Aircraft for Reduced Impact on Climate
How Aircraft Design can Contribute to Mitigating Global Warming

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Acknowledgements

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Paul Peeters (Breda University of Applied Sciences)

for providing data and figures to the talk.
Airplane with minimum climate impact?

Safe (parachute mandatory)?
Comfortable?
Fast?
Independent of the weather?
Can I put two suitcases in?
Good service?
Inexpensive?

Can I go from Munich to Berlin?

Photo credits: www.whiteplanes.com
1. Introduction
2. Aircraft emissions and their impact on climate
3. Mitigation options on the part of the airframe
4. Aircraft design methodology with full integration of climate impact
5. Conclusion
Introduction

Definition of “Environment” linked to A/C operations

Aviation

- Noise
  - local

- Emissions
  - local
  - global

Metrics?
  to enable tradeoffs

- Community health
- Local air quality
- Climate change

Regulations, Charges, external costs

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Berlin, 12 September 2007

CEAS
Growth in Airport Noise Restrictions
2006

Development of emission regulations similar?
What is the delay?

Source: Boeing
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Aircraft emissions

Relevant Emissions from Aviation

1 kg Fuel

3.4 kg O₂

1.23 kg H₂O

3.16 kg CO₂

In variable quantities:
Nitrogen oxides NOx ~ 4 - 40g
Sulphur oxides ~ 0.6 - 1g
Particles / soot ~ 0.01 - 0.03g

Contrails

forms / depletes ozone O₃
depletes methane CH₄
Ozone and methane are greenhouse gases.
Climate Impact of Aviation

Aircraft RF until 1992 / 2000

Level of scientific understanding:
- Good
- Fair
- Poor

From Sausen et al in Meteorologische Zeitschrift, Vol. 14, Number 4, 2005
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Example of **Aerodynamics Performance Improvement** – Winglets

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Design range</td>
<td>+130 nautical miles</td>
</tr>
<tr>
<td>Fuel burn</td>
<td>-2.50%</td>
</tr>
<tr>
<td></td>
<td>≈ -3.50%</td>
</tr>
<tr>
<td>NOx Emissions</td>
<td>-4.60%</td>
</tr>
<tr>
<td>Payload at fixed range</td>
<td>+6000 lb</td>
</tr>
<tr>
<td></td>
<td>≈ +1000 lb</td>
</tr>
</tbody>
</table>

⇒ The improvement depends on the individual mission.

**Structural weight** reductions referred to 1990 baseline:

- 8% until 2005
- 15% until 2010 (A350 / 787 aircraft types)
- Future?

Manufacturers’ views (2): mitigation potentials

“Breakthroughs for fuel burn reduction are possible”

- **Aerodynamics:** up to 10% of fuel
  - Advanced riblets
  - Wave drag control
  - Natural or hybrid laminar flow
  - Innovative aircraft configuration

- **Weights:** up to 5% of fuel
  - Next generation composite design and manufacturing

- **Systems:**
  - 30% energy reduction of ECS identified by using low pressure bleed
  - On-board systems optimisation offers an additional potential fuel burn benefit.
  - 3% of fuel burn in cruise through fuel cells

- **Changing cruise altitude**
  - Lowering cruise altitudes “might help for NOx, but increases fuel burn up to +6% (for 4000ft cruise altitude reduction at M0.85)”
  - Better knowledge on contrails and cirrus needed to enable tradeoffs with fuel burn

- **Biofuels**, may become standard complement to oil kerosene.

