Reducing Aviation Emissions

The Manufacturers’ Perspective

International Civil Aviation Day
7 December 2005
Reducing Aviation Emissions

CONTENTS

1. Overview
2. Background on Aviation Emissions
3. Progress in Reducing Aviation Emissions
4. Design & Technology to reduce Emissions
5. The Aviation Strands of Progress
6. Reducing Fuel Burn & Emissions in Operation
7. Epilogue
Reducing Aviation Emissions

CONTENTS

1. Overview
2. Background on Aviation Emissions
3. Progress in Reducing Aviation Emissions
4. Design & Technology to reduce Emissions
5. The Aviation Strands of Progress
6. Reducing Fuel Burn & Emissions in Operation
7. Epilogue
Reducing Aviation Emissions

**OVERVIEW - 1: Drivers & Efficiency**

- Aeronautical Manufacturers have a vocation to develop innovative technology and design highly performing products
  - Permanent challenges & efforts, with prime dimension firmly established for environmental protection
  - Supported by intensive research in cooperation with the Research Community - Needs sustained research & technology funding from Industry & Governments

- Aviation industry has been able to attenuate significantly its environmental impact
  - Noise annoyance has been divided by four, and the balanced approach to noise management should protect the future
  - Fuel consumption per pass-km has been divided by three
  - Beyond these considerable achievements, Aviation Industry targets reductions on an average basis per year of more than 1% in fuel efficiency and ≈ 0.5 dB in noise per operation
Reducing Aviation Emissions

**OVERVIEW - 2: Way Forward**

- Further well supported & coordinated efforts in a coherent and stable, harmonized international regulatory framework, and in a cooperative context, are key to progress efficiently
  - This is happening but needs to be pursued & amplified
  - ICAO plays a major « facilitator » role & provides the right forum

- Design & Technology represent only a part of the solutions: all actors have to work together to address all sources (Aircraft, airport, operations, ATM)

- A global systems approach is needed to reach optimum solutions with maximum efficiency
Reducing Aviation Emissions

CONTENTS

1. Overview
2. Background on Aviation Emissions
3. Progress in Reducing Aviation Emissions
4. Design & Technology to reduce Emissions
5. The Aviation Strands of Progress
6. Reducing Fuel Burn & Emissions in Operation
7. Epilogue
How aviation emissions are produced

1) Air is sucked into the engine, which can empty a squash court in 1 second! Also the pressure is doubled through the fan.

2) 15% of the air enters the core and is compressed to 40 times atmospheric pressure.

3) 85% of the air bypasses the core and exits the engine.

4) In the combustion chamber fuel is mixed with air and burnt at temperature \( \approx 1900 \, ^\circ K \) with peak \( \approx 2600 \, ^\circ K \).

5) The hot gas expands through the turbine which takes energy out to drive the fan and compressor.

6) Exhaust gas and bypass air mix through hot and cold nozzles to produce thrust.

7) The thrust reverser uses bypass air to slow the aircraft on landing.
Reducing aviation emissions.

**Combustion and other Exhaust Products**

- **Fuel** ($C_\text{n}H_{\text{m}}S$)
- **Air** ($N_2 + O_2$)

**Combustion Products**
- $O_2$
- $N_2$
- $H_2O$
- $CO_2$
- ($+ SO_x$)
- HC
- CO
- NOx

**Residual Products**

*non-ideal combustion

Reducing fuel consumption tends to reduce all gaseous emissions.
## Reducing Aviation Emissions

### Aircraft Engine Emission Issues

<table>
<thead>
<tr>
<th>Emission Category</th>
<th>Primary Issues</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>Local Air Quality</strong></td>
</tr>
<tr>
<td></td>
<td>(Ground Level)</td>
</tr>
<tr>
<td>Nitrogen Oxides $^{\text{*}}$ (NO$_x$)</td>
<td>Ozone production - Health/Visibility</td>
</tr>
<tr>
<td>Unburned Hydrocarbons $^{\text{*}}$ (CH$_4$, NMHC/VOC/HAPS-[hazardous air pollutants, e.g. Benzene])</td>
<td>Ozone production - Health/Visibility</td>
</tr>
<tr>
<td>Carbon Monoxide $^{\text{*}}$ (CO)</td>
<td>Ozone production - Health</td>
</tr>
<tr>
<td>Smoke [Smoke Number (SN)$^{\text{*}}$] $\Rightarrow$ Soot, Particulate</td>
<td>Aerosols, particle matters (PM) - Health</td>
</tr>
<tr>
<td>Water Vapor (H$_2$O)</td>
<td>---</td>
</tr>
<tr>
<td>Carbon Dioxide (CO$_2$)</td>
<td>---</td>
</tr>
</tbody>
</table>

