An aero-engine vision of 2020

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November 2004
Overall ACARE* environmental targets for 2020

- Reduce perceived external noise by 50% (30db Cumulative)
- Reduce NO\textsubscript{x} emissions by 80%
- Reduce fuel consumption and CO\textsubscript{2} emissions by 50%

Targets are for new aircraft and whole industry relative to 2000

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

* Advisory Council for Aerospace Research in Europe
Meeting the 50% fuel burn target needs changes in all areas

Contributions to CO₂ Reduction

Possible design solutions
Meeting the 30dB noise target needs changes in all areas

<table>
<thead>
<tr>
<th>Contributions to noise reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>0dB</td>
</tr>
<tr>
<td>-10dB</td>
</tr>
<tr>
<td>-20dB</td>
</tr>
<tr>
<td>-30dB</td>
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</table>

Possible design solutions

<table>
<thead>
<tr>
<th>Possible design solutions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aircraft &amp; engine sources</td>
</tr>
<tr>
<td>Airframe perf.</td>
</tr>
<tr>
<td>Operations</td>
</tr>
</tbody>
</table>

Rolls-Royce
Engine ACARE* environmental targets for 2020

Reduce perceived external noise by 18 dB Cumulative

Reduce $\text{NO}_x$ emissions by 80%

Reduce fuel consumption and $\text{CO}_2$ emissions by 20%

Targets are for new engines and whole industry relative to 2000

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

* Advisory Council for Aerospace Research in Europe
Affect on Future Product Capability

All parameters at 35000 ft, 0.80 Mn

Propulsive Efficiency

Thermal Transfer Efficiency

90’s

Recent engines

Current designs

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Factors influencing thermal efficiency

Component efficiency 0.85

Overall Pressure Ratio

TET (K)

Thermal Efficiency

1960’s

1970’s

1980’s

1990’s

2020 Target

Target
Emissions constraints

At idle:
- Combustor pressure and temperature are low, and primary zone is weak (high AFR)
  — 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
Forcing down emissions through innovation

Single-annular combustor
70% CAEP 2

Direct injection, lean burn single-annular combustor

Double-annular combustor
Main
Pilot
55% CAEP 2

40% CAEP 2

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EEFAE - ANTLE - proving technology for 2008

Trent 500 baseline engine with new technologies incorporated

- **Controls**
  - Distributed systems
  - Fuel pump

- **Combustor**
  - Lean burn
  - Staged combustor

- **Whole engine**
  - Increased temperatures and pressures

- **Oil system**
  - Oil pump
  - Air riding carbon seals
  - Brush seals

- **Accessory gearbox**
  - Bearings
  - Seals

- **Health monitoring**
  - Intelligent sensors
  - Advanced EHM

- **HP compressor**
  - 5 stages
  - Blisks

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

- **LP turbine**
  - 4 stages
  - Novel construction

- **IP turbine**
  - Cooled
  - Structural NGV
  - Variable capacity

- **ANTLE** = Advanced Near-Term Low Emissions

EU and UK government funded
EEFAE – CLEAN for 2012 - 2015

HP core and LPT with new technologies incorporated

LPT
  • High speed

Compressor
  • Active-surge control

Combustor
  • Lean burn
  • Staged combustor

Recuperator
  • Heat exchanger

CLEAN = Component vaLidator for Environmentally-Friendly Aero-eNgine
Rolls-Royce
Objective of VITAL

![Graph showing weight/thrust trend with EIS up to 80's and EIS 90's data points, indicating a breakthrough at BPR]
# Weight breakdown of high BPR three shaft turbofan

<table>
<thead>
<tr>
<th>Component</th>
<th>Proportion of total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fan rotor &amp; casing</td>
<td>18%</td>
</tr>
<tr>
<td>IP Comp.</td>
<td>5%</td>
</tr>
<tr>
<td>Structures</td>
<td>15%</td>
</tr>
<tr>
<td>Shafts</td>
<td>3%</td>
</tr>
<tr>
<td>LP Turb.</td>
<td>16%</td>
</tr>
<tr>
<td>Nacelle</td>
<td>22%</td>
</tr>
<tr>
<td>Core &amp; externals</td>
<td>21%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>100%</strong></td>
</tr>
</tbody>
</table>
Weight trends of subsystems

% of datum engine weight vs Bypass ratio

- Fan system
- IP comp.
- Structure
- Shafts
- LP turb.
- LP turb.
- Nacelle
- HP core & controls

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Effect of BPR & shaft torque on core mass

50% torque increase of LP shaft at dia. avoids 200% mass increase
EU VITAL programme

- Fan/IGV interaction
- Noise optimised VHBR fans
- Lightweight containment case
- Lightweight structures
- Lightweight Turbine
- High Torque shaft
- Low Noise Turbine
- Lightweight Nacelle
- Lightweight novel materials
- Manufacturing techniques
- DDTF engine
- GTF engine
- CRTF engine
- DDTF fan
- High Speed booster
- Low Speed booster
- Low noise OGV
- Variable Nozzle
- Contra rotating fan
- CR Turbine study
- Applicable to all 3 VITAL engine concepts
- Specific to a VITAL engine concept
- Also applicable to other industries
Noise benefit from increased BPR

Current technologies limit
University lead modelling work

- Assessing impact of VITAL technologies
- Combines
  - Atmospheric modelling
  - Routes/ fleet mix
  - Aircraft performance
  - Engine performance
    - Parametric
  - Engine weight
    - Parametric
  - Engine emissions
  - Economic modelling
- Optimiser software seeks ‘sweet spot’ for any scenario

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Mission NO$_x$ modelling
Trent 1000

- Latest in evolution of Trent series of engines
- Achieves improvements in line with ACARE goals
Fuel consumption (and CO$_2$) reduction

-20% -15% -10% -5% 0% 5%

Fuel consumption per unit thrust at cruise

-20% -15% -10% -5% 0% 5%


ACARE TARGET

Trent 895
- Trent 500
- Trent 900
- Trent 1000 prediction

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NOx emissions reduction

Trent 895
Trent 556
Trent 900
Trent 1000 prediction

ACARE TARGET

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Aircraft noise reduction

Average aircraft noise corrected for aircraft weight (dB)

-10 -8 -6 -4 -2 0


Trent 800 powered aircraft
Trent 500 powered aircraft
Trent 900 powered aircraft
Predicted Trent 1000 powered aircraft

ACARE TARGET
There is significant potential for technology to further reduce the environmental impact of aviation.

ACARE targets focus on noise, NOx and fuel burn (CO$_2$ emissions).

Good progress is being made towards these targets by combining the efforts of all.

Sustained and increased levels of investment in technology will be required to achieve ACARE goals.

But……although they are extremely challenging, are the ACARE goals sufficient for sustainable aviation?
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