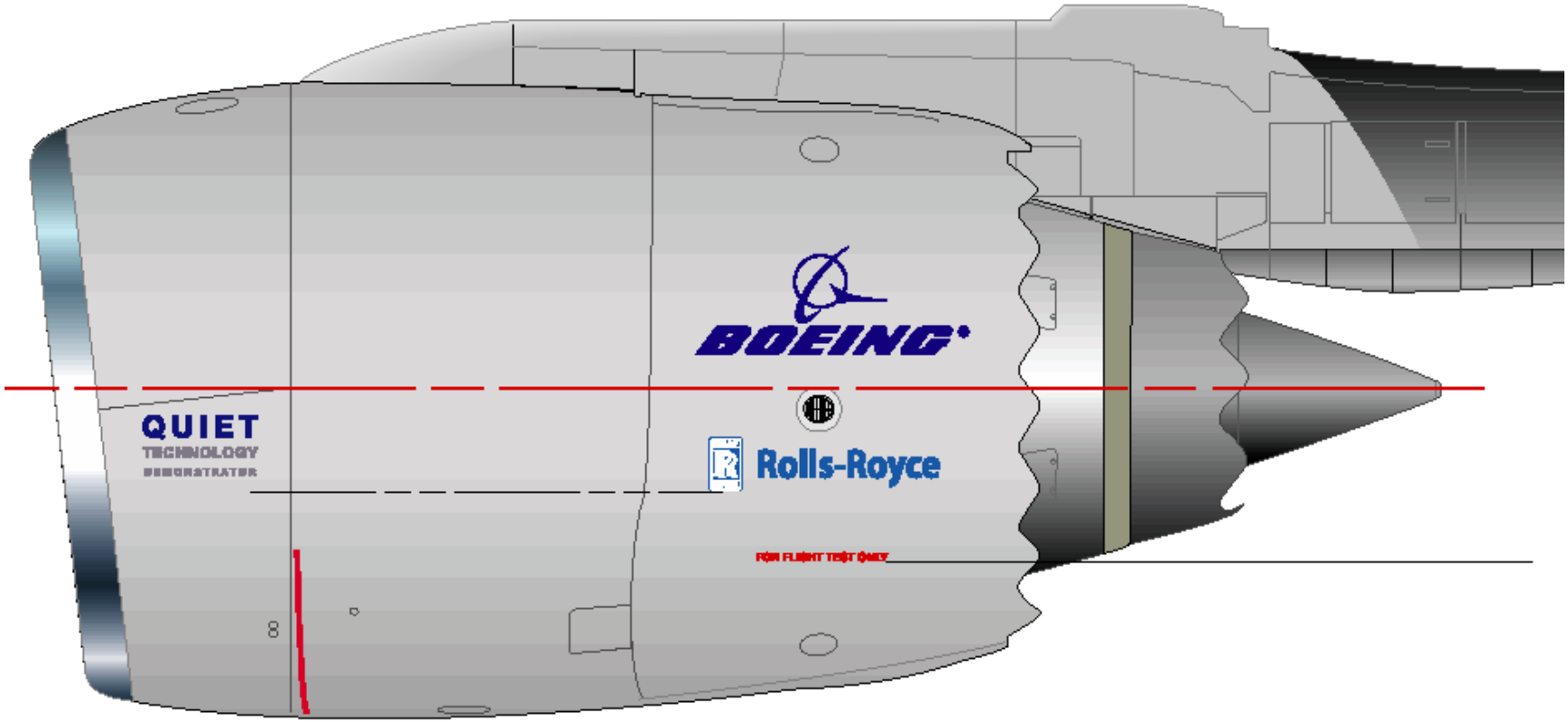
Rolls-Royce data – see front sheet

ANTLE engine test



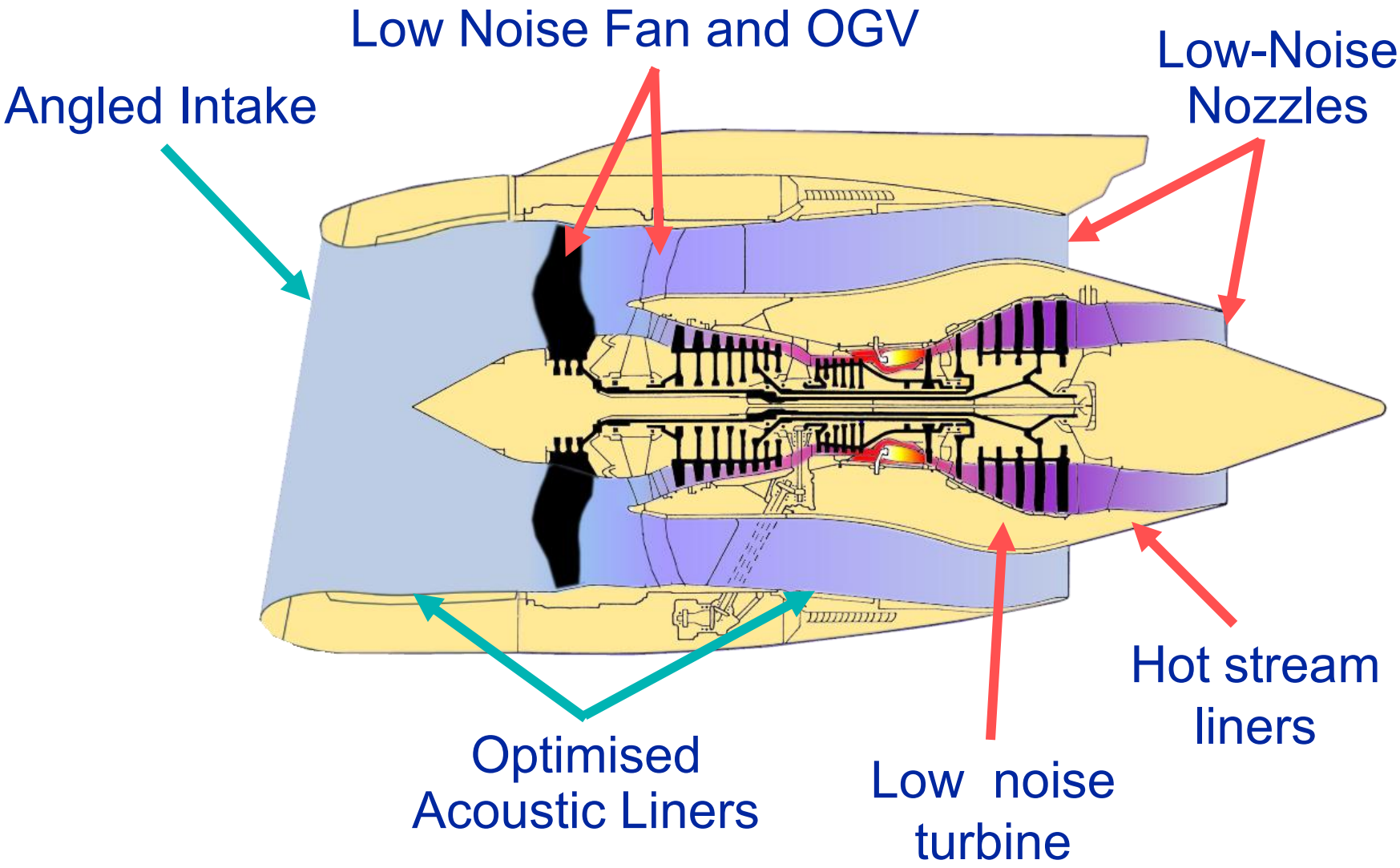
EU and DTI Funded Technology Validation Programme

Noise Technology



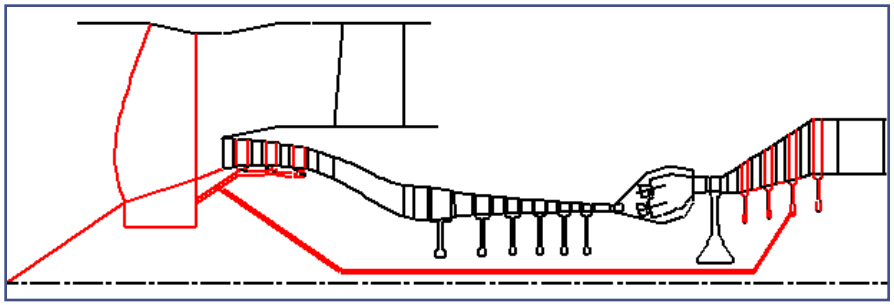
Rolls-Royce data – see front sheet

Noise Technology validation - SILENCE(R)