* Covered by Current ICAO Regulations  
RF: Radiative Forcing
Reducing Aviation Emissions

Aviation & Radiative Forcing

Overall radiative forcing vs CO2 emissions impact? (RFI value?)
Reducing Aviation Emissions

Relative Impact of Air Transport on GHG and Climate (1990-1996)

- on anthropogenic CO₂ emissions
  - Air Transport: 2%
  - Other Trans. Modes
  - Other Anthropogenic Sources

- on total radiative forcing by anthropogenic activities
  - Air Transport: 3.5%
  - Other Anthrop. activities

* « MOZAIC » project: Ex. of O₃ concentration measurements in the atmosphere

→ Improving the scientific understanding of the atmosphere and the impact of aviation emissions is key to optimize priorities and weight factors in research, trade-offs and mitigation measures

→ Industry supports and participates in these efforts *
Reducing Aviation Emissions

CONTENTS

1. Overview
2. Background on Aviation Emissions
3. Progress in Reducing Aviation Emissions
4. Design & Technology to reduce Emissions
5. The Aviation Strands of Progress
6. Reducing Fuel Burn & Emissions in Operation
7. Epilogue
Reducing Aviation Emissions

Noise annoyance was reduced by ≈ 75% (Joint Engine & Airframe Manufacturer Efforts)

Emissions were continuously reduced (Engine)
~ 70% Fuel Efficiency improvement up to 1990 at product level
- Continuing improvement reflected at fleet level (average > 1.5%/year)
- Driven by strong & efficient market forces, combined with inherent fast-evolving high technology & improved operational practices
- Needs sustained research & technology funding from Industry & Governments
Reducing Aviation Emissions

CONTENTS

1. Overview
2. Background on Aviation Emissions
3. Progress in Reducing Aviation Emissions
4. Design & Technology to reduce Emissions
5. The Aviation Strands of Progress
6. Reducing Fuel Burn & Emissions in Operation
7. Epilogue
Reducing Aviation Emissions

Technology & Design

- Specific Technologies
- Generic Technologies
- Specific Design Features
- Generic Design architectures / configurations

Product initial Development

Interdependencies & Trade-offs

« Internal » trade-offs: within technologies & within design features, with iterations vs requirements
Reducing Aviation Emissions

Technology & Design

SAFETY

Performance
Operability
Reliability
Maintainability
Durability
Costs

Fuel Efficiency
Emissions
Noise
Comfort
Capacity
Timing

Product Development & Optimization

Technologies development

Maturity level

T1
T5

Time

t1

t2

mature
Reducing Aviation Emissions

CONTENTS

1. Overview
2. Background on Aviation Emissions
3. Progress in Reducing Aviation Emissions
4. Design & Technology to reduce Emissions
5. The Aviation Strands of Progress
6. Reducing Fuel Burn & Emissions in Operation
7. Epilogue
## Reducing Aviation Emissions

### Multiple Paths & Opportunities to reduce Emissions

#### 1. Propulsion System

<table>
<thead>
<tr>
<th>Weight Reductions</th>
<th>Aerodynamic &amp; Engine Performance Improvements</th>
<th>Operations</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Engine, Nacelle &amp; Propulsion System</td>
<td>- Engine turbomachinery efficiency (swept fans &amp; 3D aero shapes) - Optimized cycle (Intercooler, HBPR, UHBPR, Geared Turbofan, Contra-fan)</td>
<td>- FADEC - Enhanced Controls &amp; Sensors</td>
</tr>
<tr>
<td>- Advanced lightweight materials</td>
<td></td>
<td>- Optimized Engine Operating Procedures</td>
</tr>
<tr>
<td>- Weight optimized Configuration</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**HBPR:** High Bypass Ratio  
**UHBPR:** Ultra High Bypass Ratio  
**FADEC:** Full Authority Digital Engine Control