Summarised from Alain Garcia: Technical Press Briefing, Airbus, April 2007
Also in Aviation Week and Space Technology, August 20/27, p. 60.
Manufacturers’ views (3): mitigation potentials

New technologies:
• Next generation composites
• Reducing pneumatic systems
• Biofuels with priority of BTL

Airplane performance improvements (ongoing programs):
• Increased precision navigation for operational efficiency (737 NG)
• Lighter weight carbon brakes (737 NG)
• Blended winglets (737 NG): 3-5% aerodynamic efficiency / 2-4% in fuel burn
• Advanced wing design: raked wing tip, smaller wing vortex generators, revised ram air inlet for lower drag (777)
• Manoeuvre load alleviation for lower empty weight (777F)

At least 15% improvement in fuel efficiency is required by the market in order to justify the development of a new generation of airplanes.
Increasing L/D

Increase span. Wing weight ↑ - stronger lightweight materials, reduced Mach could compensate

Radical solutions:
- Blended wing body
- Natural laminar flow control
- Hybrid laminar flow control (HLFC)
- Full (all-over) laminar flow control

Also see:
- Aeronautical Journal, Aug 2006
- Greener by Design, The Technology Challenge, 2001
- Greener by Design, Mitigating the Environmental Impact of Aviation: Opportunities and Priorities, 2005

From Prof. Jeff Jupp: The Impact of Aviation on the Environment – How will the future for Air Transport be Affected? RAeS lecture at the Technical University of Munich, 14th of June 2007
Fuel efficiency is only one of many design requirements of commercial aircraft.

From Greener by Design: Mitigating the Environmental Impact of Aviation: Opportunities and Priorities, Report 2005
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Fuel consumption depends on the mission (operations).

And: Climate impact does not only depend on the quantities emitted, but also on where the gases occur. That’s why we need to couple aircraft design with operations and we need an atmospheric / climate metric.
It is important, **where** the aircraft fly!

Most important parameter: altitude

⇒ Interdependence with classic aircraft design parameters
Aircraft design today

- Configuration
- Weights
- Lift
- Drag
- Thrust
- Consumption
- Emissions
- Noise

Aircraft design tomorrow

- Structures
- Aerodynamics
- Design Loop
- Engine Technology
- Parameter?

Atm. Impact
Design approach including global warming

Aircraft Design / Perf.

Climate impact eval.

Holistic approach at system level

Emission scenarios

Impact-driven instead of emissions-driven design!

Credits: Eurocontrol

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Berlin, 12 September 2007
Example 1: Benefit of fleet renewal 1995-2005

Virtual scenario:
2005 traffic, 1995-type fleet
Only routes that existed in both years (OAG)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Available Seat Kilometres (ASK)</td>
<td>$10^{12}$</td>
<td>3.00</td>
<td>3.72</td>
<td>3.75</td>
</tr>
<tr>
<td>Estimated Load Factor</td>
<td>[-]</td>
<td>69%</td>
<td>75%</td>
<td>75%</td>
</tr>
<tr>
<td>Total flown distance from OAG</td>
<td>$10^9$ km</td>
<td>13.97</td>
<td>16.55</td>
<td>16.55</td>
</tr>
<tr>
<td>Considered number of flights in OAG</td>
<td>[million]</td>
<td>10.5</td>
<td>11.2</td>
<td>11.2</td>
</tr>
<tr>
<td>Total flown distance calculated</td>
<td>$10^9$ km</td>
<td>13.58</td>
<td>16.09</td>
<td>16.11</td>
</tr>
<tr>
<td>Fuel consumption</td>
<td>[Tg]</td>
<td>73.5</td>
<td>84.4</td>
<td>91.2</td>
</tr>
<tr>
<td>NOx emissions</td>
<td>[Tg]</td>
<td>0.90</td>
<td>1.12</td>
<td>1.14</td>
</tr>
<tr>
<td>Global NOx emissions index</td>
<td>[g/kg]</td>
<td>12.21</td>
<td>13.33</td>
<td>12.48</td>
</tr>
<tr>
<td>Average seat capacity</td>
<td>[-]</td>
<td>215</td>
<td>225</td>
<td>227</td>
</tr>
<tr>
<td>Average sector length</td>
<td>[km]</td>
<td>1329</td>
<td>1479</td>
<td>1479</td>
</tr>
<tr>
<td>Consumption/100ASK</td>
<td>[kg]</td>
<td>2.45</td>
<td>2.27</td>
<td>2.43</td>
</tr>
<tr>
<td>Consumption/100RPK</td>
<td>[kg]</td>
<td>3.55</td>
<td>3.02</td>
<td>3.24</td>
</tr>
<tr>
<td>Consumption/100RPK</td>
<td>[l]</td>
<td>4.44</td>
<td>3.78</td>
<td>4.05</td>
</tr>
</tbody>
</table>

