Future Civil Aeroengine Architectures & Technologies

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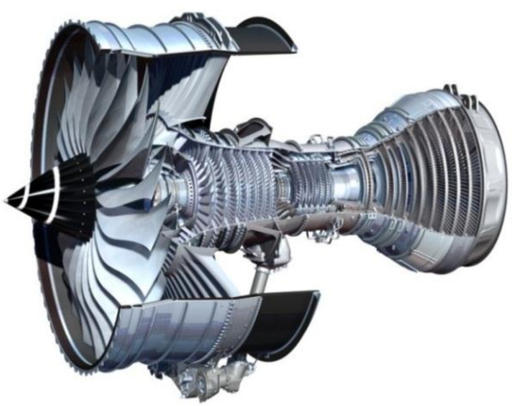
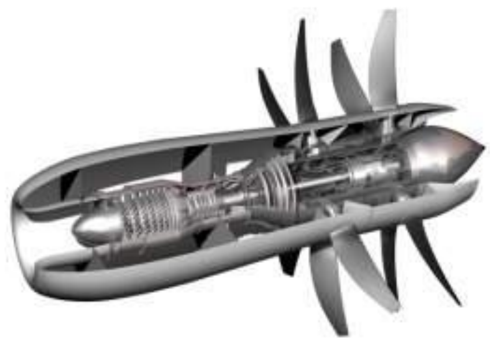
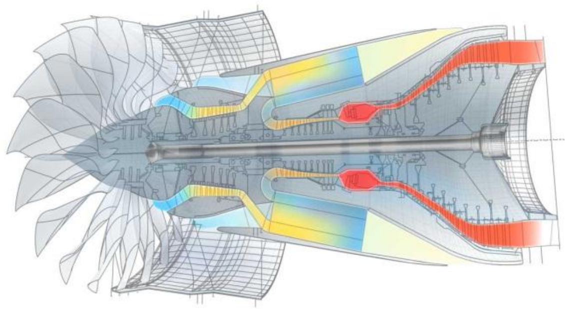
Future Civil Aeroengine Architectures & Technologies

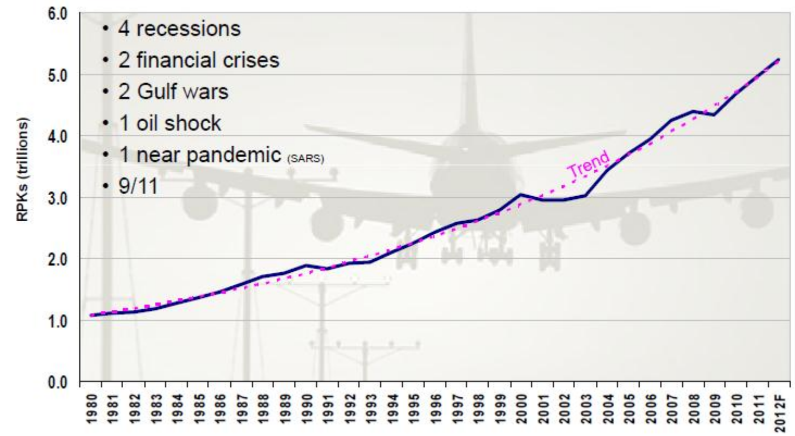
- **Opportunities & Challenges**
- **Cycle design & concept optimisation**
- **The next generation: Trent XWB - principal features & attributes**
- **Advanced architectures & technology requirements for future propulsion concepts**
- **Meeting the long term challenge & opportunities: “Vision 20”**
  - **Novel aircraft & propulsion solutions**

Company Overview

Rolls-Royce is a global company, providing integrated power solutions for customers in civil & defence aerospace, marine and energy markets

World air travel has grown 5% per year since 1980



RPKs = Revenue Passenger Kilometers
Sources: ICAO Scheduled Traffic

2012 financial highlights

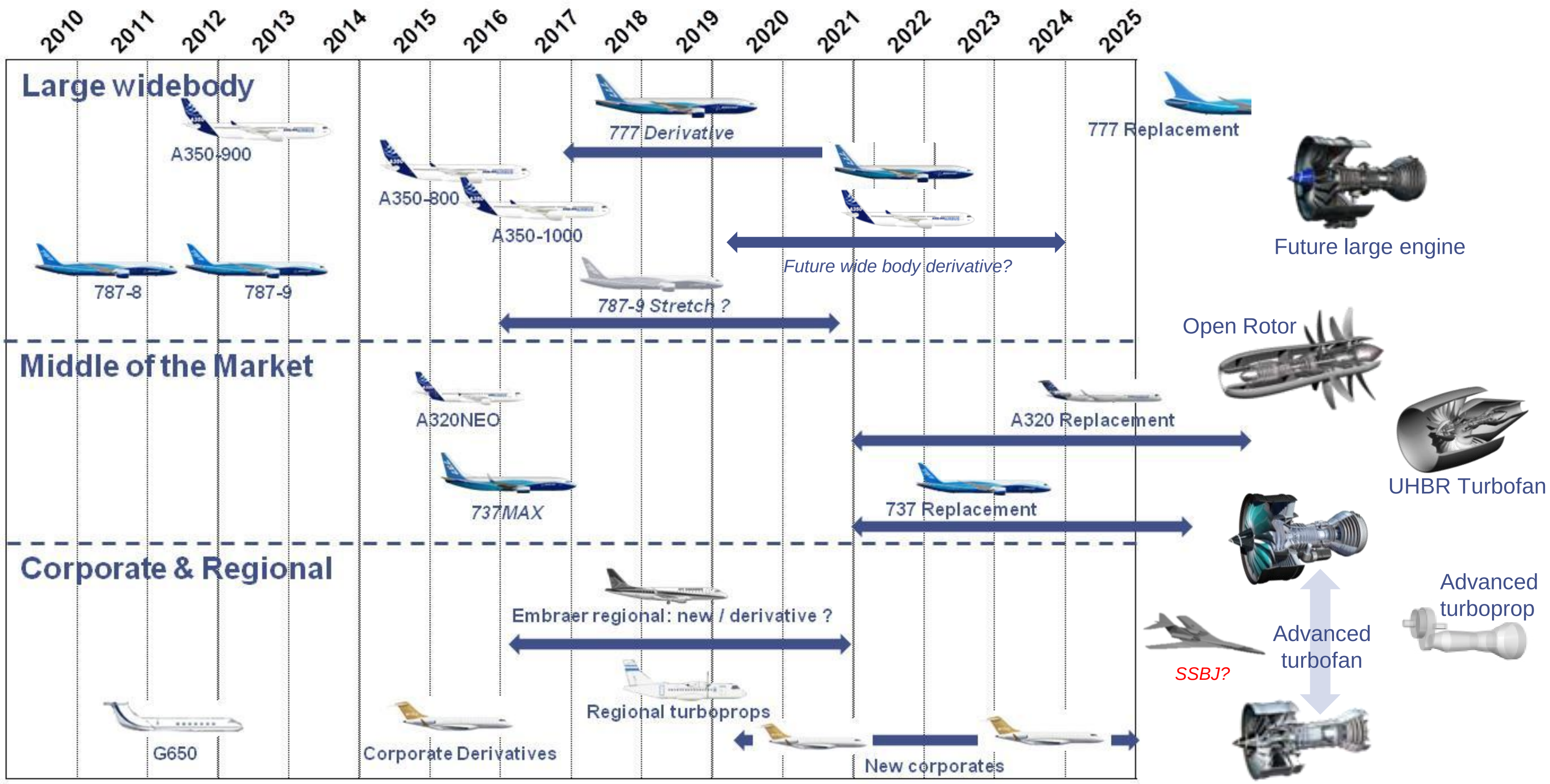
order book	underlying Group revenue	underlying profit
£60.1bn	£12.2bn	£1.4bn

original equipment	services
48%	52%

Underlying Group revenue by business segment

Civil aerospace	53%
Defence aerospace	20%
Marine	18%
Energy	8%
Engine Holding	1%

Future Opportunities – Presence in all sectors



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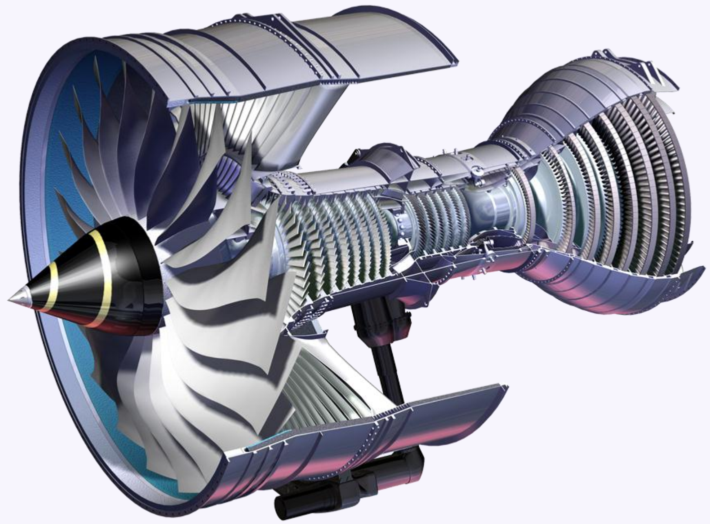
Overall ACARE* Environmental Targets for 2020

Reduce Perceived External Noise by 50% (30db Cumulative)

Targets are for new aircraft and whole industry relative to 2000….