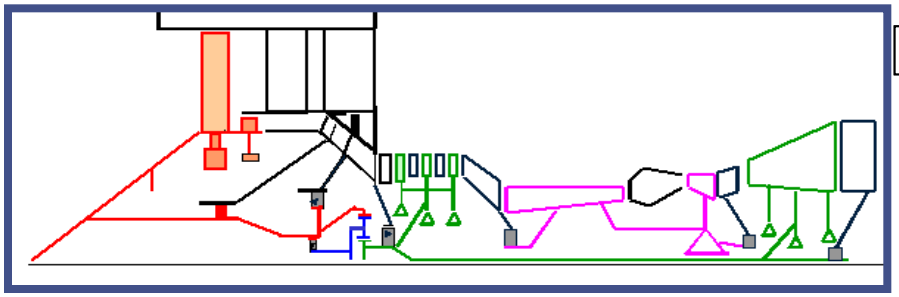


Rolls-Royce data – see front sheet

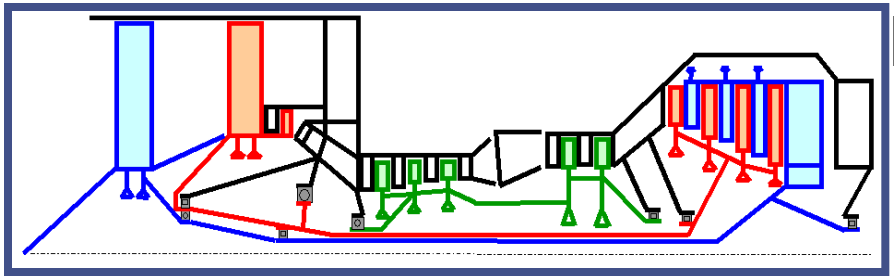
VITAL project overview



DDTF



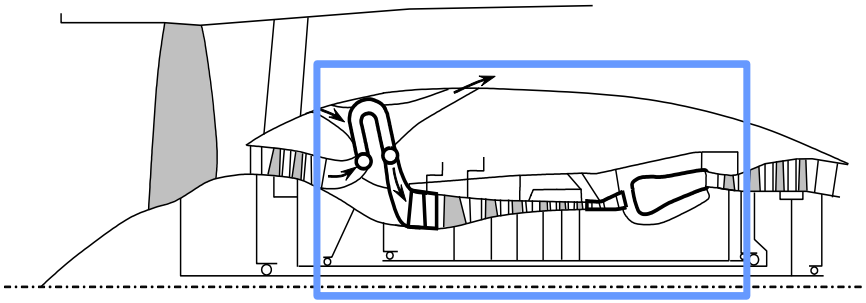
GTF

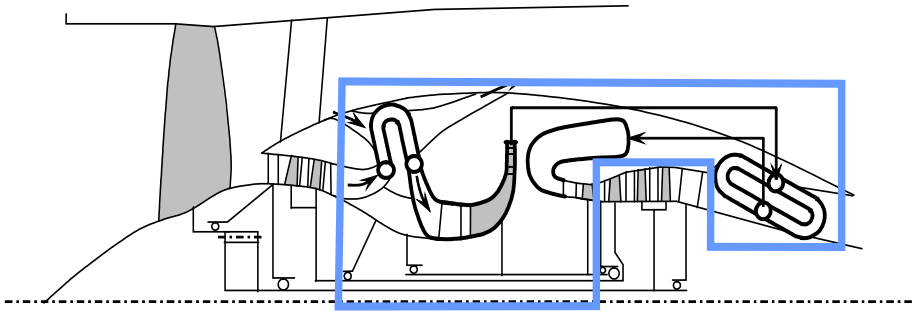


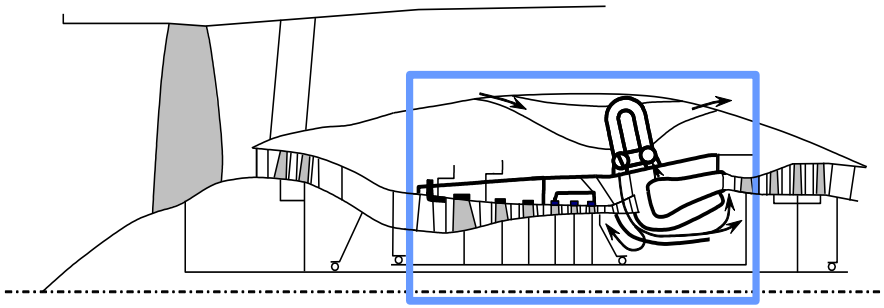
CRTF

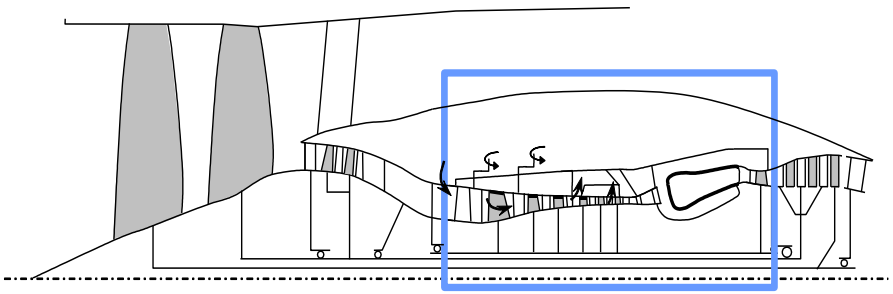
- Enabling higher propulsive efficiency through lightweight LP technologies
- 3 engine configurations
- Technology to TRL5 by 2009

NEWAC project overview





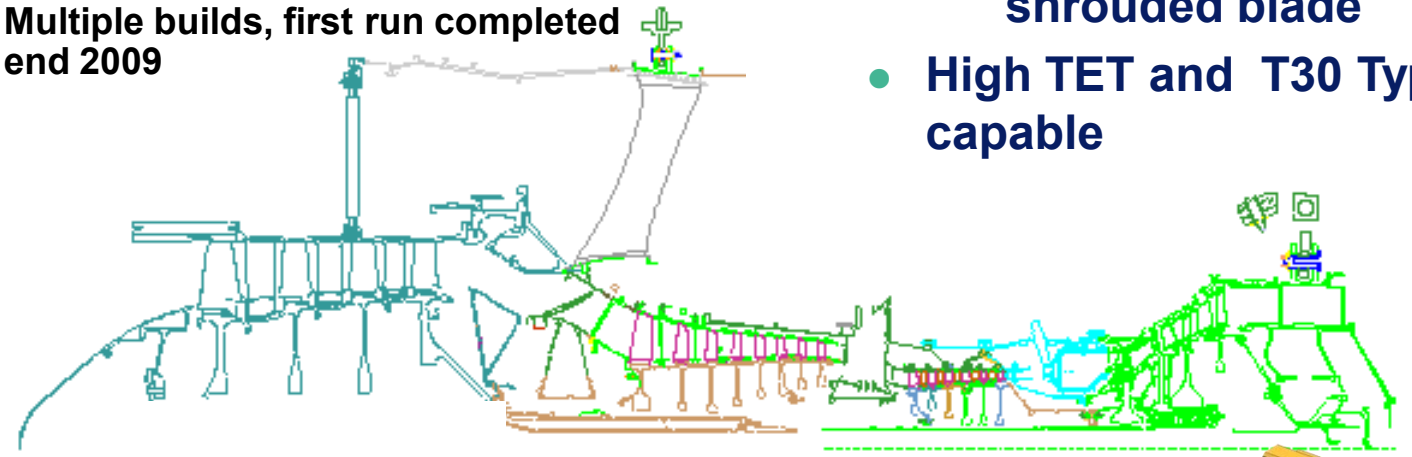




- Enabling higher cycle efficiency
- 4 engine configurations
- Technology to TRL4 by 2010

EFE – Environmentally Friendly Engine

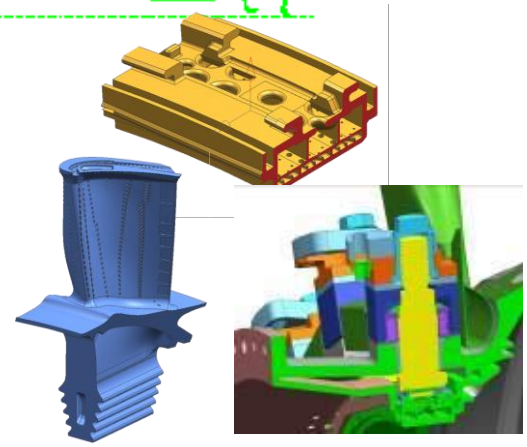
- **EFE (Environmental Friendly Engine)**
  - ~£100m programme
  - Trent 1000 donor hardware
  - Multiple builds, first run completed end 2009



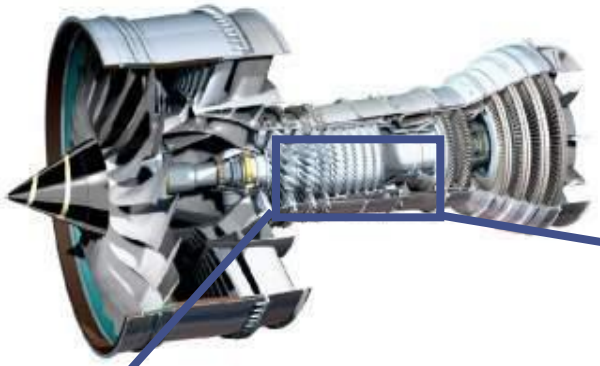
- **Turbine**
  - **Tip clearance control system**
    - **Efficiency target as shrouded blade**
  - **High TET and T30 Type Test capable**

- **Lean Burn Combustion system**
  - **Target 30% CAEP 6 NOx**
  - **Combustion efficiency targeted at current rich burn levels**
  - **Fuel management system**

