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

2012 financial highlights

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<th>order book</th>
<th>underlying Group revenue</th>
<th>underlying profit</th>
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<tr>
<td>£60.1bn</td>
<td>£12.2bn</td>
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original equipment 48% services 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

- **Large widebody**
  - A350-800
  - A350-1000
  - 777 Derivative
  - 777 Replacement

- **Middle of the Market**
  - A320 NEO
  - 737 MAX
  - 787-9 Stretch
  - Future wide body derivative?
  - A320 Replacement
  - 737 Replacement

- **Corporate & Regional**
  - G650
  - Corporate Derivatives
  - Regional turboprops
  - New corporates

- **Future large engine**
- Open Rotor
- UHBR Turbofan
- Advanced turboprop

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Overall ACARE* Environmental Targets for 2020

Reduce Perceived External Noise by 50% (30db Cumulative)
Reduce Perceived External Noise by 18 dB Cumulative
Reduce EINO\textsubscript{X} Emissions by 60%
Reduce NO\textsubscript{X} Emissions by 80%

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

Reduce Fuel Consumption and CO\textsubscript{2} Emissions by 50%
Reduce Fuel Consumption and CO\textsubscript{2} Emissions by 20%
Engine level targets

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

* Advisory Council for Aerospace Research in Europe

November 2007
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Customer Expectations

Reduced cost, increased safety, reliability, availability

Flawless

- New engines
- Trent XWB
- Trent 1000
- Trent 500, 700, 800 now best in class

Dispatch Availability

Safety & Basic Integrity

Project Zero Fleet Reliability Assurance + Fleet Proactive Engine Life Management

Historical Approach – Including Trent 900

Systems Eng, Robust Design / Manufacture

Design for Service (DfS)
Turbofan Thermodynamic Cycle Efficiencies: Propulsive, Transfer & Core Thermal

Core thermal efficiency = \( \frac{E_{\text{core}}}{E_{\text{fuel}}} \)

Transfer efficiency = \( \frac{(E_{\text{jets}} - E_{\text{inlet}})}{E_{\text{core}}} \)

Propulsive efficiency = \( \frac{F_n V_0}{(E_{\text{jets}} - E_{\text{inlet}})} \)
Turbofan Thermodynamic Cycle Efficiencies: Advancement in different thrust classes

Approaching Theoretical Limit for conventional gas turbines – Near-Stoichiometric TET, Ultimate Component Efficiencies

Current Rolls-Royce HBR Engines

≈ 30% Theoretical Improvement @ 0.8Mn

Approaching practical limit for Low NOx combustion?

Lower NOx

Quieter

Lower SFC

Propulsive Efficiency $\eta_{prop}$

Thermal Efficiency $\eta_{th}$

x Transfer Efficiency $\eta_{tran}$

Large Turbomachinery

Small – Medium engines

Large Turboprops

Robust engine design

Lower SFC

Robust engine design

Robust engine design

Quieter

Current Rolls-Royce HBR Engines

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

Requirements: Market, legislation, competition, business case

Thermodynamic fundamentals, cycle design & optimisation

Collaborative Airframe/propulsion System Conceptual Design

R&T: Technology Acquisition – “The Art of the Possible”

Trent 1000

Trent XWB

Advance 3 Technology Demonstrators

EFE

ALPS

ALECSYS

Next Large Engine

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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

75-84,000lb
Fully interchangeable
Lowest weight

97,000lb
High thrust economics

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The Trent XWB
Advanced components & novel features

- Hybrid mount system
- Composite rear fan case
- Single skin combustor casing - enabled by advanced WEM & hybrid mount
- Modulated turbine tip clearance control & cooling air
- Short, lightweight LP turbine
  End wall profiling, 3D aero
  Semi-hollow blades for optimum 3D aero & minimum weight
- 2 stage IP turbine
- High pressure ratio core compression system
- Advanced 3D aerodynamics
  - facilitates high OPR at acceptable T30
- Blisked HPC stages 1 - 3
- Optimised bearing load management system
  - front location bearing
- 118” low htr fan
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

- 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)
Trent XWB Turbine Architecture

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 very 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
The Trent XWB
Reducing environmental impact