Reduce Fuel Consumption and CO_2 Emissions by 50%

Reduce Perceived External Noise by 18 dB Cumulative



Reduce Fuel Consumption and CO_2 Emissions by 20%

Reduce $EINO_X$ Emissions by 60%

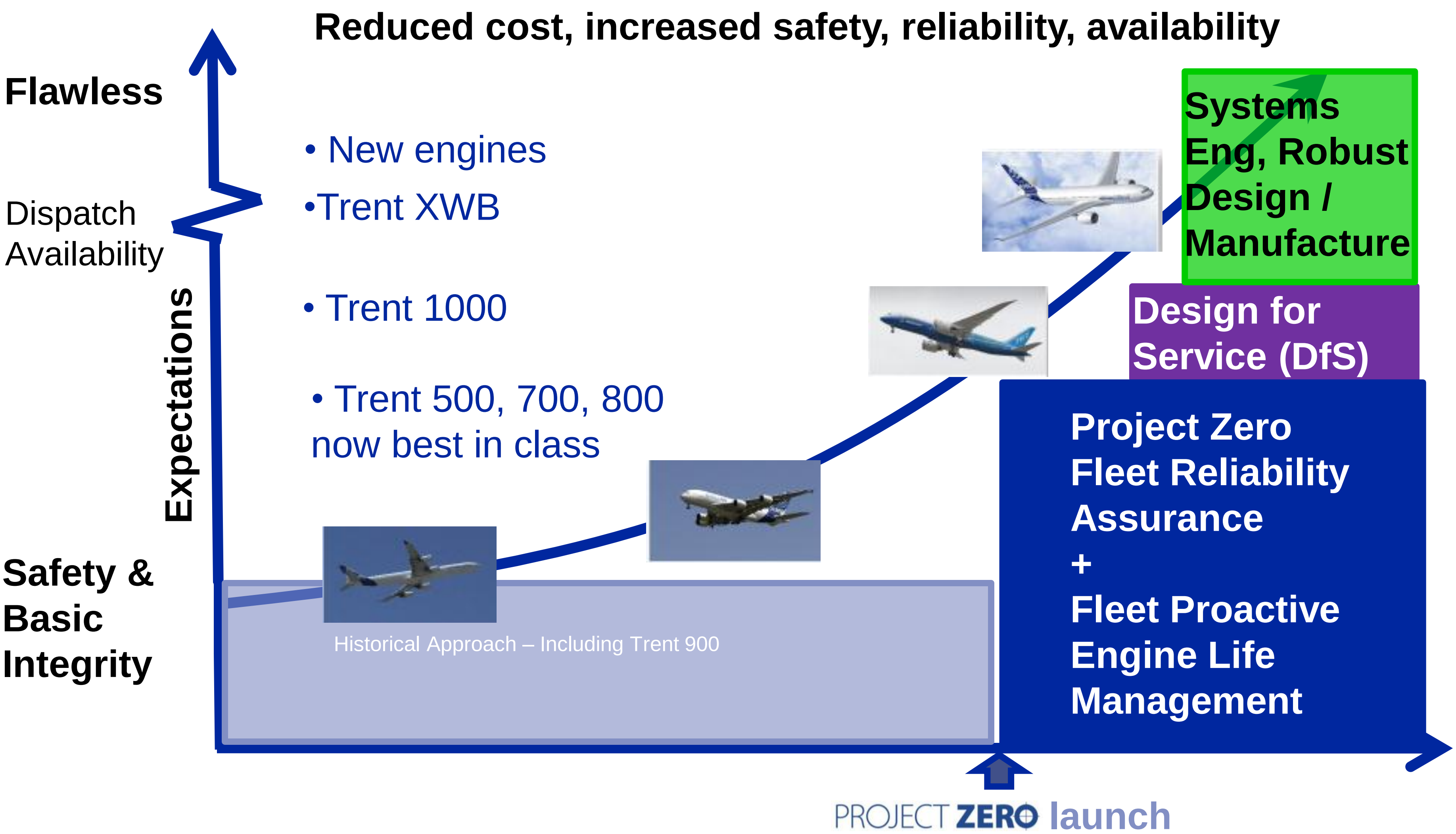
Engine level targets

Reduce NO_X Emissions by 80%

……..and represent a doubling of the historical rate of improvement

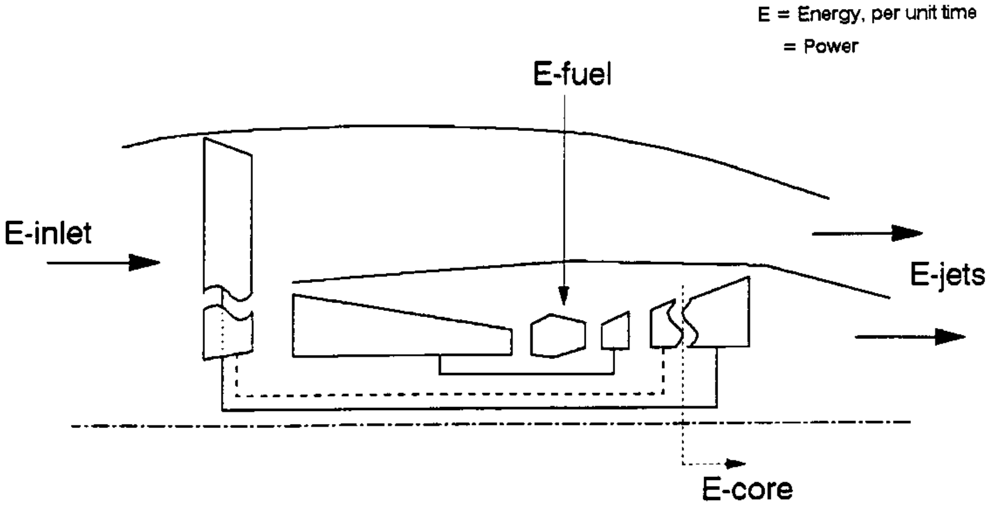
* Advisory Council for Aerospace Research in Europe

Customer Expectations



Rolls-Royce

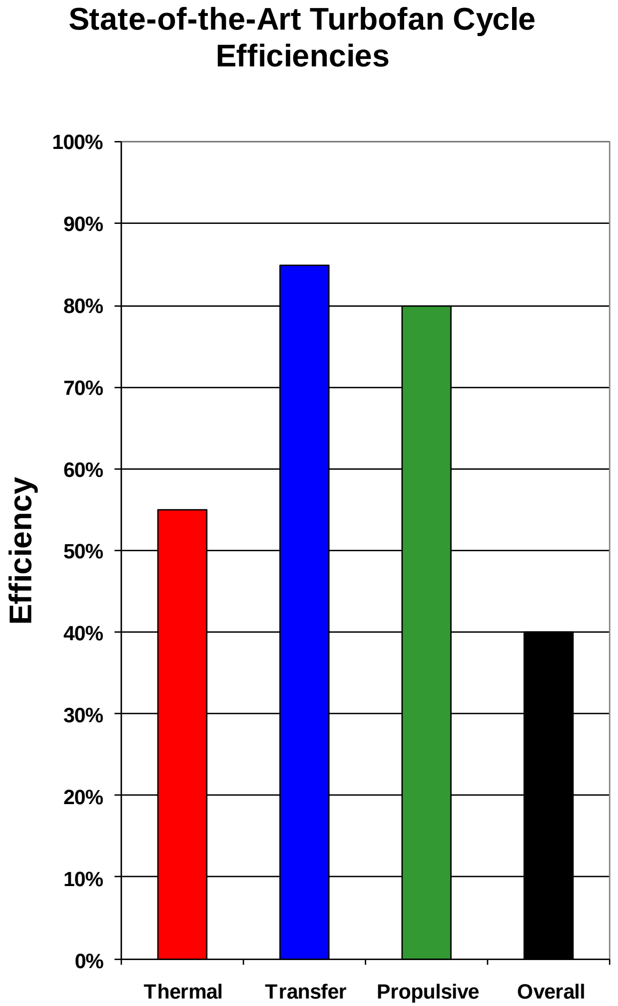
Turbofan Thermodynamic Cycle Efficiencies: Propulsive, Transfer & Core Thermal



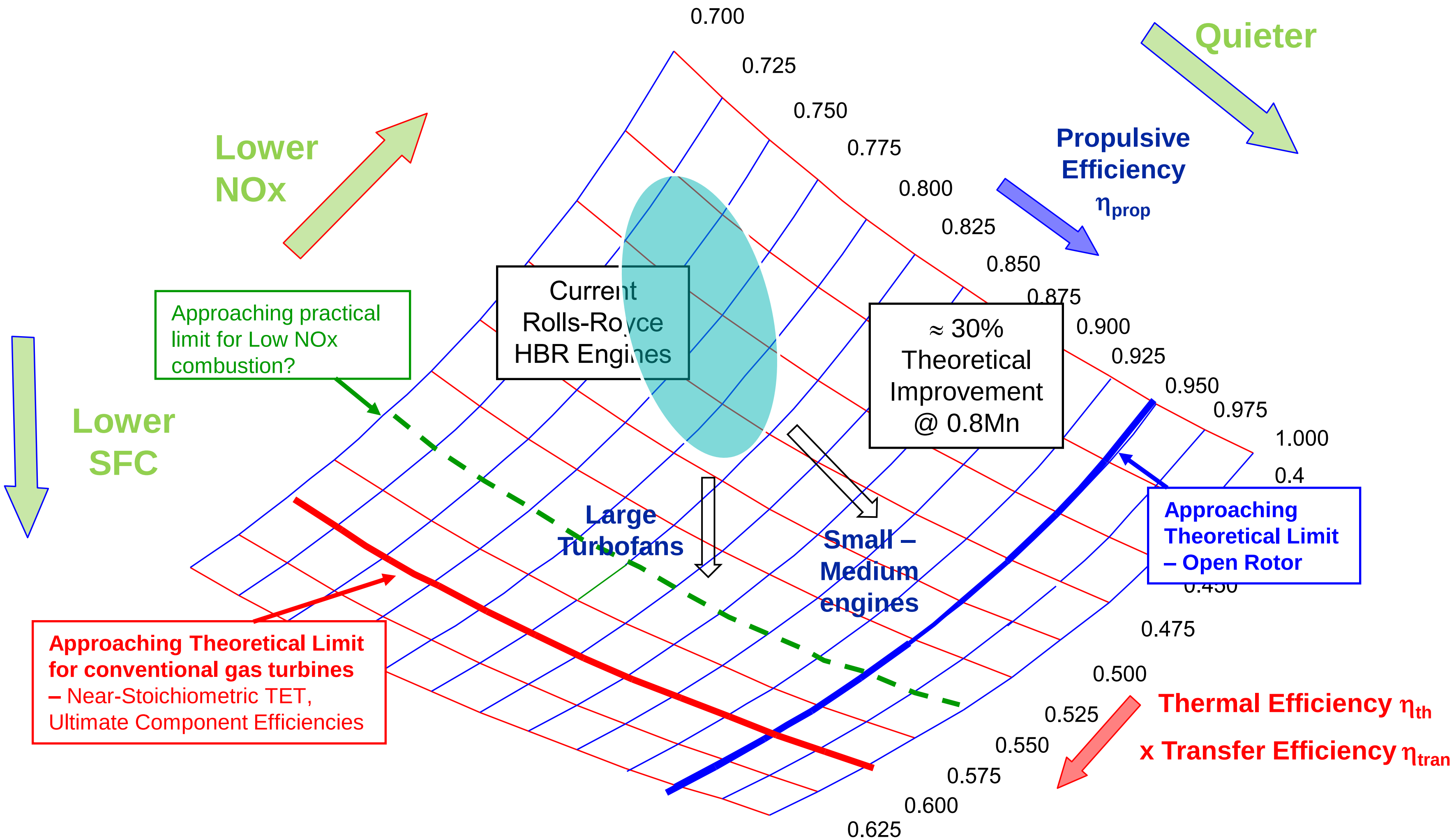
Core thermal efficiency = E-core/E-fuel

Transfer efficiency = (E-jets - E-inlet)/E-core

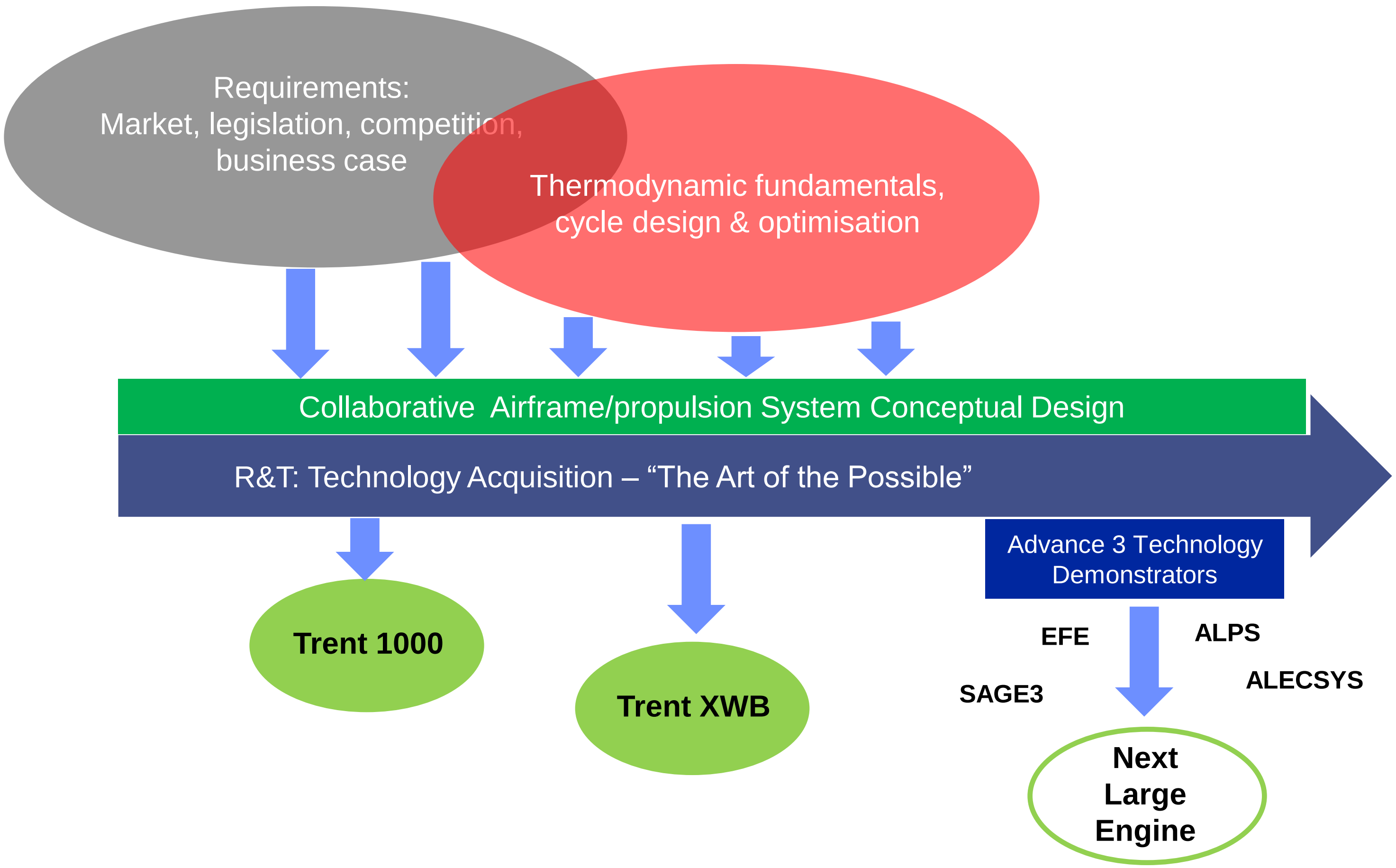
Propulsive efficiency = Fn.V0/(E-jets - E-inlet)