All new test bed in Bristol



E3E programme

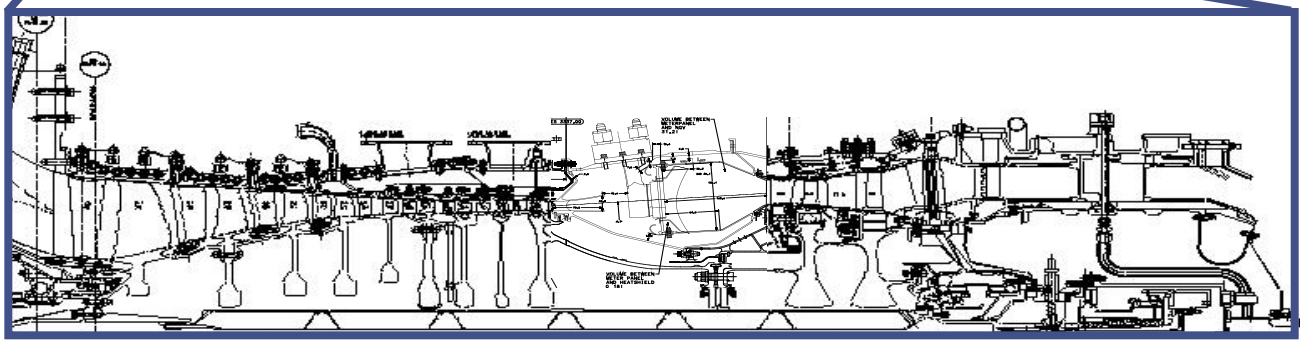


Core engine technology enabling:

- 15% fuel burn reduction

German funded programme

- 2nd test just completed
- Follow on builds in 2011 and 2012 planned



Compressor

- 22:1 in 9 stages
- Blisks

Lean burn combustion

Turbine

- 2 stage shroudless
- VPC
- Shroud and tip coating

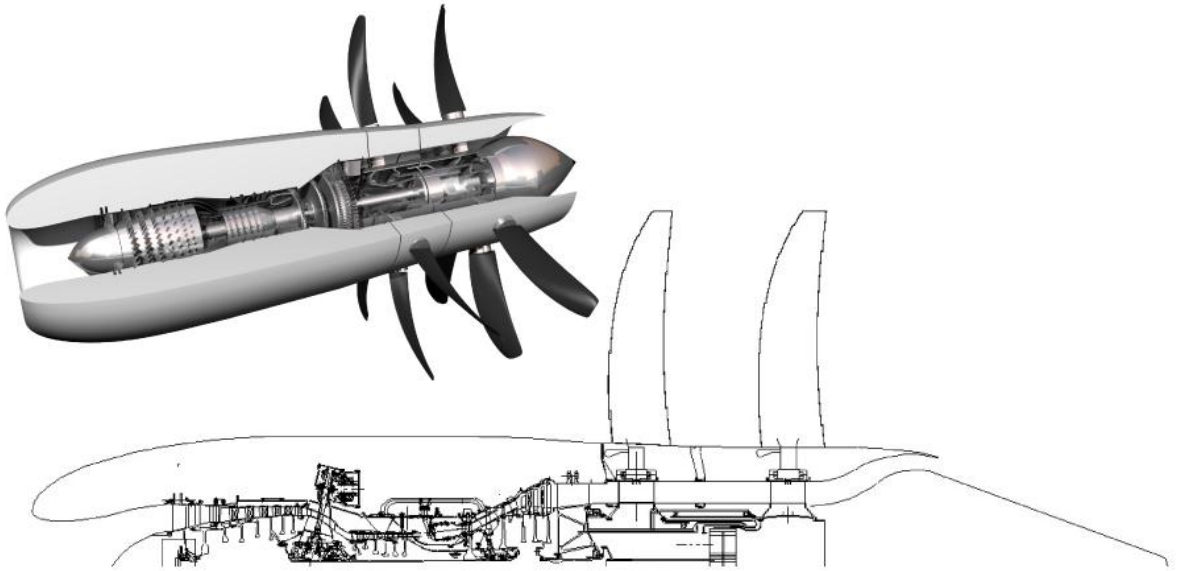
Rolls-Royce

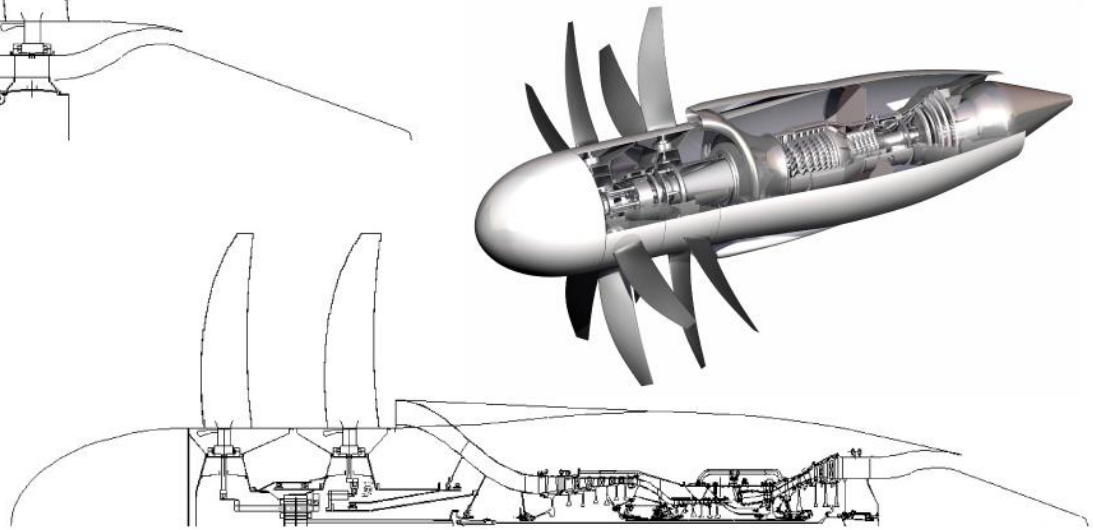
Core 3/2b test programme

- Test Campaign in Altitude Test Facility Stuttgart from March to May 2010
  - 15 days of engine test, approx. 70 starts and 40 running hrs
- Extensive Test Matrix for Altitude Relight
  - successful light-ups exceeding target envelope
  - successful Quick Windmill Relights
- Turbine Liner Concept
  - successful validation of tip clearance system

- Engine Performance Validated at Sea Level and Altitude
- Full air system validation including:
  - Pressures and temperatures
  - Seal performance
  - Bearing loads