20% lower CO₂

60% lower NOx

Target 50% CO₂ overall reduction:
- 15-20% from engine
- 20-25% from airframe
- 5-10% from operations

Target 80% NOx overall reduction:
- 60% from engine technology
- 20% from operational efficiency improvements

Target 50% aircraft noise reduction:
- 30dB cumulative
- 10dB average at each condition

Trent family

ACARE target (Advisory Council for Aeronautics Research in Europe)
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

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Advance 3 Large Engine Technologies

- Lightweight composite fan, containment case & dressings
- Lean burn combustor
- Advanced turbine materials
- Smart, adaptive systems
- 3 core turbines
- Novel IP/LP structural arrangement
- Advanced high OPR cycle, with cooled cooling air
- Blisked construction
- Light-weight high efficiency compressors
- Advanced active systems
- Advanced sealing

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Advance 2 Medium/Small turbofan technologies

- Lightweight composite fan blade & casing
- Advanced shroudless HPT with rub-in CMC liner
- Lightweight TiAl LPT
- Fan blisk
- Advanced blisked 22:1 HPC
- Advanced sealing and externals
- MMC Blings
- Advanced phase 5 or lean burn combustor

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Vision 20 Propulsion Requirements
Long Term Market Scenario Evaluation

- Technology will become more valuable
- Novelty will have increased value at concept and technology level
- Mid-life technology insertion will become viable & desirable
- CO2 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 CO₂ per passenger kilometre
- 90% reduction in NOx emissions
- 65% reduction in noise

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
Improving propulsive efficiency

Ongoing improvements in fuel burn and noise enabled through:
- Lightweight fan and LP turbine
- Lightweight, low drag nacelle
- Fan and LPT efficiency improvements

1980s
2000s
Next Gen

Reducing engine noise

Fan Diameter (Propulsive Efficiency)

Aircraft Fuel Burn & CO₂

Aircraft Noise
# Driving propulsive efficiency

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<td><strong>Direct Drive</strong></td>
<td><strong>UHBR Turbofan</strong></td>
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<td>• Power gearbox</td>
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<td>• High-speed LPT</td>
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<td>• Composite props</td>
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<td>• Variable pitch props</td>
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<td>• Integrated nacelle</td>
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**Applying Open Rotor technologies to turbofan solutions**

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

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

**Installation issues**

**Technical risk**

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Open Rotor propulsion

- Ultra high bypass ratio (50+) with a contra-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

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**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

**High flow distortion from swallowing BL:**
- Penalty on fan efficiency
- High fan forced response
- Require distortion tolerant fan (& core compressors?)
Driving thermal efficiency

| OPR | 40 | 65+ |

Applying advances in technology across market sectors

Fuel burn improvements
Reducing life requirements

Cycle temperatures
Mechanical difficulty

Trent 1000
Trent XWB
E3E Core

Military
ADVENT/HEETE

Wide Body

Narrow Body

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Vision 20 Propulsion

- Advanced intercooling using fuel as the heat sink
- Metal matrix composite (MMC) bladed drum
- System optimised lean burn combustion
- Embedded centreline electric motors/generators
- All-ceramic self-diagnostic bearings
- Stator-less contra-rotating HP/IP turbines
- Ceramic Matrix Composite (CMC) turbine components
- Variable cycle engine with mini-mixer, variable core systems, nozzles and chevrons
- Intelligent control systems with advanced prognostics, diagnostics and connectivity

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Intercooled Turbofan Concepts

Bypass duct offtake and LP ducting

Intercooler compromises BPD & nacelle increasing losses & drag

Ducting for intercooler

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

Geared LP sool

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

Cycle benefits

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

Image courtesy of NEWAC
Intercooled Turbofan Concepts

Bypass duct offtake and LP ducting

Intercooler compromises BPD & nacelle increasing losses & drag

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

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

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Vision 20 Propulsion Concepts

Cryo-fuel Intercooled & Recuperated Cycle

Multi Intercooled & Reheated Cycle

Compound Cycle Propfan

Long term strategy

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

“The invention was nothing. The achievement was making the thing work”

- Sir Frank Whittle