Turbofan Thermodynamic Cycle Efficiencies: Advancement in different thrust classes



The Rolls-Royce 'Technology Continuum'
Continuous Innovation & Pursuit of Advanced Technology



The Trent XWB
Evolving with the A350 family

Trent XWB

Single engine type

Optimised for cruise efficiency

Common external envelope, interfaces, operating procedures and GSE

A350-800

Trent XWB-75, -79

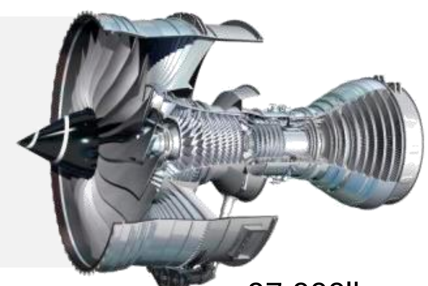
A350-900

Trent XWB-84

A350-1000

Trent XWB-97

75-84,000lb
Fully interchangeable
Lowest weight



97,000lb
High thrust economics

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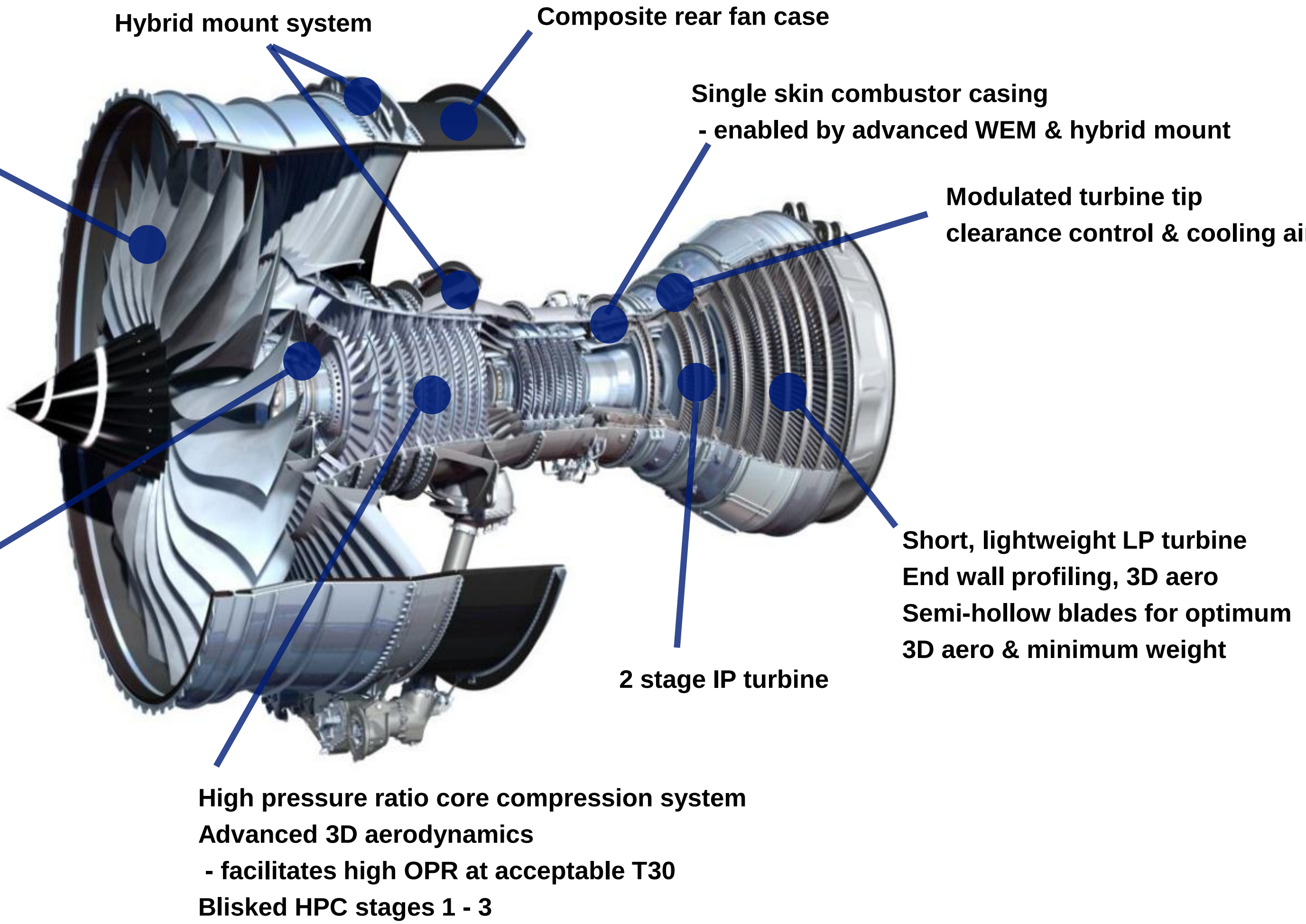
The Trent XWB
Advanced components & novel features



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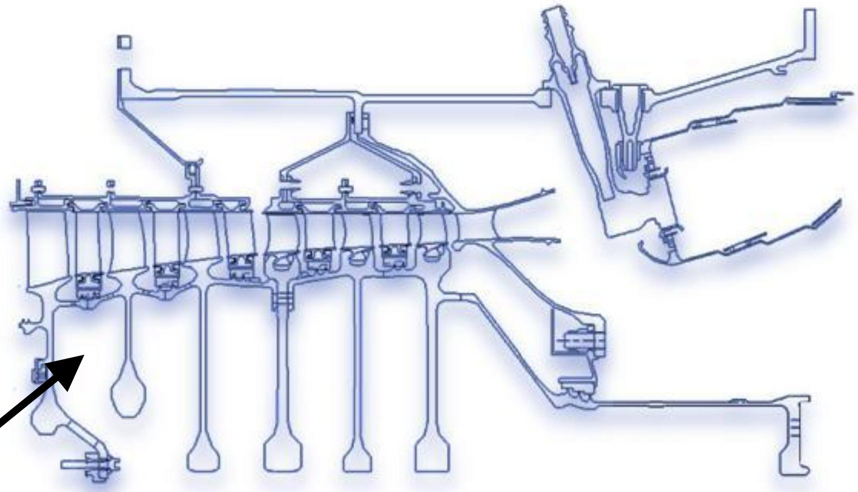
Trent XWB HP Compressor
Advanced Aero & Mechanical Design

- Advanced 3D aerodynamics
- Derived from NEWAC
- High efficiency enables high OPR at acceptable T30

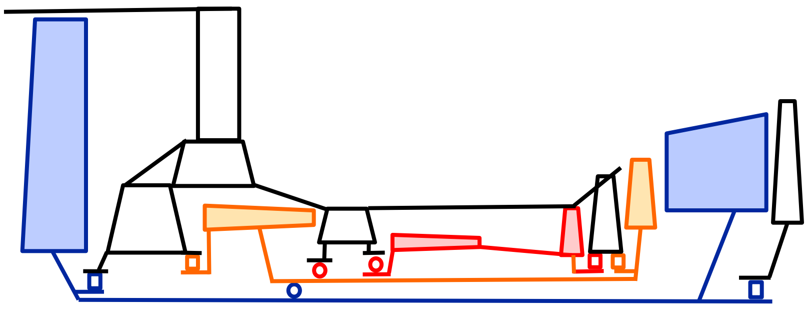
- First application of Ni blisk technology in the HPC of a Trent engine
- Wealth of experience from BR715, BR725, JSF, TP400 & EJ200 blisk manufacture



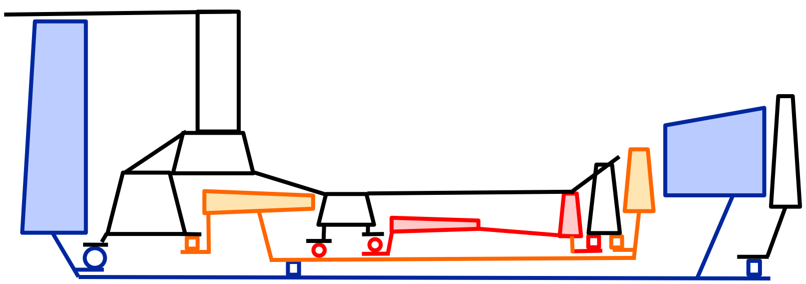
Stage 1 – 3 blisk configuration selected following assessment of:
- Weight reduction
- Unit cost impact
- Aerodynamic improvement
- Ability to produce in volume and to salvage during manufacture
- Repairability in service

Trent XWB Bearing Structure
LP Front Location Bearing

FUTURE PROGRAMMES

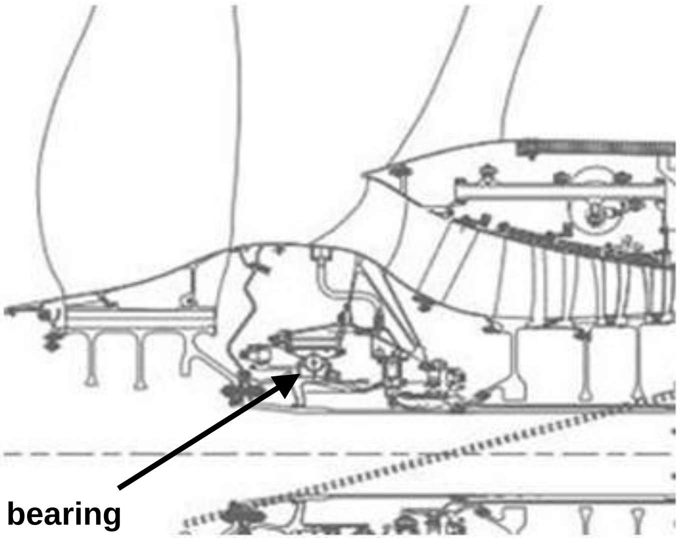


Conventional RB211/Trent



Trent XWB

- Reducing specific thrust and increasing BPR increases axial thrust load on the LP shaft
- Load is balanced by pressurising the fan rear seal
- Capacity of conventional LP intershaft location bearing is limited by rotational speed
- Moving location bearing to FBH doubles its capacity
- lower pressure air can be used to pressurise the fan rear seal, providing significant SFC improvement
- Enabled by detailed WEM analysis (FBO)