Open Rotor – the game changer
Pusher and Puller Configurations

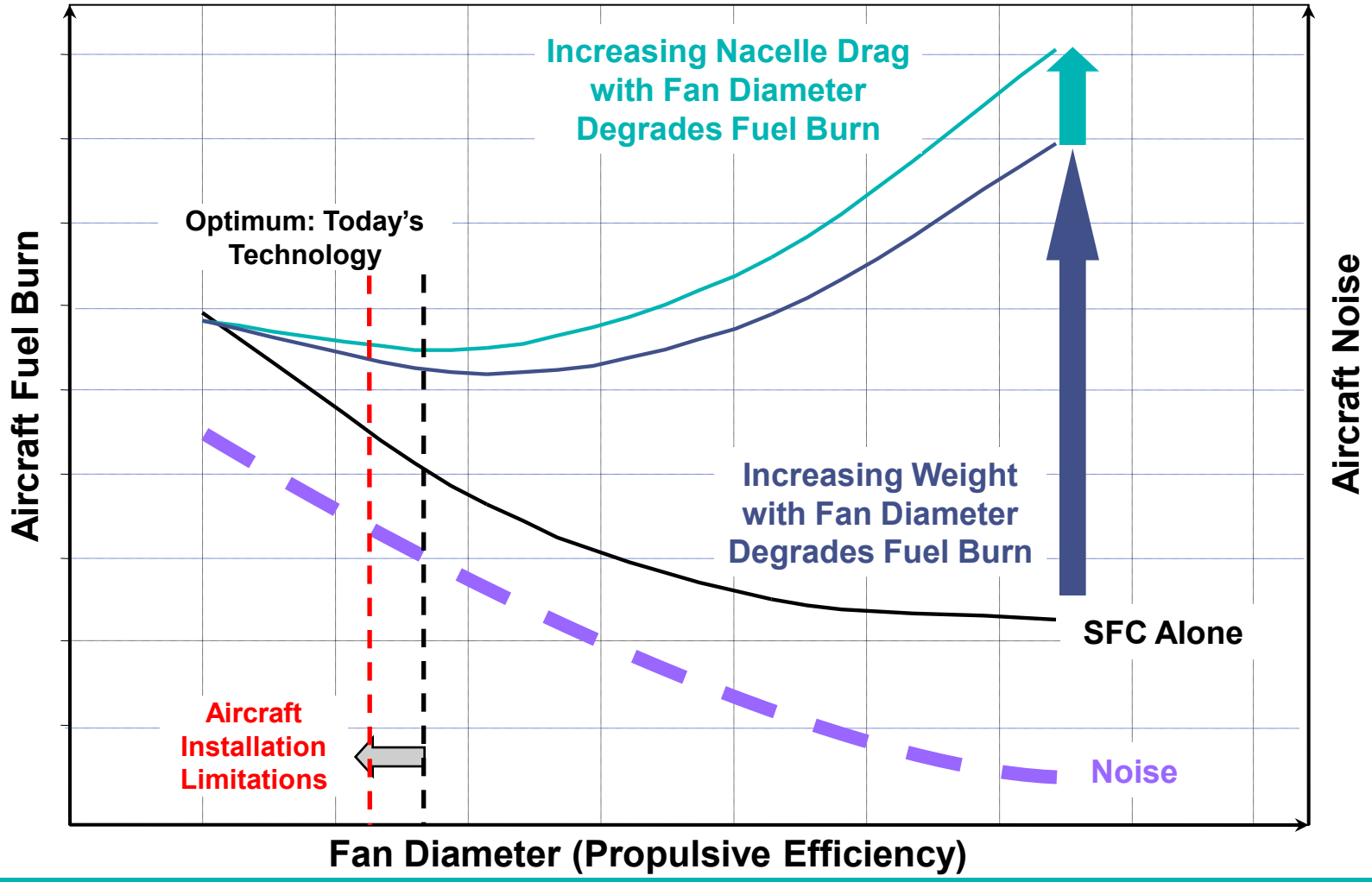




Rolls-Royce data – see front sheet

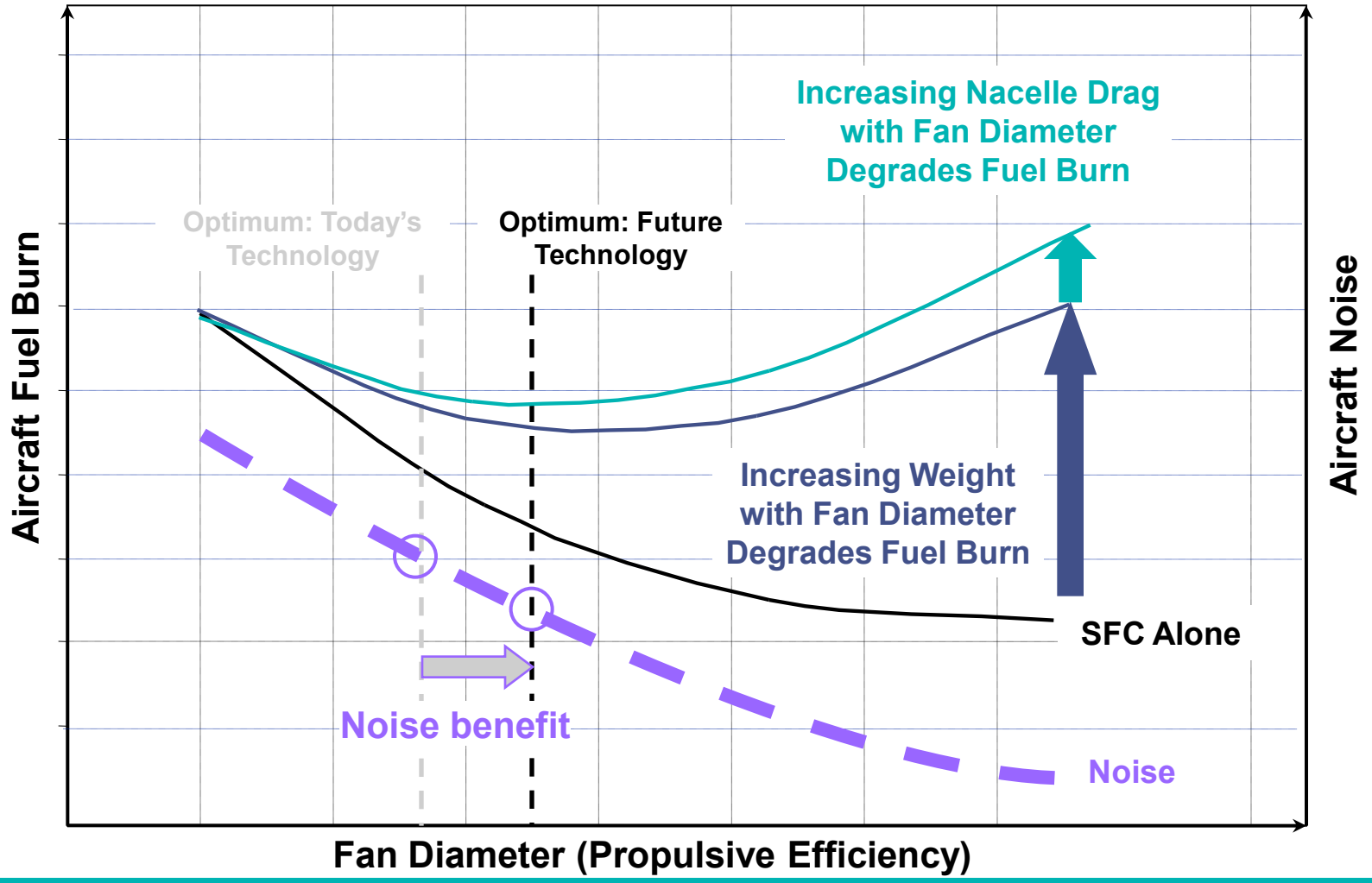
Rolls-Royce

Optimum Fan Diameter – Fuel Burn



Rolls-Royce data – see front sheet

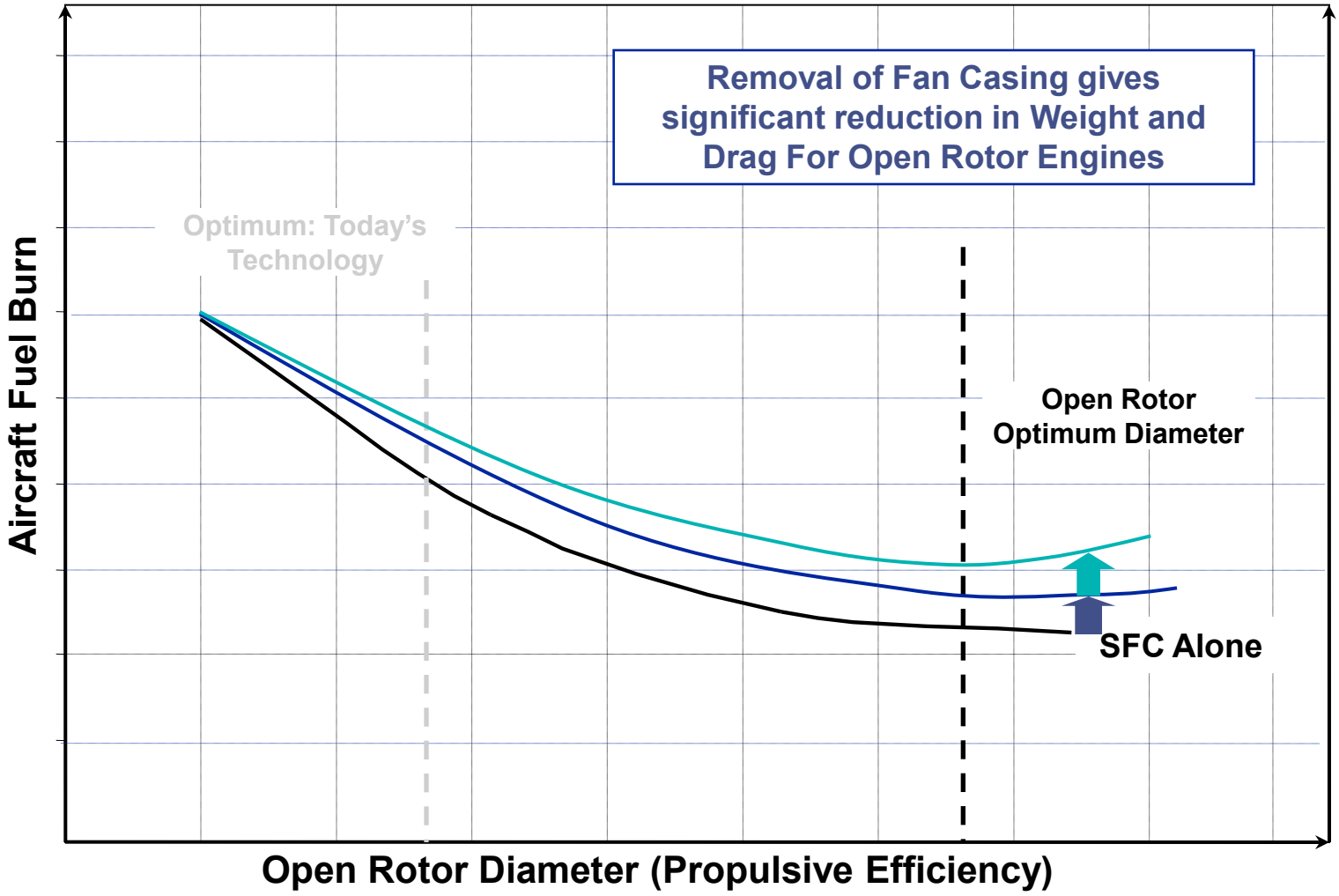
