AHEAD : Advanced Hybrid Engines for Aircraft Development (ACP1-GA-2011-284636)

Level 1: Start 1/10/2011, duration 3 years

Scientific coordination: Dr. Arvind G. Rao, TU Delft

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Improvement in Aircraft Fuel Burn

IATA Forecast 2014

• On Friday, IATA released its first 20 year passenger growth forecast.
• The number of passengers travelling in 2034 is expected to be 7.3 Billion.
• This is 4 Billion passenger more than 2014. (If Ebola doesn’t affect).
• That is an annual growth of 4.1% per annum.
• At present, aviation helps sustain 58 million jobs and $2.4 trillion in economic activity.
• In 2034 aviation would be supporting around 105 million jobs and $6 trillion in GDP.
• The US will remain the largest air passenger market until around 2030, when it will drop to number 2, behind China.
ACARE Goals for EU

- Year 2000
- Year 2020
- FP 2050

- Perceived Noise
- Lower CO2
- Lower Nox, CO, UHC

% reduction

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Fuel demand and supply

World jet fuel consumption between now and 2020 (Million liters per day)

Source: US Department of Energy
Fuel demand and supply
Fuels / energy sources for Aviation

What is LNG?

- Brought to the temperature of -161°C at 1 atm in order to be liquefied
- Purified, methane is the largest concentration component
- Bio-LNG

Comparison of chemical compositions [6]

Comparison of the volumes

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Cryogenic Fuel

Advantages of LNG
- Lower fuel weight compared to kerosene.
- 25% reduction in CO2 emission.
- Approximately 70% reduction in NOx-and particulate emissions.
- Usage of cryogenic heat sink can increase engine thermal efficiency.
- The LNG is substantially cheaper than conventional jet fuels.
- Can be produced from renewable energy.

Disadvantages of LNG
- Requires pressurised and insulated tanks for storage resulting in increased aircraft OEW.
- Increased storage space for LNG compared to conventional jet fuels.
- Airport facilities and logistics for tanking LNG are required.
- Increased water vapour emission by 40%
Methane Fuel

Joint transport research center “Biofuels-Linking support to Performance”, Round Table, June 2007, Paris
LNG Vs Kerosene

Conversion to LNG Price

<table>
<thead>
<tr>
<th>Component</th>
<th>Price (MMBtu)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural Gas</td>
<td>$6.00</td>
</tr>
<tr>
<td>Liquefaction</td>
<td>$6.00</td>
</tr>
<tr>
<td>Transportation</td>
<td>$0.30</td>
</tr>
<tr>
<td>Storage</td>
<td>$0.82</td>
</tr>
<tr>
<td><strong>Total LNG</strong></td>
<td><strong>$13.12</strong></td>
</tr>
</tbody>
</table>

*Prices are per MMBtu

**JET A-1**

100%

40.22 MJ/$

LNG

80.38 MJ/$
Possible Energy Sources/carries for Long Range Aircraft

Aircraft Primary Energy Source

2000 2020 2040 2060 2080 2100

Kerosene  Synthetic fuel / GTL/CTL/Biofuels  LNG/ Hydrogen

Storage of hydrogen rich fuels in conventional aircraft

• Cyrogenic fuels should be stored in cylindrical tanks
• Fuel storage was the biggest challenge
Can we design new type of aircraft and engine taking into account the future energy challenges of the air-transport system?
Storage of hydrogen rich fuels in BWB

• BWB has inherently has extra volume which can be used to accommodate the cylindrical fuel tanks
• This novel idea of multi fuel BWB is unique which optimizes the usage of space in a BWB
Why Multifuel

Multi-fuel: Cryogenic and Liquid fuel (kerosene/ Biofuel)

- 300 passengers
- Range: 14,000 km
Preliminary design

Results – Passenger compartment

- 302 seats
- 8 lavatories and 7 galleys
- 6 Type-A emergency exits
Preliminary design