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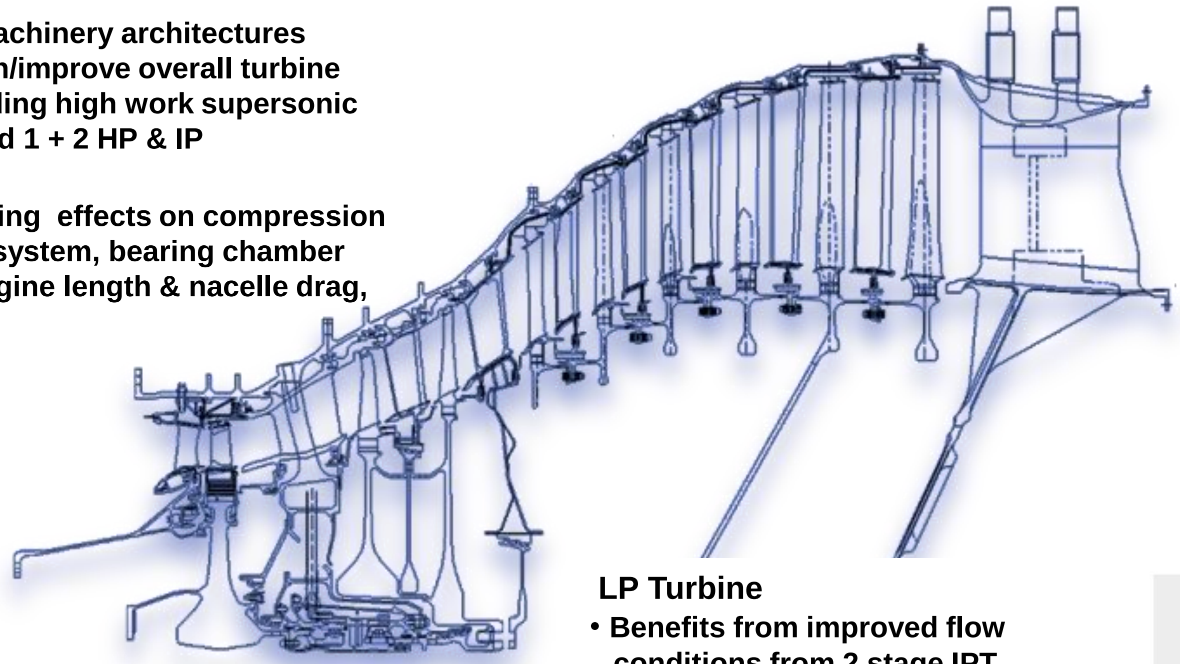
Trent XWB Turbine Architecture

FUTURE PROGRAMMES

IP Turbine

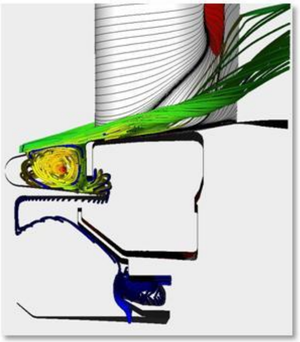
- Increasing OPR increases specific work of the core turbines
- Range of core turbomachinery architectures considered to maintain/improve overall turbine suite efficiency: including high work supersonic single stages, 2 + 1 and 1 + 2 HP & IP configurations
- Optimisation considering effects on compression system efficiency, air system, bearing chamber conditions, weight, engine length & nacelle drag, net fuelburn & cost



- Architecture selection:
  - Desirable that 3rd stage should be uncooled
  - 2 HP + 1 IP configuration would result in v low work, inefficient IP turbine
  - 1 HP + 2 IP architecture selected as providing lowest fuelburn solution

LP Turbine

- Benefits from improved flow conditions from 2 stage IPT
- Latest generation LP turbine aero / mechanical design
- Semi-hollow blades for optimum aerodynamics and minimum weight.
- Multi-stage 3D CFD, validated by multiple codes & latest Trent engine tests



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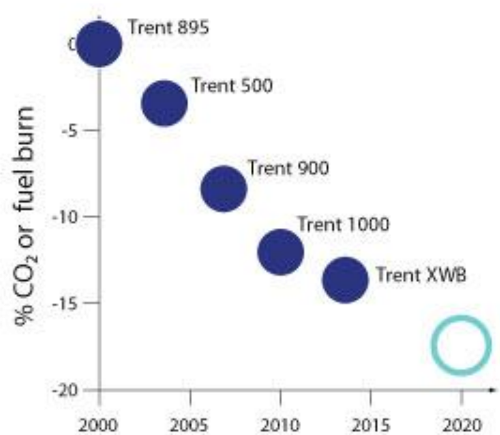
The Trent XWB
Reducing environmental impact

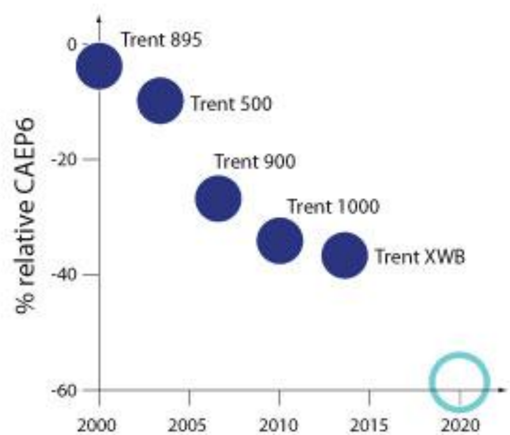
20% lower CO_2



Target 50% CO_2 overall reduction:

- 15-20% from engine
- 20-25% from airframe
- 5-10% from operations

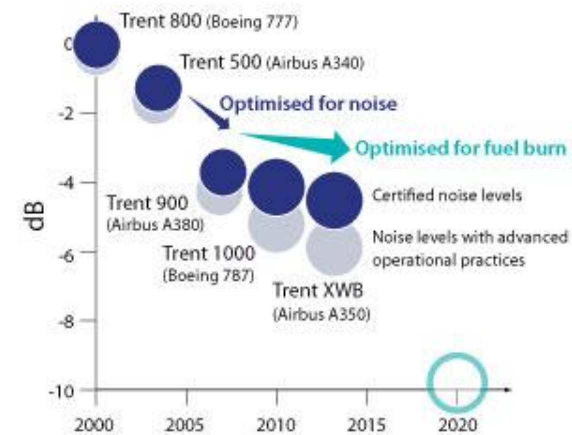
60% lower NOx



Target 80% NOx overall reduction:

- 60% from engine technology
- 20% from operational efficiency improvements

Half perceived noise



Target 50% aircraft noise reduction:

- 30dB cumulative
- 10dB average at each condition

Departures QC1 | Arrivals QC0.5

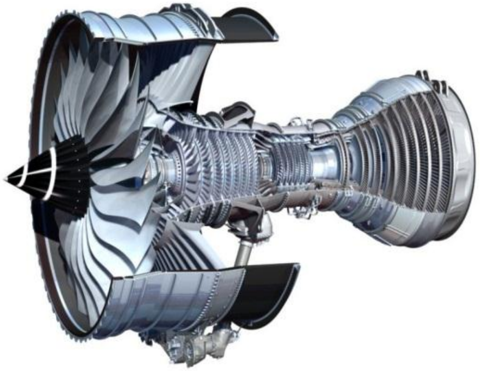
84K A350 - 800/900 | Agreed Rolls-Royce / Airbus objectives

Trent family — ACARE target (Advisory Council for Aeronautics Research in Europe)

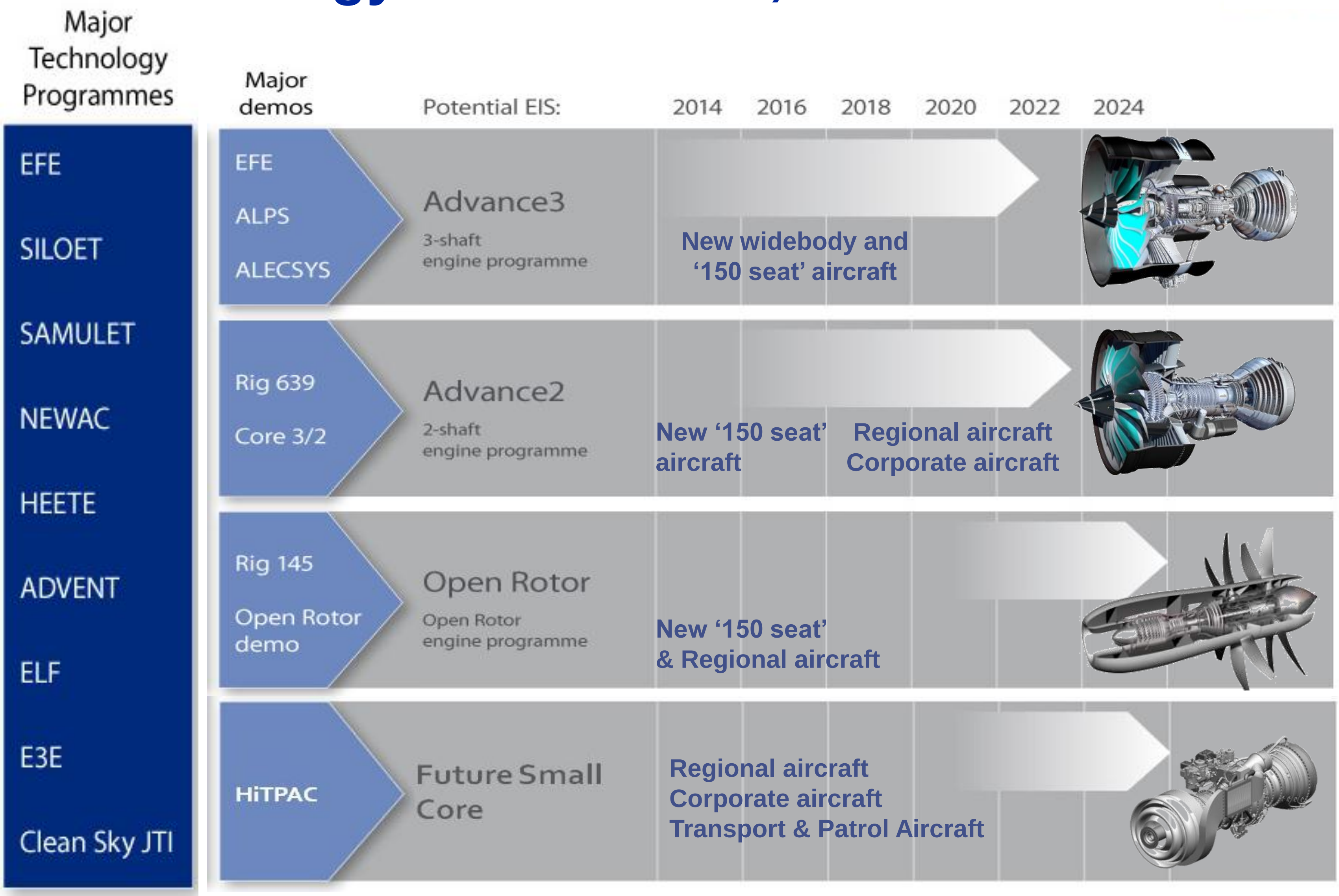
Rolls-Royce

The Trent XWB
Programme Status

- Hit all major milestones
- Successfully completed 84klbf 150hr Type Tests
- Successfully passed bird & FBO tests
- 42 flights, 140hrs flying on FTB
- Achieved certification on schedule Q1 2013
- "The most fuel efficient jet engine running in the world today"
- High confidence in meeting performance & acoustic targets
- Will enter service in 2014 delivering lowest fuelburn of any jet engine in operation