Optimum Fan Diameter – Fuel Burn



Rolls-Royce data – see front sheet

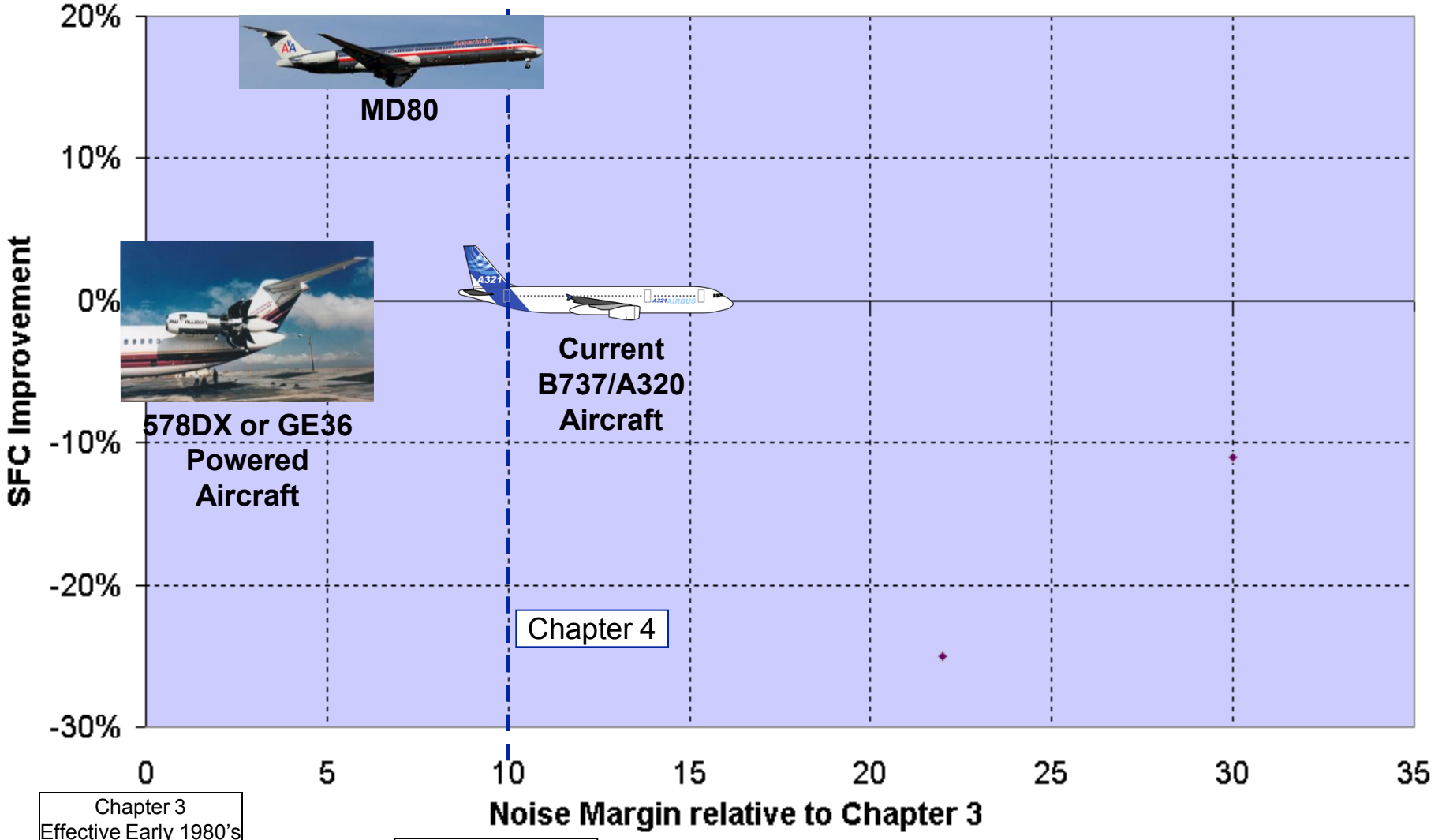
Rolls-Royce

Optimum Fan Diameter – Fuel Burn



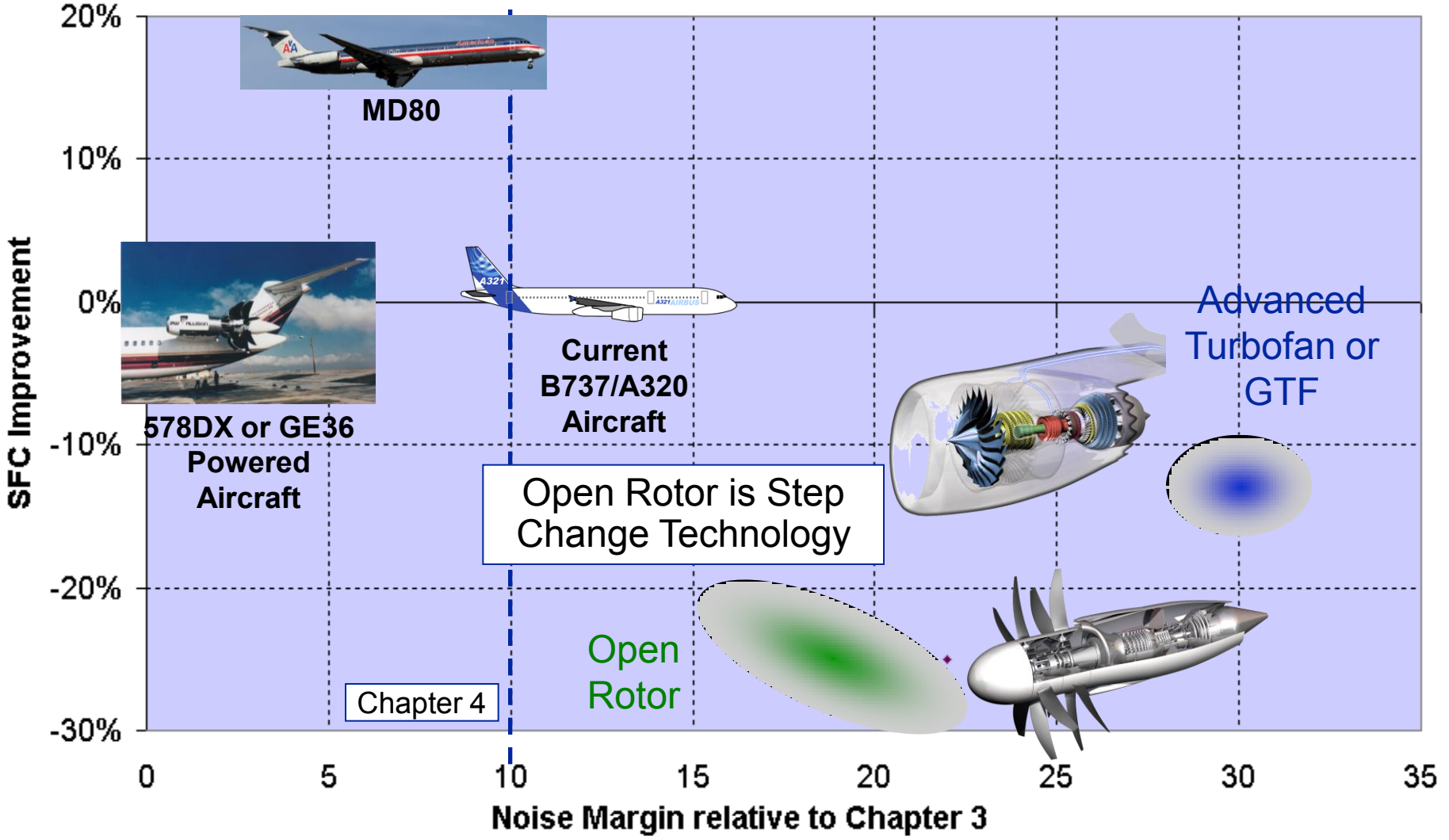
Rolls-Royce data – see front sheet

Why Open Rotors Did Not Succeed in the 1980's?
Difficulty in Achieving Current and Future Noise Margins