Atmospheric evaluation: LEEA project (1)

LEEA: Low Emissions Effect Aircraft. Project sponsored by DTI (UK) and Airbus

Global Ozone Burden Perturbation

- Complicated processes in the atmosphere
- Simple atmospheric metrics (Kyoto GWP) not sufficient to represent aviation’s climate impact.

From: Köhler et al., TAC Conference 2006, Oxford

Normalised Burden Change [Tg O₃ / Tg N]

From: Köhler et al., TAC Conference 2006, Oxford
Atmospheric evaluation: LEEA project (2)

LEEA: Low Emissions Effect Aircraft. Project sponsored by DTI (UK) and Airbus

Ozone forcing per TgN (ALT)

Only ozone forcing, methane effect not included!

From: Rädel and Shine, TAC Conference 2006, Oxford
Example 2: Climate impact of combustor techn.

Climate impact ratio (based on LEEA):

<table>
<thead>
<tr>
<th>2000 nm</th>
<th>Flight altitude</th>
<th>Distance</th>
<th>Fuel burn</th>
<th>Climate impact ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Taxi and Takeoff</td>
<td>750</td>
<td>0%</td>
<td>3%</td>
<td>1</td>
</tr>
<tr>
<td>Climb</td>
<td>18750</td>
<td>7%</td>
<td>14%</td>
<td>1.20</td>
</tr>
<tr>
<td>Step 1</td>
<td>36000</td>
<td>13%</td>
<td>13%</td>
<td>0.96</td>
</tr>
<tr>
<td>Step 2</td>
<td>38000</td>
<td>70%</td>
<td>63%</td>
<td>0.95</td>
</tr>
<tr>
<td>Step 3</td>
<td>40000</td>
<td>4%</td>
<td>3%</td>
<td>0.94</td>
</tr>
<tr>
<td>Descent</td>
<td>20750</td>
<td>6%</td>
<td>2%</td>
<td>1.01</td>
</tr>
<tr>
<td>Landing and Taxi</td>
<td>750</td>
<td>0%</td>
<td>2%</td>
<td>1</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>100%</strong></td>
<td><strong>100%</strong></td>
<td></td>
<td><strong>0.96</strong></td>
</tr>
</tbody>
</table>

* 1995-1996 technology level: Double annular combustor / single annular combustor

• Complexity: Data management and uncertainties
• Lack of appropriate / reliable metrics at several levels
• Which metrics could allow tradeoffs to non-environmental issues (monetary / regulations)?
• Competences within industry (atmospheric sciences)?
• Competences within sciences (aircraft design and operations)?

⇒ Continue existing and create new research cooperation
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We should re-open the design space:

- Design Range?
- Speed?
- Cruise altitude?

of today’s aircraft are no premises.
Rebalancing the importance of the atmosphere presumes **reliable metrics** (need for development / improvement / validation).

Engineering shall keep the pace of atmospheric scientists in order to be able to integrate new knowledge as quickly as possible.

Any financial penalties and restriction systems have to be coherent and goal-orientated.

All stakeholders of the air transport system must work hand in hand (systems approach).

The early consideration of the environment in aircraft design will be **vital** for the manufacturer, once regulations represent the actual impact.

Anticipating political conditions and designing respective aircraft will then provide an **economic asset and competitive advantage** for the aircraft manufacturer.

The **social acceptance** of aviation could increase, if advances are appropriately **communicated** (!).

Aviation should not be afraid of new **environmental regulations**, but take advantage of them as **drivers for innovation**.

Let’s go back to work!
Thank you for your attention!