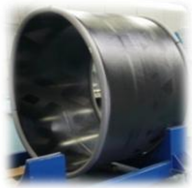


Technology Foundations, Product Solutions

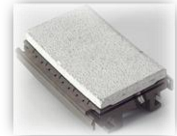


Advance 3 Large Engine Technologies

Lightweight composite fan, containment case & dressings

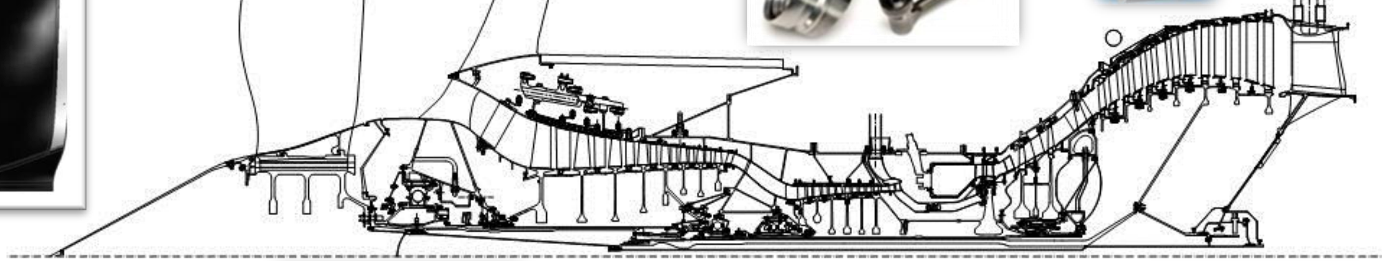


Lean burn combustor



Advanced turbine materials

Smart, adaptive systems

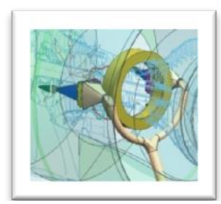


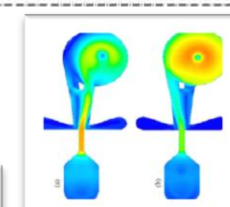
Advanced sealing

Light-weight high efficiency compressors

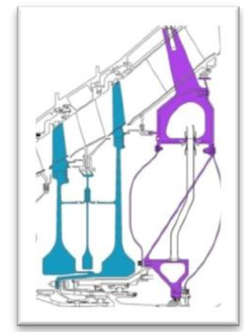
Blisked construction

Advanced high OPR cycle, with cooled cooling air





Advanced active systems



3 core turbines

Novel IP /LP structural arrangement

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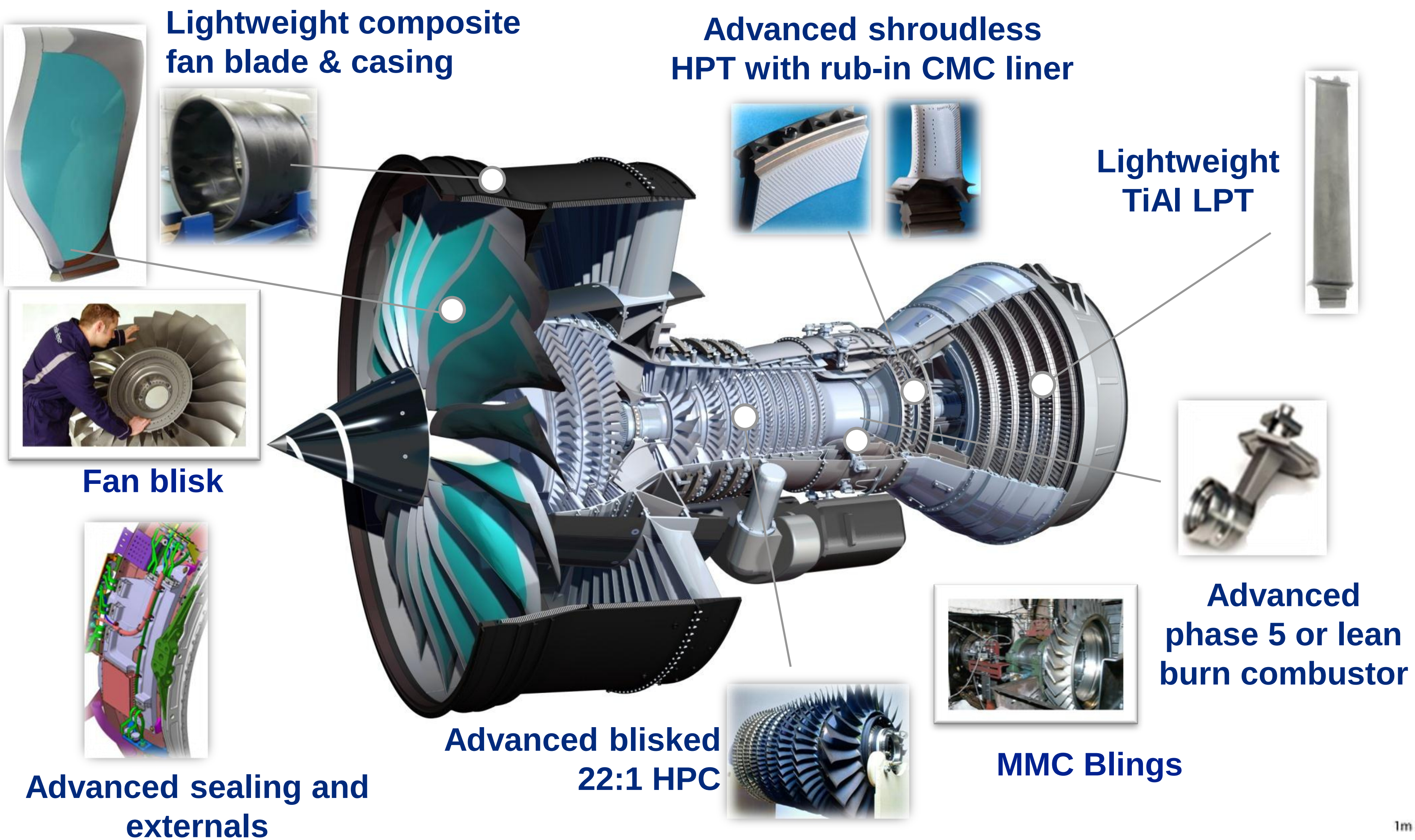
Advance 2 Medium/ Small turbofan technologies



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Vision 20 Propulsion Requirements
Long Term Market Scenario Evaluation

FUTURE PROGRAMMES

- Technology will become more valuable
- Novelty will have increased value at concept and technology level
- Mid-life technology insertion will become viable & desirable
- CO_2 will dominate other emissions and noise
- Greater demand for bespoke aircraft solutions
- Increased focus on operational optimisation
- Incremental steps will have increased value driving increased frequency of change, shorter service lives (increased clock speed)
- Tendency towards lower average flight speed
- Tendency towards greater market segmentation & diversification
  - Potential emerging demand for very large low, low speed, low cost people carrier
  - Significant demand for high speed transports

Flightpath 2050

Goals to take ACARE* beyond 2020

*Advisory Council for Aviation Research in Europe

By 2050 compared to year 2000 datum

- 75% reduction in CO_2 per passenger kilometre
- 90% reduction in NOx emissions
- 65% reduction in noise

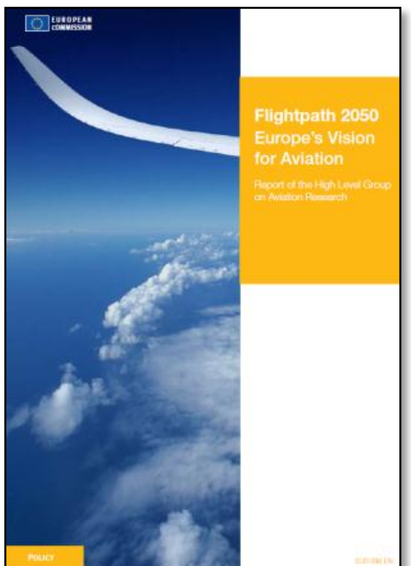
ACARE

Requires Improvement in all areas

Airframe

Engine

ATM & Operations



Strategic Research & Innovation Agenda – goals:

- Meeting Societal and Market Needs
- Maintaining and Extending Industrial Leadership
- Protecting the Environment and the Energy Supply
- Ensuring Safety and Security
- Prioritising Research, Testing Capabilities & Education

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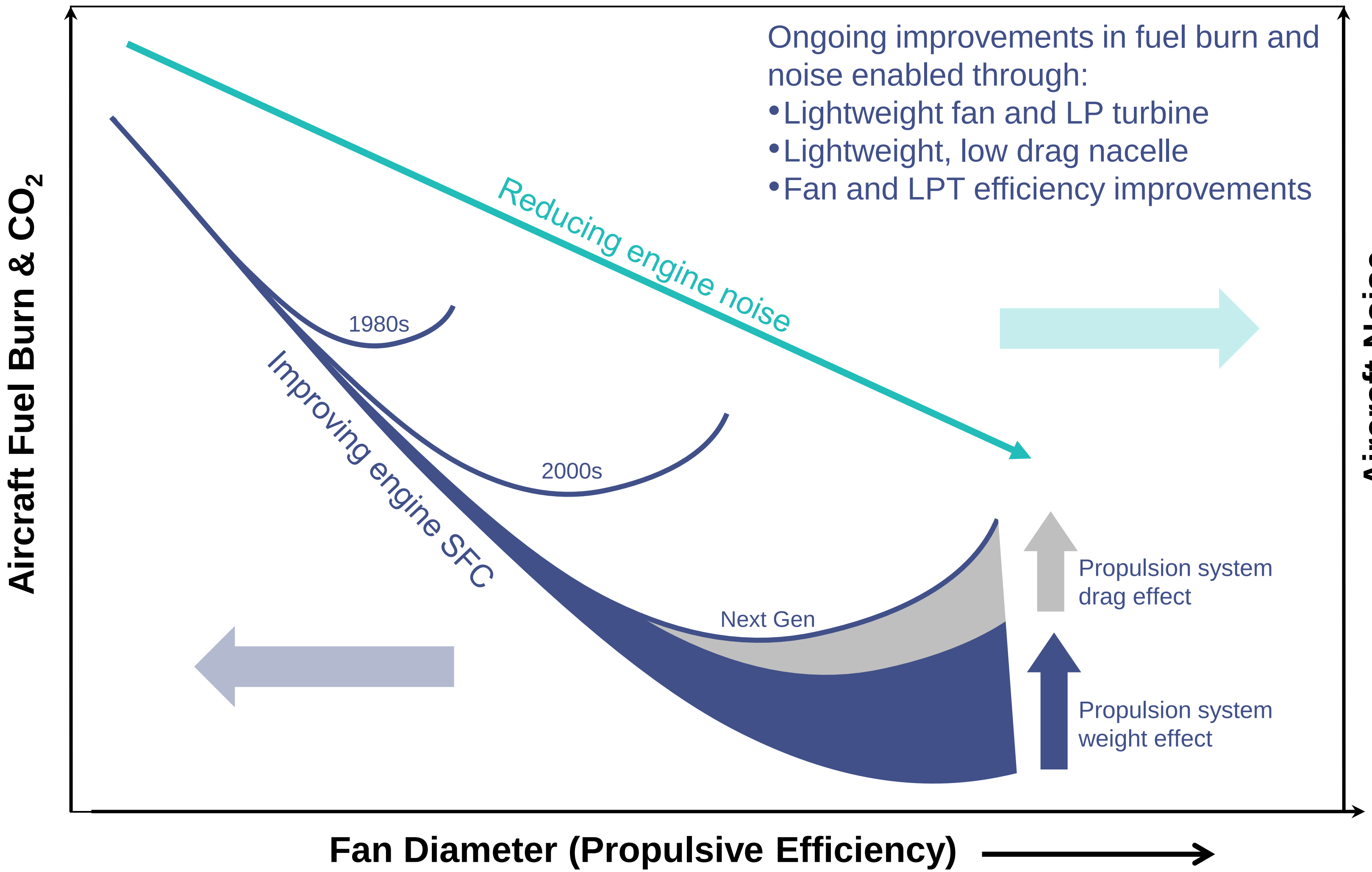
Improving propulsive efficiency



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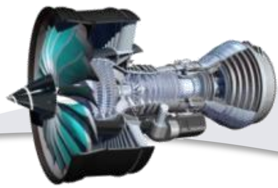
Driving propulsive efficiency

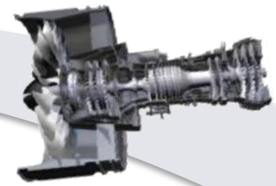
BPR	10+ ⟷ 50+

Technology	Direct Drive	UHBR Turbofan	Open Rotor

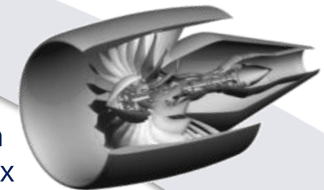
SFC ↓ Fuel burn ↓



Advanced HBR turbofan
- Lightweight fan & LPT
- Integrated propulsion system
- High efficiency LP system



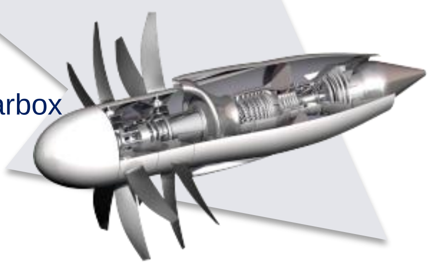
Geared-Drive turbofan
- Power gearbox
- High-speed LPT
- Variable Area Nozzle (VAN)