Rolls-Royce data – see front sheet

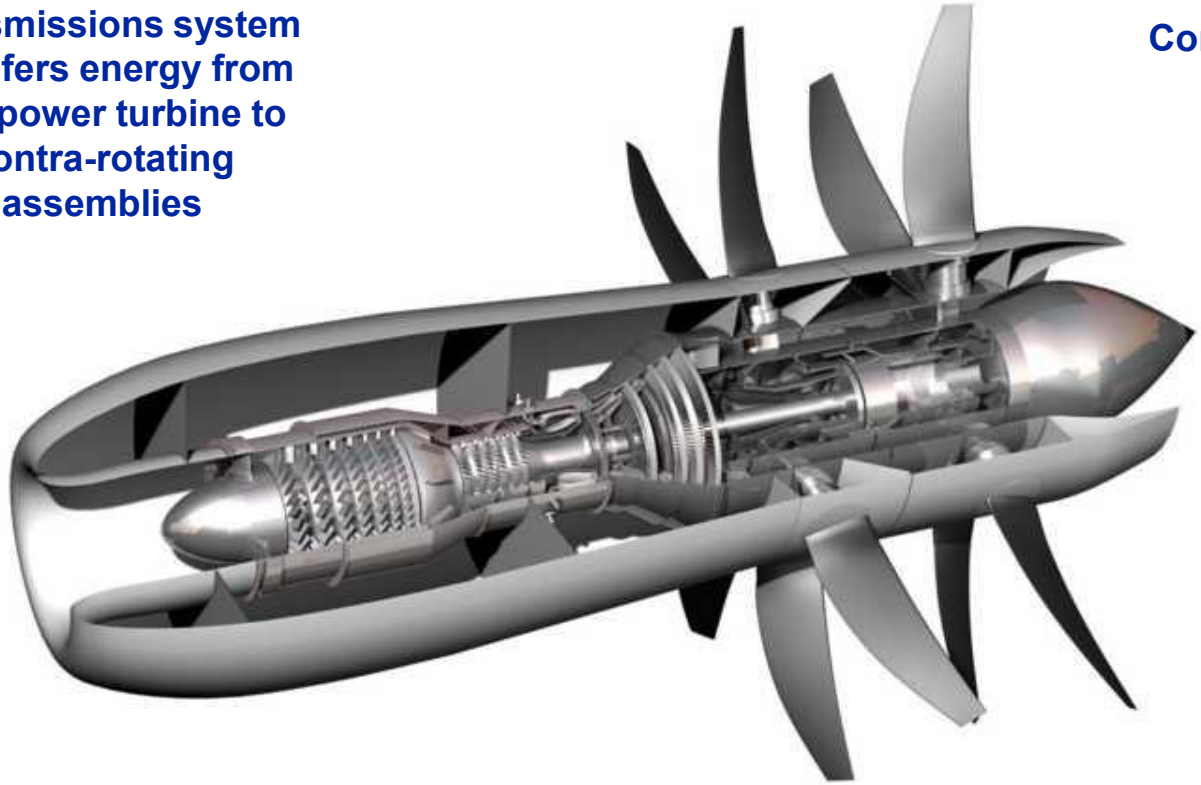
Local and Environmental Trade-Offs
A320/737 Aircraft Sector



Rolls-Royce data – see front sheet

Enabling technologies - Open Rotor

Transmissions system transfers energy from free power turbine to contra-rotating assemblies



Contra rotating propellers Noise optimised configuration

Advanced gas turbine 2 spool core based on turbofan technology programme

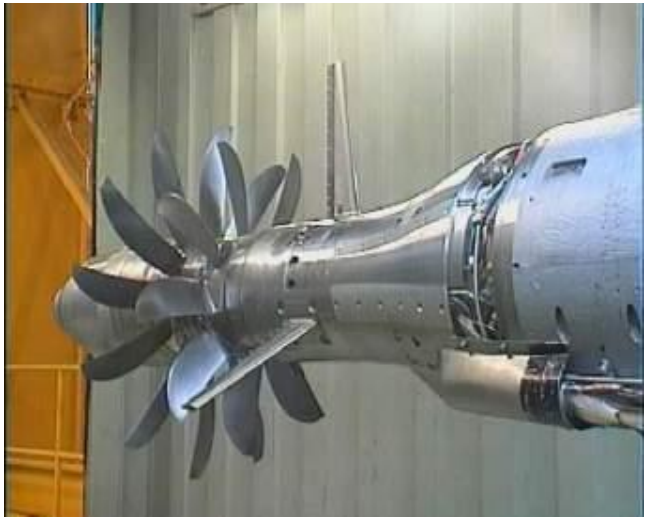
High speed Free Power Turbine drives propellers through transmission system

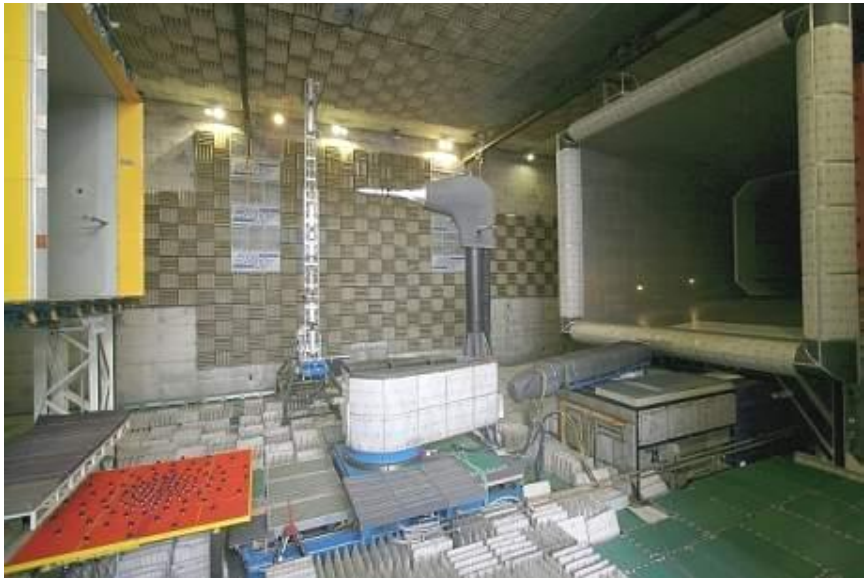
Propeller pitch change mechanism to maintain optimum propeller angle and torque split

Open Rotor verification

Rig 145 at DNW and ARA test facilities

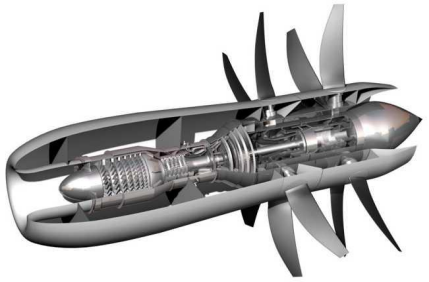
- 1/6th scale rig (28” diameter)
- Aero and acoustic verfication
- Isolated and installed
- Low speed in DNW
- High speed testing at ARA Bedford
- Phase 1 testing complete 2008/9
- Phase 2 currently underway

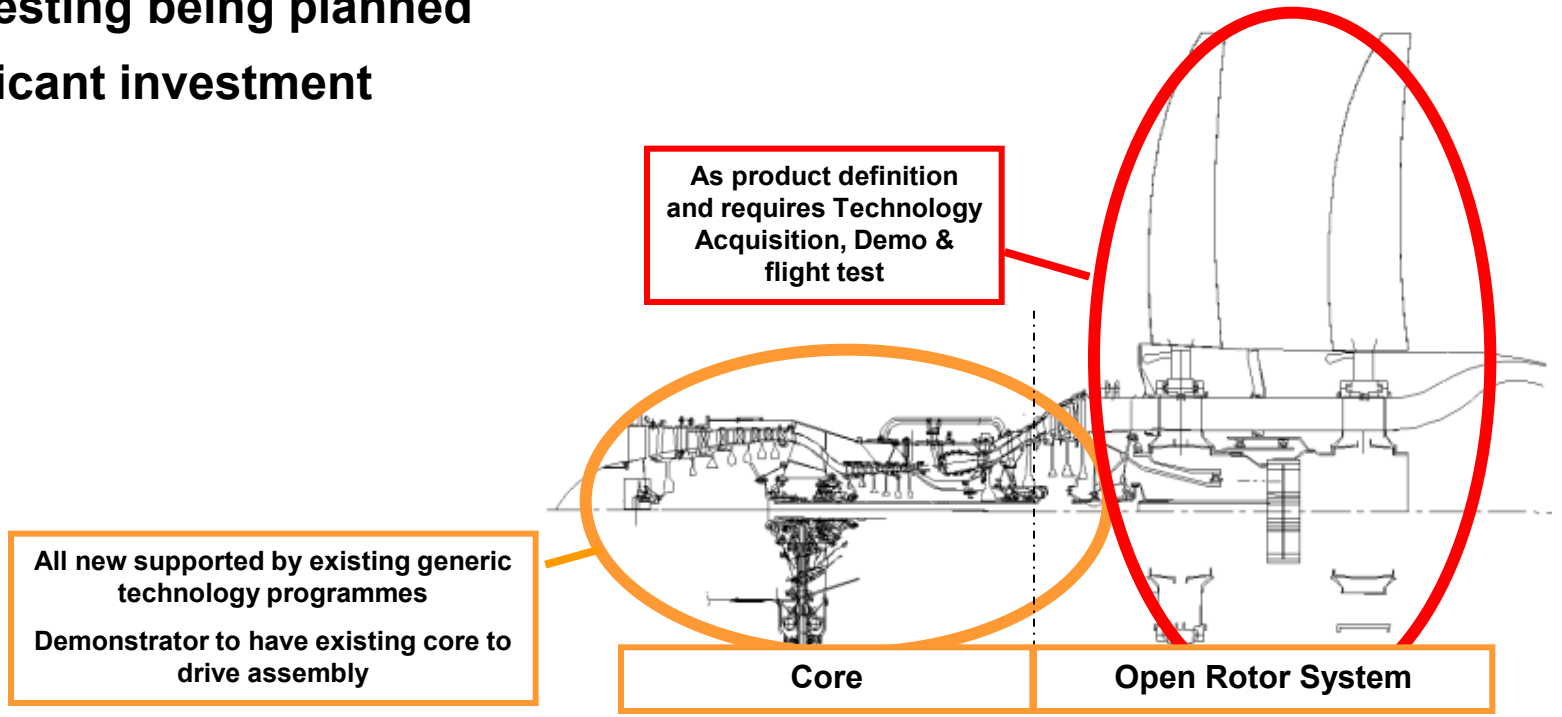




Open Rotor validation

- Validation of technologies required by ground and flight test
- Whole engine demonstrator using slave core
- FTB Testing being planned
- Significant investment