Results – Weight breakdown

<table>
<thead>
<tr>
<th></th>
<th>Early Results</th>
<th>New-BWB</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wo</td>
<td>-</td>
<td>242,800 kg</td>
</tr>
<tr>
<td>MTOW</td>
<td>205,991.5 kg</td>
<td>237,970 kg</td>
</tr>
<tr>
<td>OEW</td>
<td>85,834.5 kg</td>
<td>122,220 kg</td>
</tr>
<tr>
<td>W/S</td>
<td>225.62</td>
<td>265.04</td>
</tr>
<tr>
<td>(T/W)_TO</td>
<td>0.28</td>
<td>0.21</td>
</tr>
<tr>
<td>T_TO</td>
<td>565,800 N</td>
<td>527,810 N</td>
</tr>
<tr>
<td>T_cruise</td>
<td>75,800 N</td>
<td>98,195 N</td>
</tr>
</tbody>
</table>
The AHEAD Multi-Fuel BWB
The Low NOx Hybrid Engine

- Cryogenic Main Combustor -> Low Nox and CO2
- Kerosene/ Biofuel Secondary Flameless Combustor -> Low Nox, Soot & HC
- Bleed cooling by cryogenic fuel -> lower fuel consumption
- Counter rotating shrouded fans -> Low Noise, BLI capable
- Higher Specific Thrust
- Low Installation Penalty

Summary on the H2 combustor

- Design of lean premixed burner applying axial air injection
- Gas-fired tests
  - Proof of flashback-safety
  - Single-digit NOx emissions
  - Zero CO, CO2, UHC or soot
- Future work: proof excellent performance and NOx emissions at elevated pressure

H2 combustion is **safe** and **low** in emissions (CO, CO2, UHC, soot, NOx)
The different combustion regimes

Final Combustor Geometry

Air Inlets scheme, internal part

LH2 COMBUSTOR

JP8 / BIOJET FUELED COMBUSTOR

D2

D1
Experimental model of Flameless Combustor
Towards Flameless Combustion
CO₂ Emission

![Graph showing CO₂ emission per kg payload * km range vs. range (km)].

- B777
- B787
- A330
- BWB
- Range BWB

Emission in kg CO₂ per (kg payload * km range)

Range [km]

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Some Highlights

Comparison with Boeing 777-200ER

- CO$_2$ emissions reduced by around 50%.
- NO$_x$ emissions reduced substantially.
- LNG used as fuel.
- Significant reduction of soot and particulates.
## Cost Benefit Analysis

Difference in cost for a trip JFK/HKG:

<table>
<thead>
<tr>
<th></th>
<th>CO2 ETS low</th>
<th>CO2 ETS high</th>
</tr>
</thead>
<tbody>
<tr>
<td>B777</td>
<td>€ 175,932</td>
<td>€ 182,654</td>
</tr>
<tr>
<td>MF BWB LNG</td>
<td>€ 131,662</td>
<td>€ 134,890</td>
</tr>
<tr>
<td>Difference</td>
<td>€ 44,270</td>
<td>€ 47,764</td>
</tr>
<tr>
<td>CO2 saving</td>
<td>174.7ton</td>
<td>174.7 ton</td>
</tr>
<tr>
<td>CO2 saving in %</td>
<td>52%</td>
<td>52%</td>
</tr>
</tbody>
</table>
Climate Assessment

Climate impact of B777-200ER fleet with 2000 technology

Climate impact of AHEAD LNG fleet with 2050 technology
**Climate Assessment**

<table>
<thead>
<tr>
<th>CO₂</th>
<th>NOₓ</th>
<th>Cont</th>
<th>H₂O</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>12</td>
<td>-8</td>
<td>-2</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>0</td>
<td>1</td>
</tr>
</tbody>
</table>

-2  -15 -6  +10
-1  -13 -6  +12
-1  -19 -8  +5

-12% / -8%
-23%

AHEAD-LH₂
AHEAD-LNG

B777-200
B787-8
B787-FUT

Reference
IATA technology projection

- Serial Upgrade
- Retrofit
- Before 2020
- After 2020

Δ TRL

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The AHEAD Consortium

- Delft University of Technology
- WSK PZL-Rzeszow S.A
- Technical University of Berlin
- DLR, IAP
- Israel Institute of Technology-Technion
- Ad Cuenta b.v.

Advisory Board

- MTU Aero Engines
- EASA
- KLM
- Airbus Group Innovations
The AHEAD Multi- Fuel BWB

Thank You
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