UHBR turbofan
- Power gearbox
- High-speed LPT
- Variable pitch fan / VAN
- Integrated slim-line nacelle / no TRU

Applying Open Rotor technologies to turbofan solutions

Open Rotor
- Counter rotating gearbox
- High-speed LPT
- Composite props
- Variable pitch props
- Integrated nacelle



Installation issues

Technical risk

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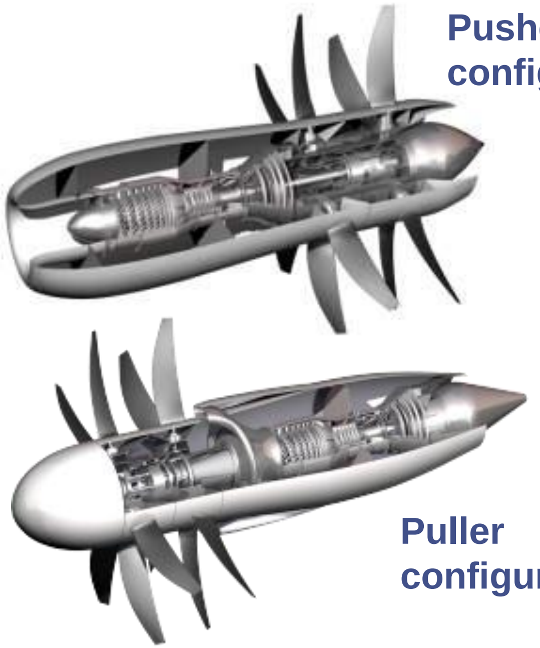
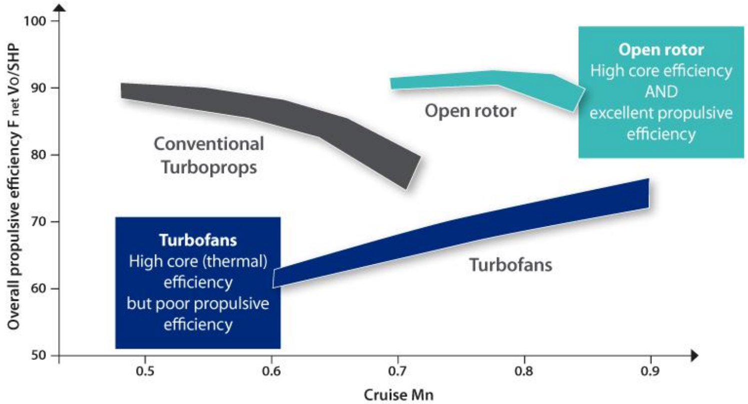
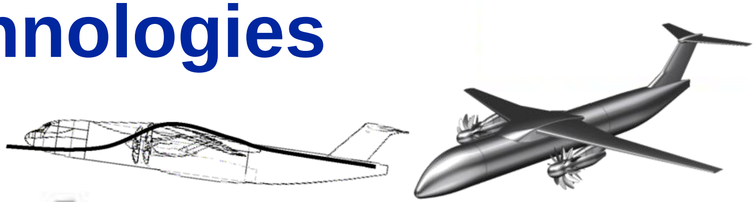
Open Rotor propulsion

- Ultra high bypass ratio (50+) with a conta-rotating unducted propeller system and conventional core
- Provides fundamental propulsive efficiency benefits but eliminates the weight and drag associated with conventional ducted propulsors
  - 10%+ fuel burn improvement relative to advanced turbofans
- Contra-rotating prop system retains high efficiency up to 0.8 Mn unlike conventional turboprops
- Modern design tools show that noise problems associated with previous designs can be minimised through careful prop optimisation

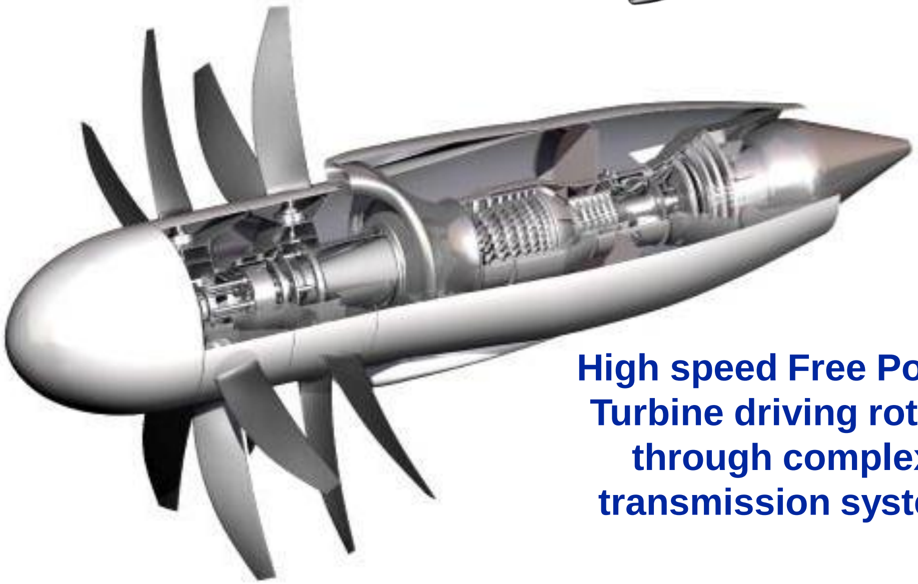




Open Rotor – Enabling Technologies



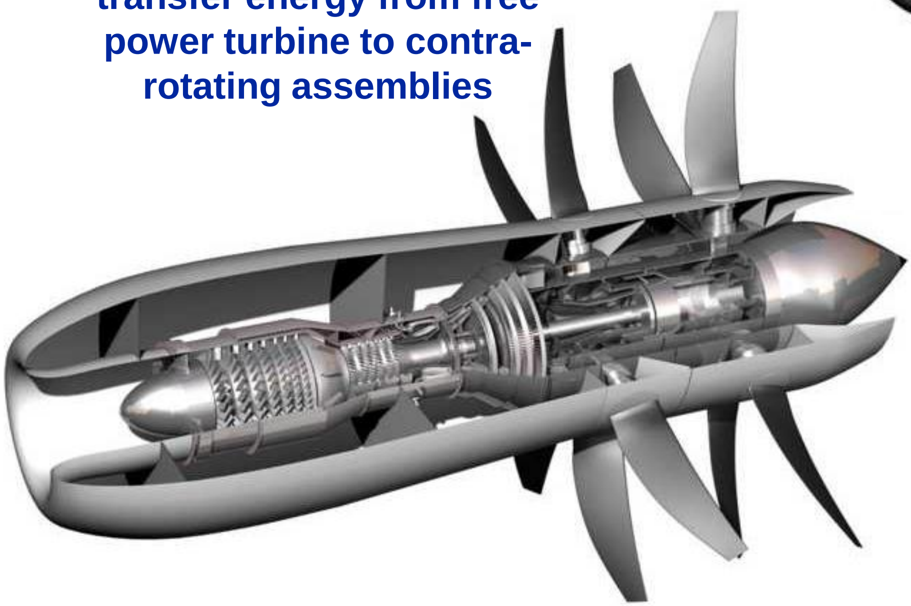
Advanced gas turbine
2 spool core based on turbofan technology programme



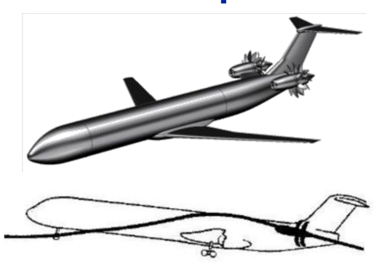
Aircraft aero/acoustic and structural integration

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

High speed Free Power Turbine driving rotors through complex transmission system



Contra rotating blades Noise and performance optimised configuration



Blade pitch change mechanism to maintain optimum blade angle and torque split

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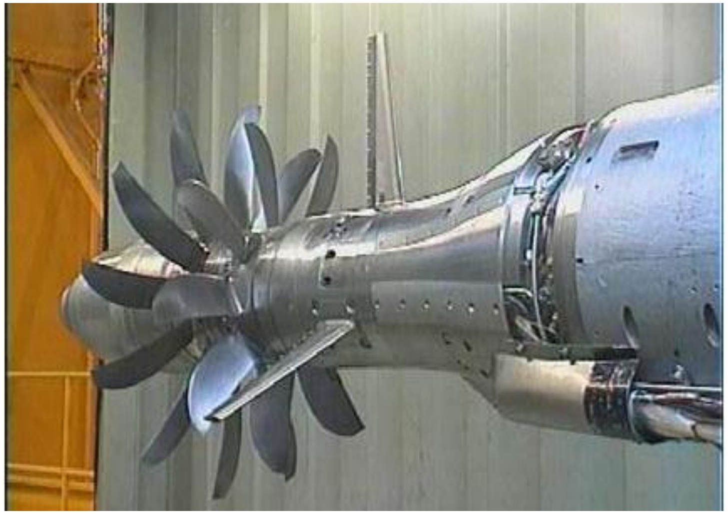
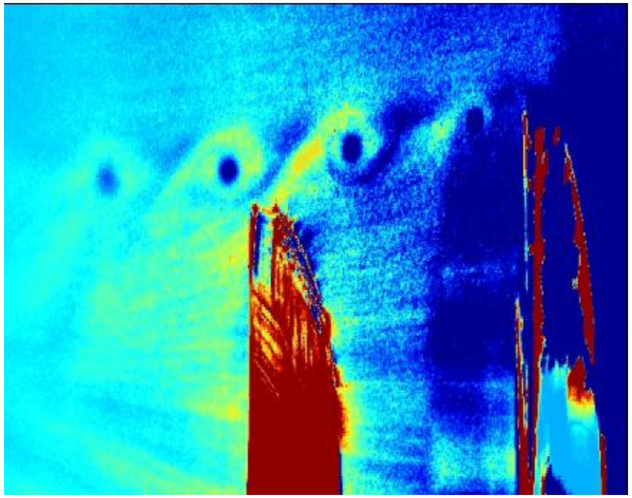
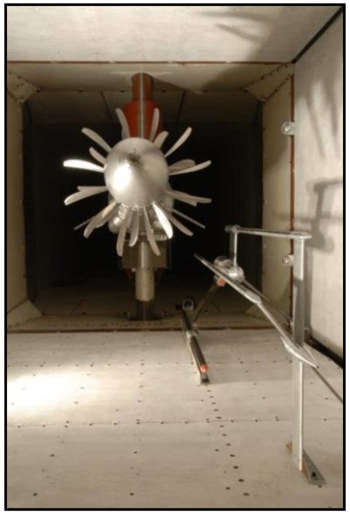
Open Rotor Verification

Rig 145 at DNW and ARA Test Facilities

- 1/6th scale rig (28” diameter)
- Aero and acoustic verification
- Isolated and installed
- Phase 1 testing complete 2008/9
- Phase 2 installed and uninstalled testing of RR low noise, birdworthy blade design completed in DNW
- High speed testing of RR design completed at ARA Bedford







Ultrafan™ technologies

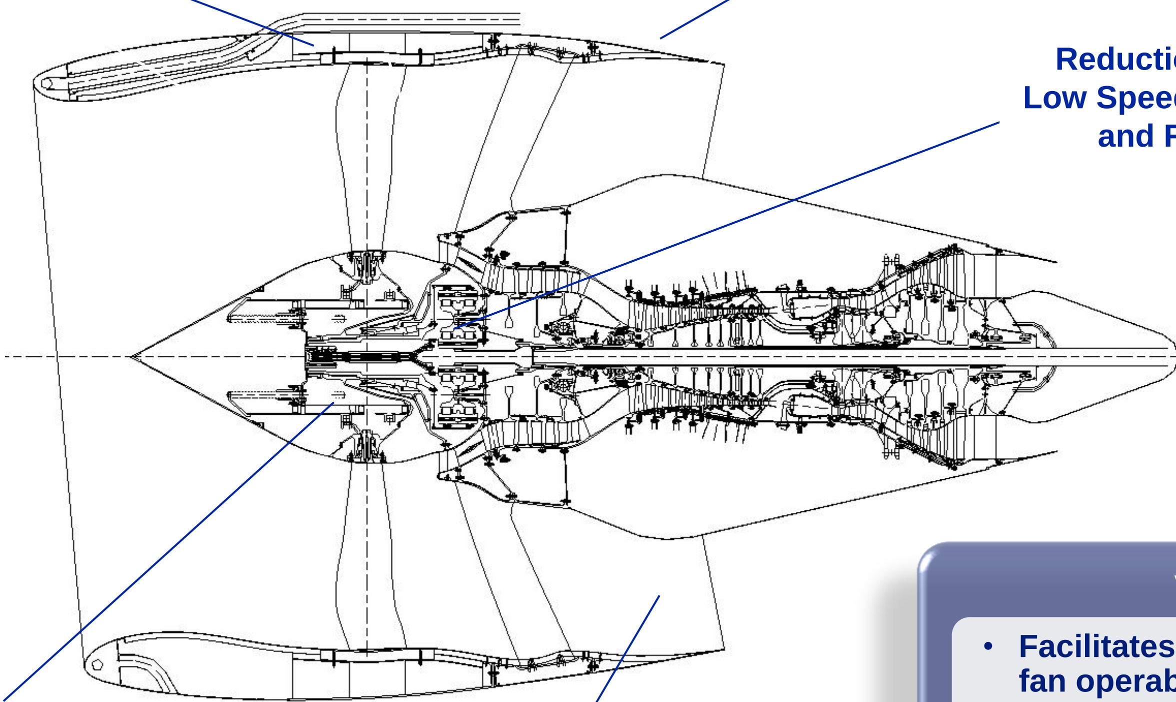
Nacelle and Fan Case

Slimline Nacelle (& active flow control?)