Rolls-Royce

Future Engines and technologies

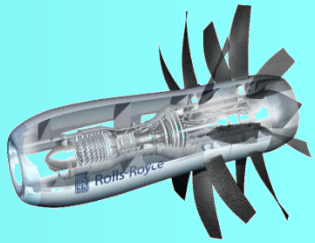
Technology Programmes Examples	Major Demos
EFE	EFE
SILOET	ALPS
SAMULET	
NEWAC	Rig639
HEETE	Core 3/2
ADVENT	
ELF	Rig145
E3E	Open Rotor Demo
Clean Sky JTI	

Potential EIS: 2014 2016 2018 2020 2022

Advance3
3-shaft Engine
A350XWB-1000
Wide-body replacement

Advance2
2-shaft Engine
Middle of the Market
Future Corporate & Regional Applications

AdvanceOR
Open Rotor Engine
Middle of Market replacement



Rolls-Royce data – see front sheet

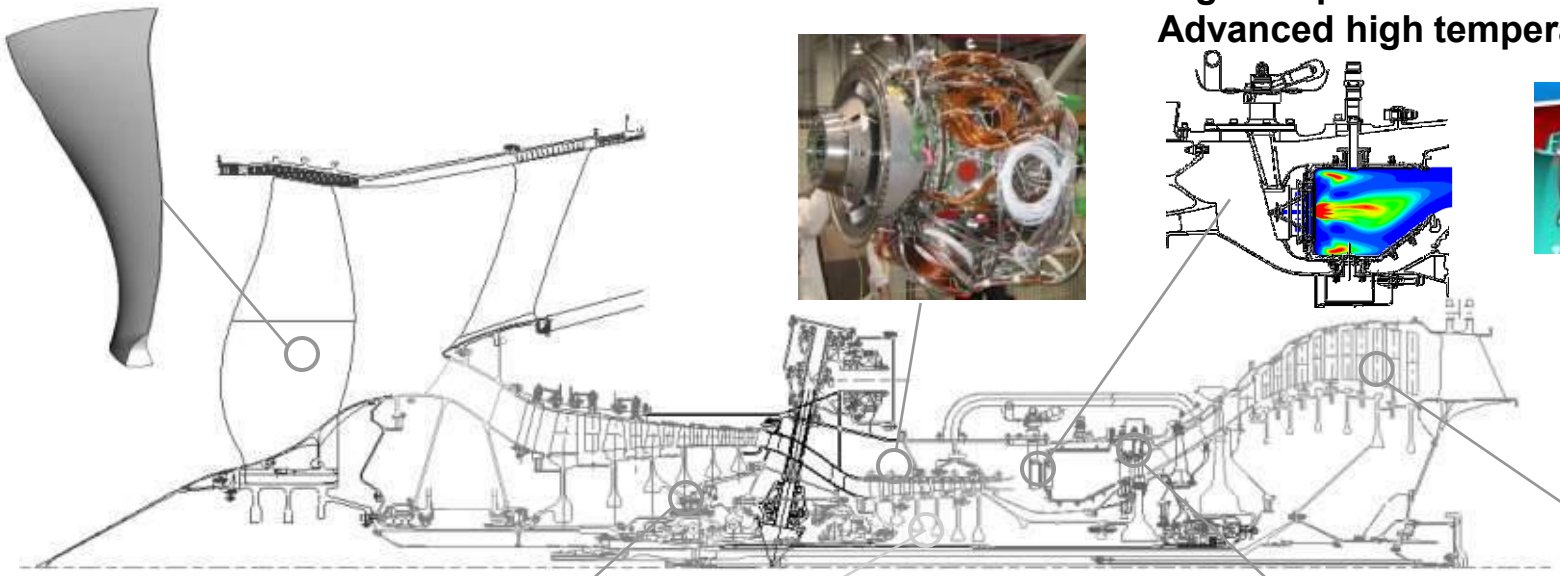
Rolls-Royce

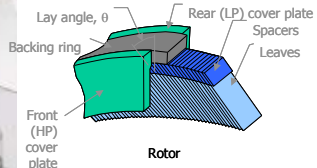
3 Shaft Engine Technologies

VITAL & ELF:
Lightweight composite fan

NEWAC:
HPC Aerodynamics

EFE:
Lean burn combustion
High temperature shroudless HPT
Advanced high temperature materials





ASER:
Advanced Sealing Endurance Rig

ANTLE
3D blisk des / manuf

Generic Rig:
Turbine performance

LP Turbine
Lightweight
blading

Rolls-Royce data – see front sheet

Rolls-Royce

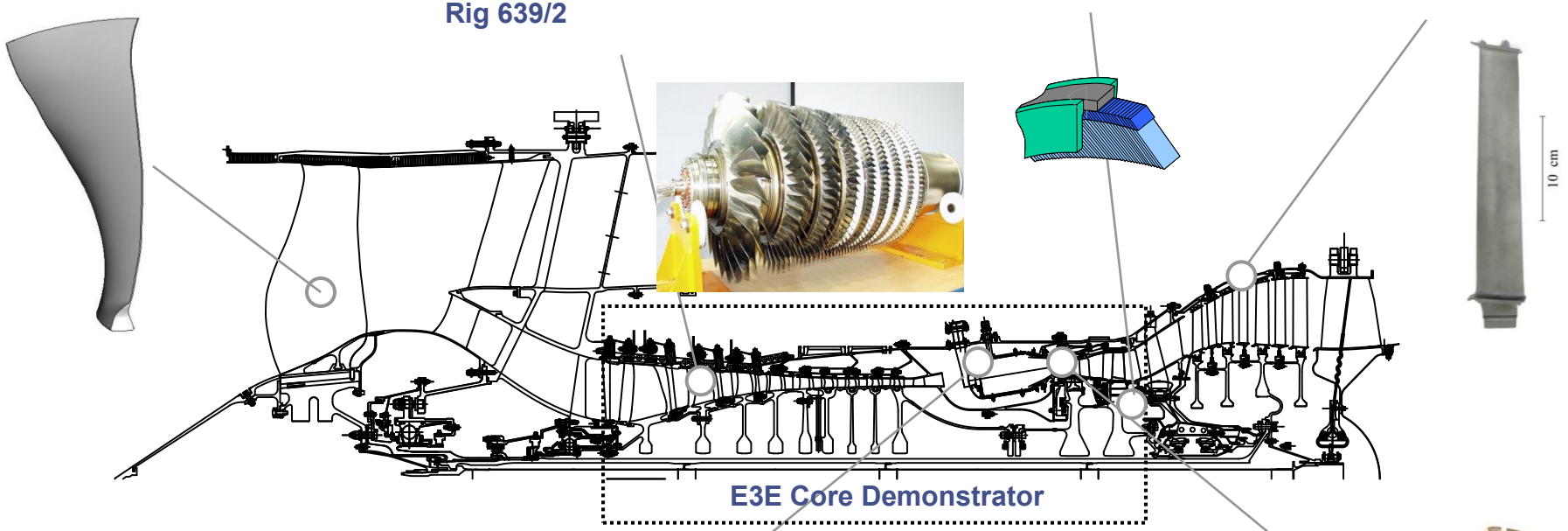
2 shaft engine technology roadmap
E3E Programme & core demonstrator

VITAL & ELF:
Lightweight composite fan

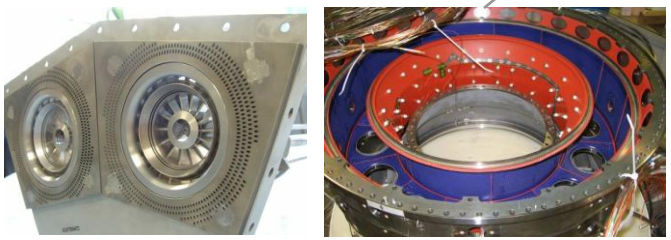
High Pressure Compressor
9 stage, PR 22:1
TiAl materials, blisks
Rig 639/2