Thinner, Shorter Outer Cowls

Reduction Gearbox Enables Low Speed Fan for Performance and Reduces LPT Size

BPR 20+



Pitch Change Mechanism

Reverse thrust mode requires flow to turn sharp lips of cold nozzle & core splitter

VP Fan

- **Facilitates low pressure ratio fan operability**
- **Enables deletion of thrust reverser**

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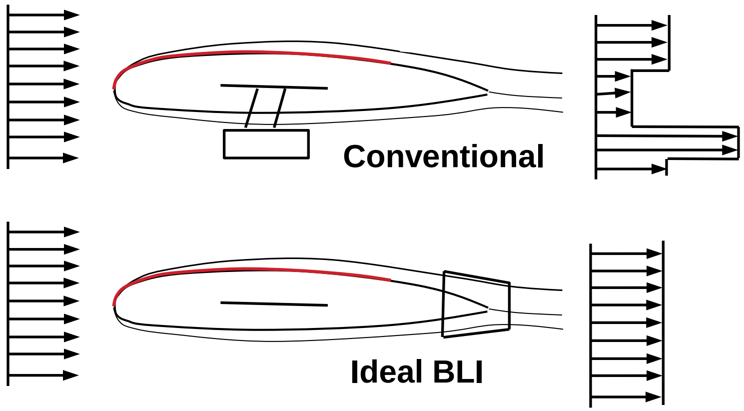
Boundary Layer Ingestion & Distributed Propulsion

Benefit of BLI:

- **Improves overall vehicle propulsive efficiency by reenergising low energy low momentum wake flow**



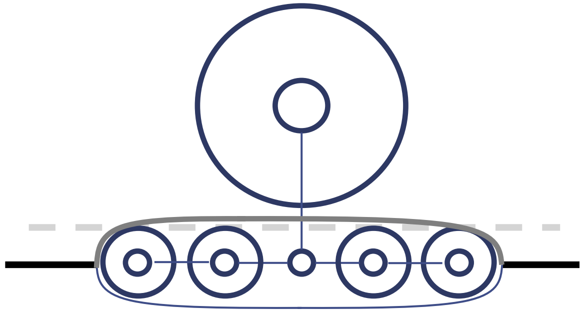
Distributed Propulsion Benefits

1. Maximises opportunity for BLI
2. Facilitates of installation of low specific thrust propulsion
3. Structural efficiency/optimised propulsion system weight
4. Minimises asymmetric thrust, reducing vertical fin area
5. Reduced jet velocity & jet noise

Boundary Layer Ingestion & Distributed Propulsion

Alternative Distributed Propulsion Concepts:

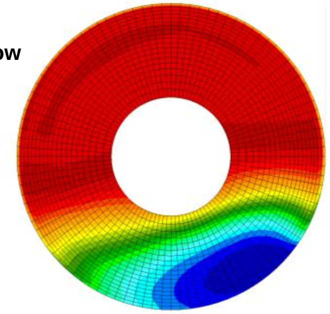
- Mechanical Distribution
  - Complex transmission
- Electrical Transmission
  - Requires superconducting electrical machines
  - Requires cryo-coolers or cryogenic fuel



Fuelburn assessment

- 5% fuelburn reduction on BWB with electrical distribution, slightly less with mechanical distribution
- Lower benefit for conventional T&W aircraft

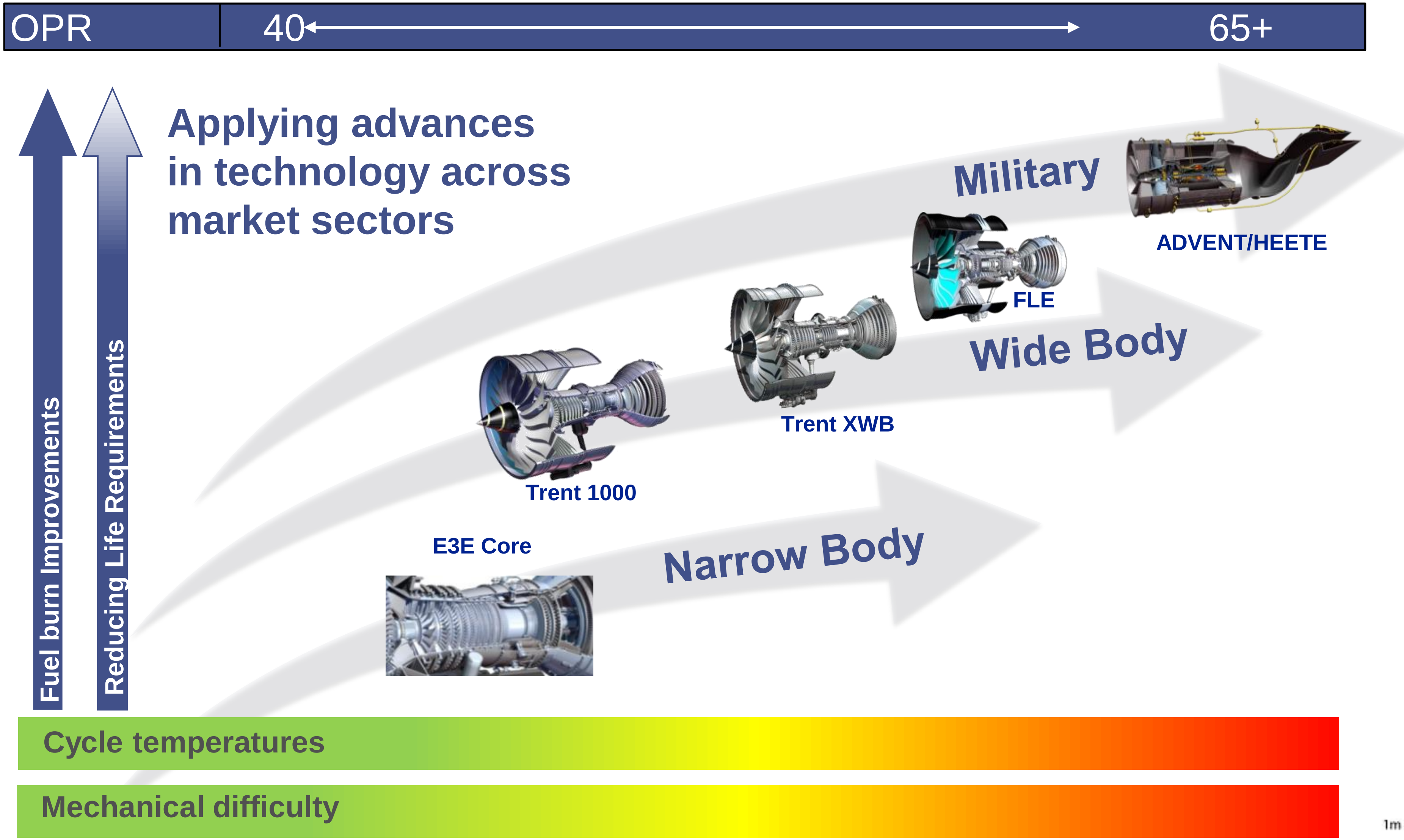
Fan inlet flow pressure profile



High flow distortion from swallowing BL:

- Penalty on fan efficiency
- High fan forced response
- Require distortion tolerant fan (& core compressors?)

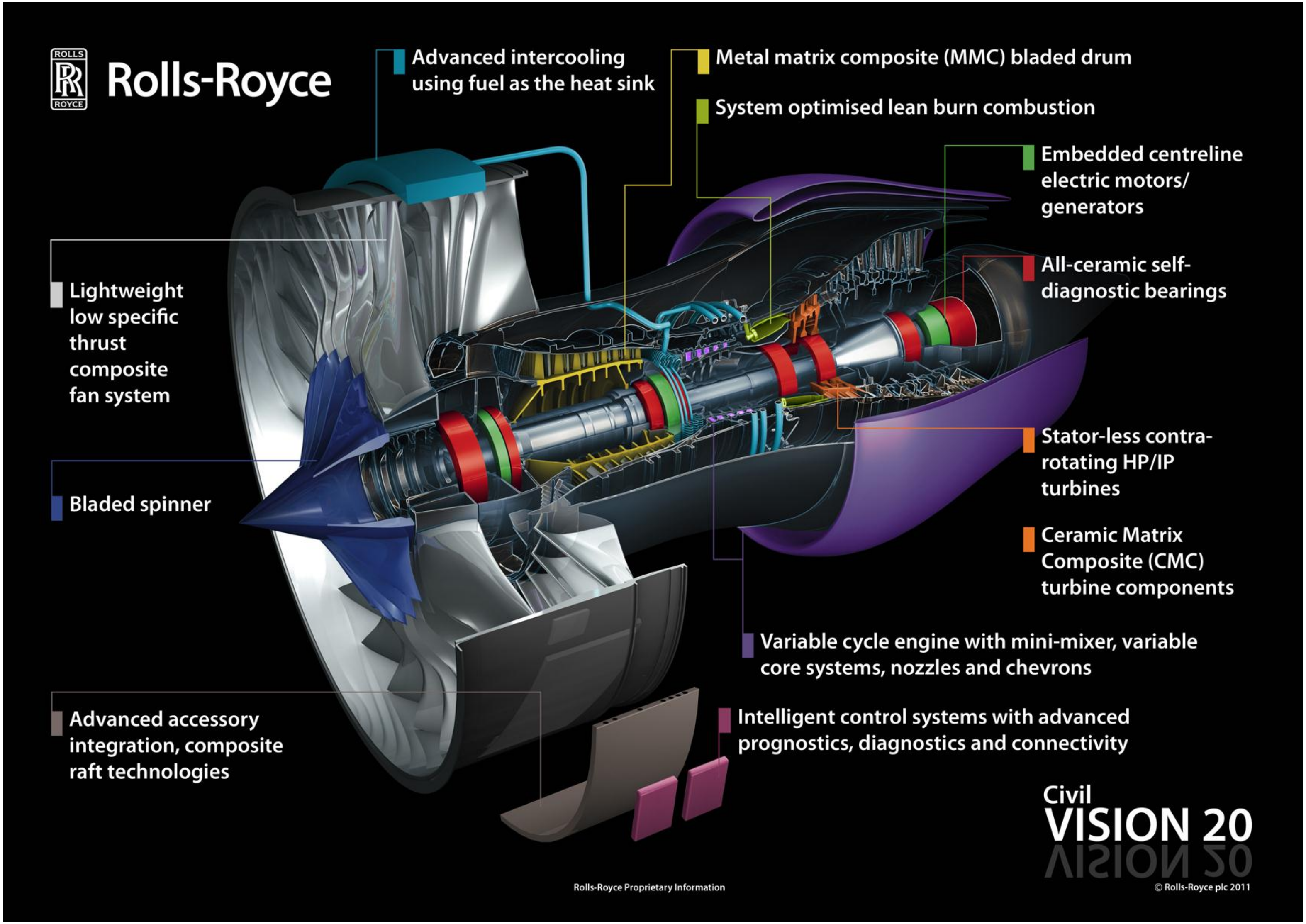
Driving thermal efficiency



Rolls-Royce

Vision 20 Propulsion

FUTURE PROGRAMMES

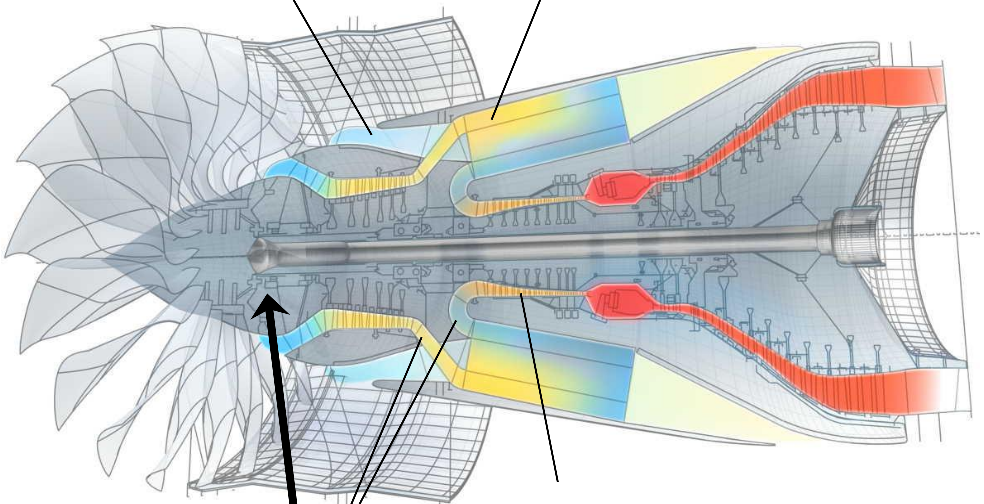


Intercooled Turbofan Concepts

FUTURE PROGRAMMES

Bypass duct offtake and LP ducting

Intercooler compromises BPD & nacelle increasing losses & drag



HP compressor aerodynamics compromised by small core size, large dia. LP shaft & structural loads on core casings

Ducting for intercooler

Cycle benefits

- High OPR cycle, low T26 & T30
- Theoretical 4% fuelburn improvement eliminated by compromised core component efficiencies, BPD loss & nacelle drag

Geared LP sool

- Reduced LP shaft dia.
- Reduced compromise to compressor & turbine efficiencies

Image courtesy of NEWAC

Rolls-Royce

Intercooled Turbofan Concepts

Bypass duct offtake and LP ducting

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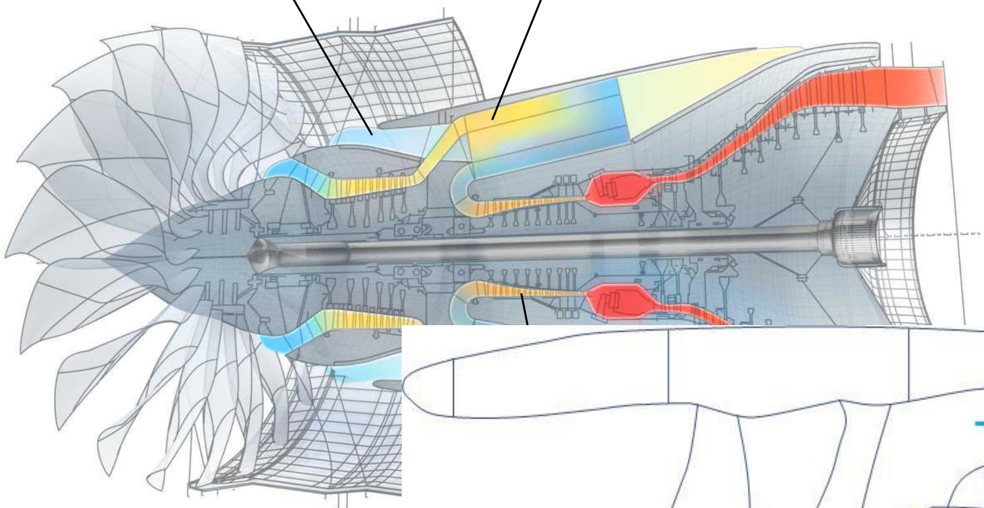

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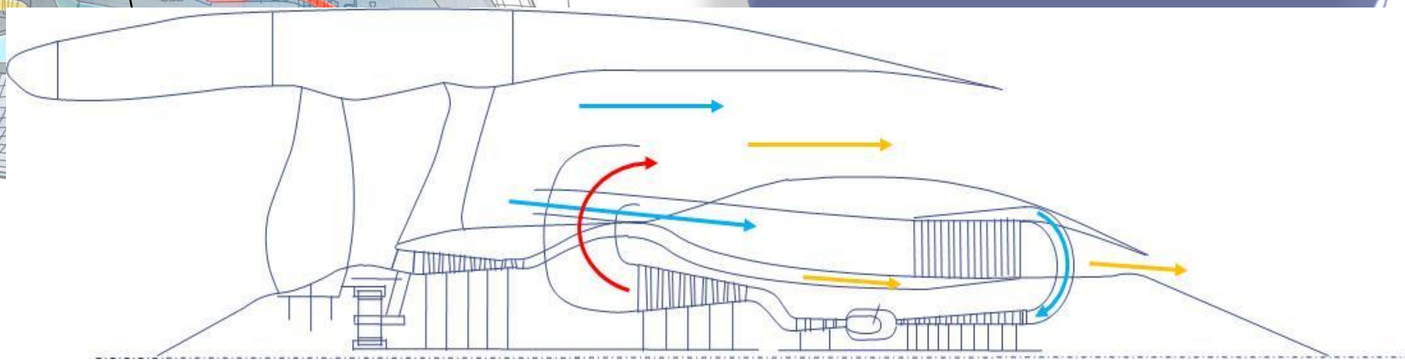
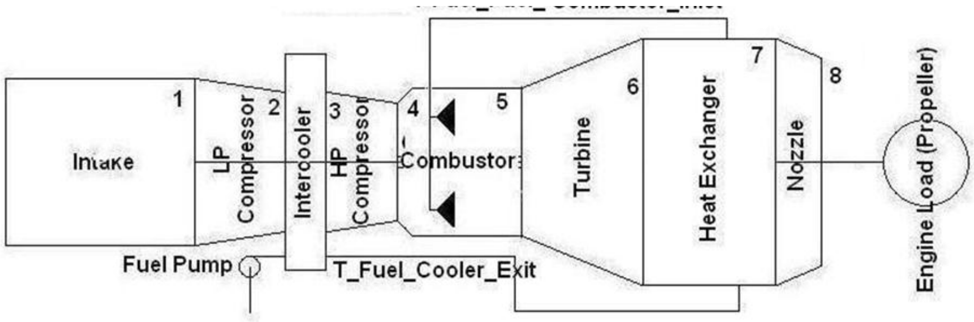


Reverse Flow Core

- Eliminates LP shaft & structural load constraints – optimised core
- Accessible rear mounted HX reduces BPD loss & nacelle drag penalties

Vision 20 Propulsion Concepts

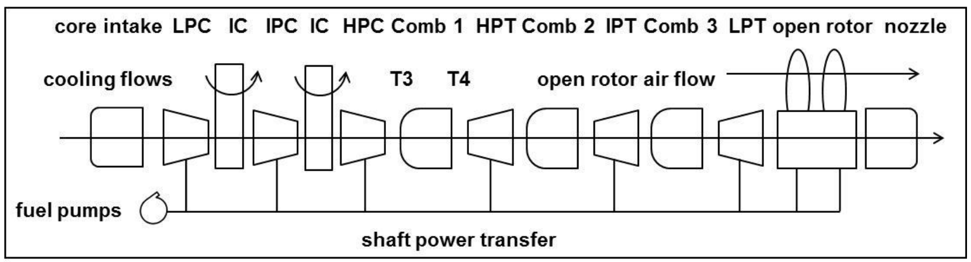
Cryo-fuel Intercooled & Recuperated Cycle



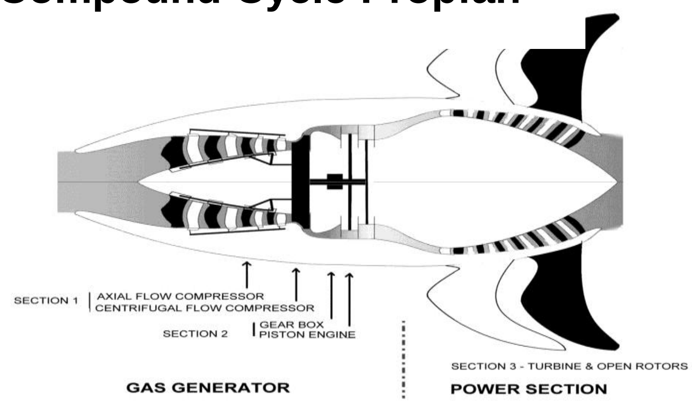
Long term strategy

Deliver radical, advanced propulsion concepts capable of achieving the enhanced capability, performance, fuelburn, noise and emissions required by the market

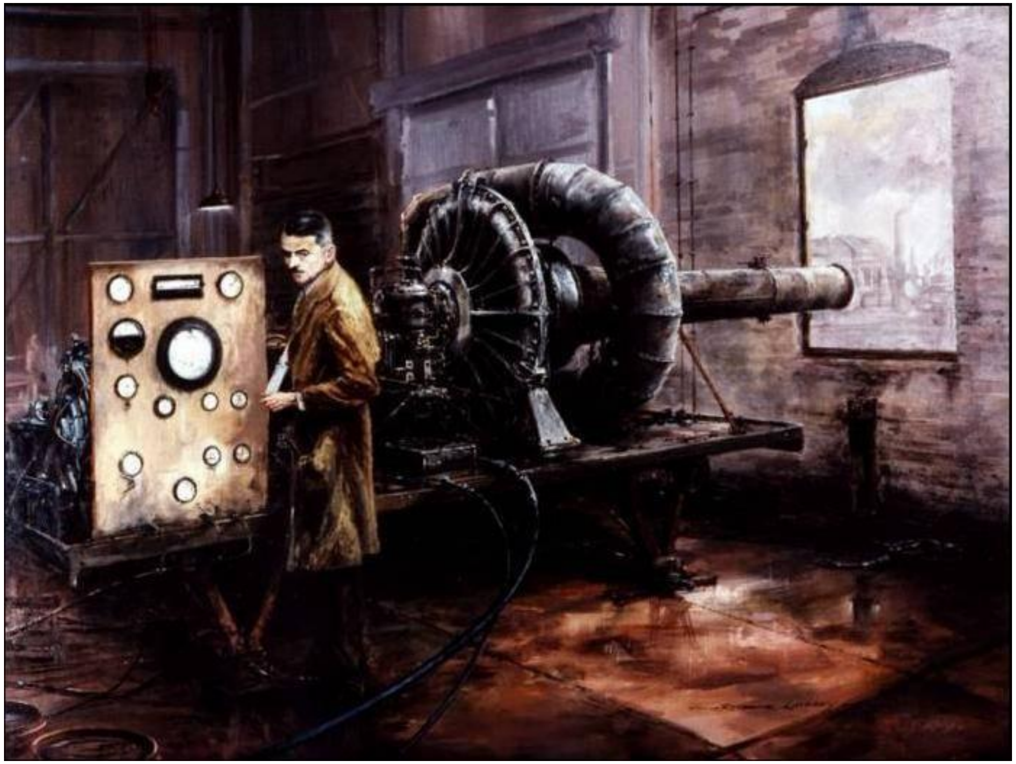
Multi Intercooled & Reheated Cycle



Compound Cycle Propfan



The Original Whittle Engine



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

- Sir Frank Whittle

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FUTURE

PROGRAMMES