Air System & Transmissions
Innovative seals and bearings

LP Turbine
Lightweight TiAl blading



Low NOx Combustor internally staged lean premixed

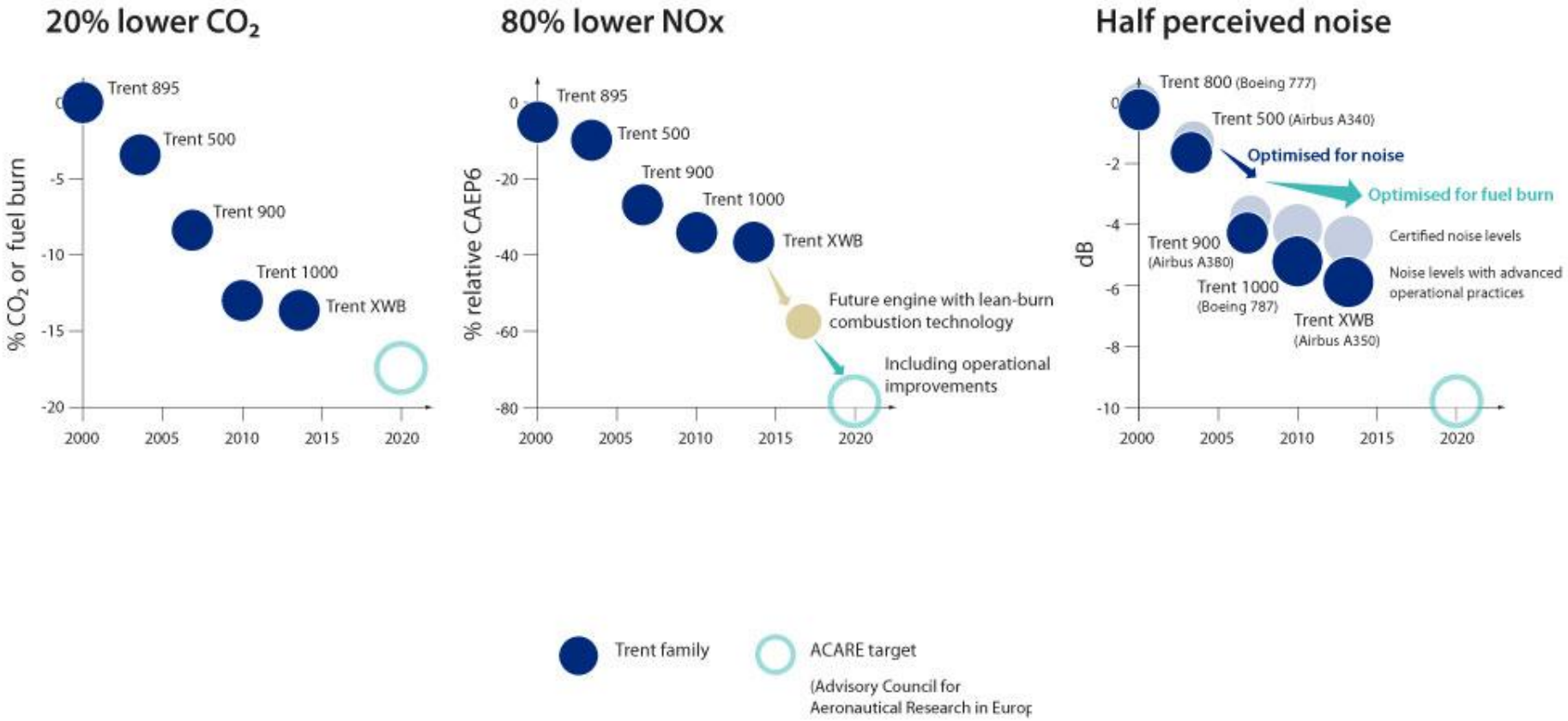


Advanced cooled 3D turbine blade featuring contoured endwalls Rub in TCC concept

Rolls-Royce

Reducing environmental impact

TRENT



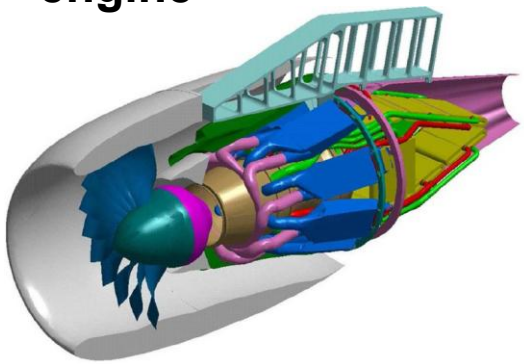
1c

Rolls-Royce data – see front sheet

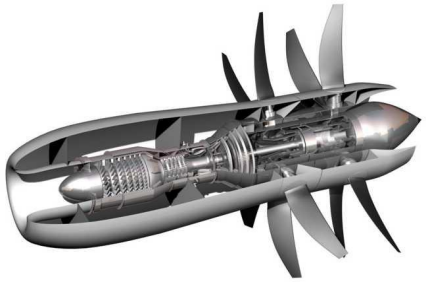
Rolls-Royce

A vision of the future of Civil Aerospace?

Intercooled, recuperative aero-engine

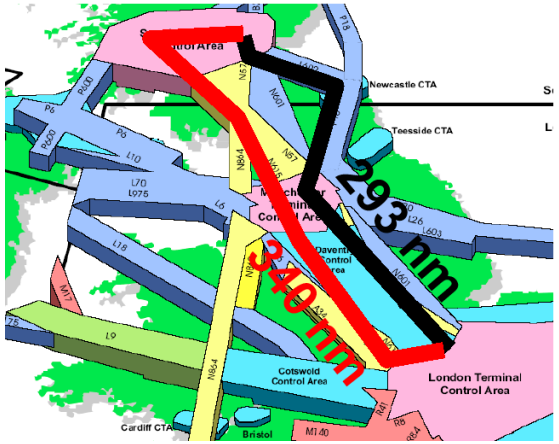


Blended Wing Body



'Open rotor'

Revised operations giving shorter routes



Research now will feed into commercial products in a 10-20 year timescale

Rolls-Royce data – see front sheet

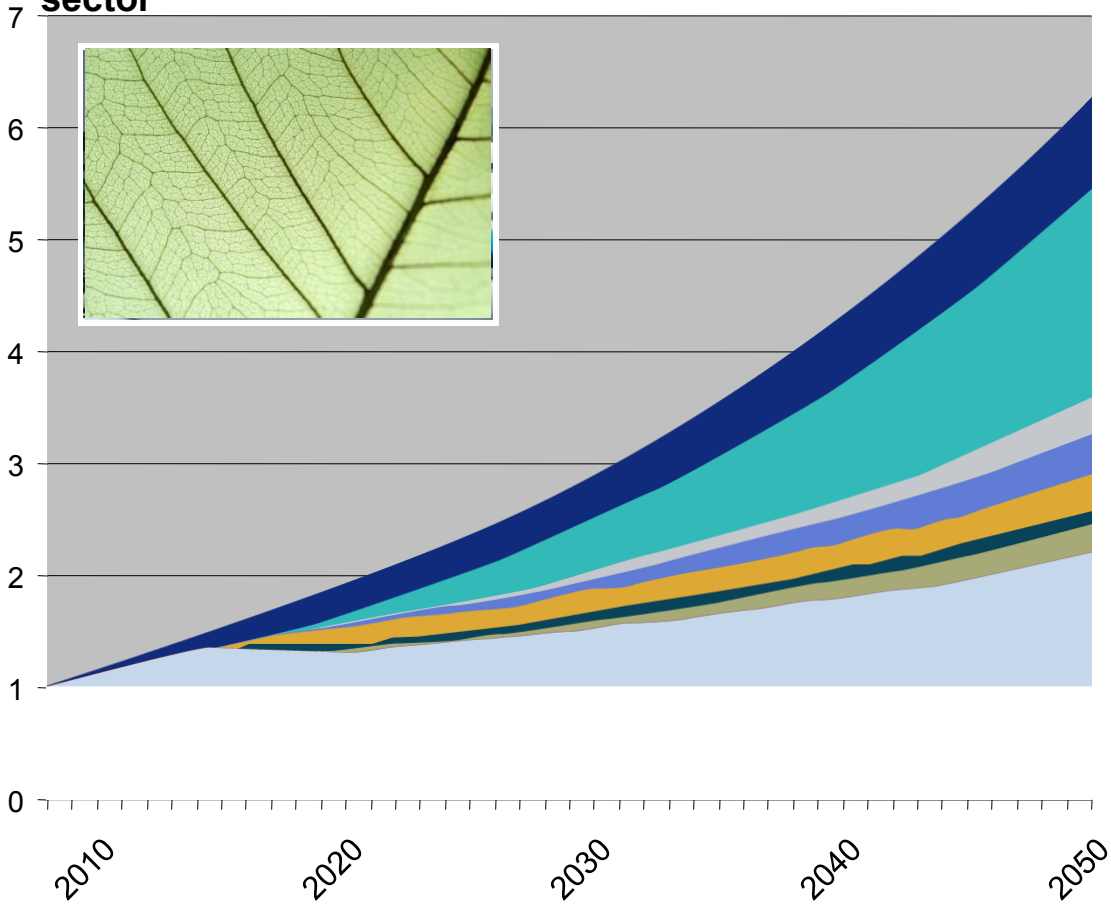
Alternative fuels

Suitability	Sustainability	Industrialisation
		
energy density fuel specification	CO_2 benefit Food / water	mass production global distribution

Offering longer term potential for ‘drop-in’ fuels

CO_2 – Prevention via technology
100 to 200 seat market

Relative % CO_2 production from market sector



Today's fleet

Current products (replacing old aircraft)

Open rotor technology
Incremental engine - 0.3% pa
Upgauge aircraft size by 15 seats
ATM improvement of 12%
Airline operations improve by 6%
Alternate fuel 33% alternate fuel by 2050
33% less CO2 per gallon
Carbon Neutral Growth

Rolls-Royce data – see front sheet

Summary

- Technology has already delivered massive improvements in aircraft emissions
- The environmental challenge is real
- The aviation industry is taking the environment seriously
  - Current programmes will deliver further improvements
- Needs combined industry, academic and government effort and investment to achieve and carry on beyond ACARE goals

Rolls-Royce data – see front sheet

Thank you for listening