![Diagram](image)
## Reducing Aviation Emissions

### Multiple Paths & Opportunities to reduce Emissions

### 2. Materials

<table>
<thead>
<tr>
<th>Weight Reductions</th>
<th>Aerodynamic &amp; Engine Performance Improvements</th>
<th>Operations</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Composites</td>
<td>- High temperature Alloys in efficient engine technology and low NOx combustors</td>
<td></td>
</tr>
<tr>
<td>- Advanced light Alloys (Ti, Al-Li, Mg), New Hybrid Alloys</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Innovative, smart materials</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Ti: Titanium  
Al-Li: Aluminium-Lithium
### Reducing Aviation Emissions

#### Multiple Paths & Opportunities to reduce Emissions

**3. Structure, Aero & Systems Design & Methods**

<table>
<thead>
<tr>
<th>Weight Reductions</th>
<th>Aerodynamic &amp; Engine Performance Improvements</th>
<th>Operations</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>-Aero-elasticity (load alleviation &amp; control)</strong></td>
<td><strong>- Engine, Wing, HLD, HTP, Winglets, Fuselage</strong></td>
<td><strong>- Systems Modelling</strong></td>
</tr>
<tr>
<td><strong>- Structural optimization, integration &amp; new concepts</strong></td>
<td><strong>- Engine/nacelle/ pylons integration</strong></td>
<td><strong>- Systems Simulation &amp; Virtual Testing</strong></td>
</tr>
<tr>
<td><strong>- Smart, morphing structures, nanotechnologies (future)</strong></td>
<td><strong>- Flow control</strong></td>
<td><strong>- Adaptive flight path to reduce emissions</strong></td>
</tr>
<tr>
<td><strong>- Wing, fuselage, empennage, landing gear, pylon innovative features</strong></td>
<td><strong>- New unconventional configurations &amp; concepts (future)</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>- Multi-disciplinary Design methods - Virtual Engineering</strong></td>
<td></td>
</tr>
</tbody>
</table>

HLD: High Lift Devices  
HTP: Horizontal Tail Plane
### Reducing Aviation Emissions

#### Multiple Paths & Opportunities to reduce Emissions

#### 4. Manufacturing Processes

<table>
<thead>
<tr>
<th>Weight Reductions</th>
<th>Aerodynamic &amp; Engine Performance Improvements</th>
<th>Operations</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Welding processes (EBW, LBW, FSW)</td>
<td>- Welding Processes (drag reduction)</td>
<td></td>
</tr>
<tr>
<td>- Innovative structures &amp; processes</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

EBW: Electron Beam Welding  
LBW: Laser Beam Welding  
FSW: Friction Stir Welding
### Reducing Aviation Emissions

**Multiple Paths & Opportunities to reduce Emissions**

#### 5. Aircraft Systems

<table>
<thead>
<tr>
<th>Weight Reductions</th>
<th>Aerodynamic &amp; Engine Performance Improvements</th>
<th>Operations</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Fly by Wire</td>
<td>- Advanced flight controls, more electronic systems: optimized control surface deflections, level &amp; trajectory control</td>
<td>- Advanced Cockpit, Flight Management &amp; Navigation Systems</td>
</tr>
<tr>
<td></td>
<td>- Optimized, integrated &amp; simpler electrical &amp; mechanical systems, less components</td>
<td>- Optimized Energy &amp; Electric Power management (generation / distribution)</td>
</tr>
<tr>
<td>- IMA</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Fuel transfer/load alleviation</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

IMA: Integrated Modular Avionics
Reducing Aviation Emissions

Multiple Paths & Opportunities to reduce Emissions

6. Operating Procedures

<table>
<thead>
<tr>
<th>Weight Reductions</th>
<th>Aerodynamic &amp; Engine Performance Improvements</th>
<th>Operations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Some procedures are linked with minimizing TOW</td>
<td>Several procedures optimize operations based on Aircraft &amp; Engine performance</td>
<td>- Optimized ground &amp; flight, Maintenance procedures</td>
</tr>
<tr>
<td><img src="image1" alt="Weight Reductions Image" /></td>
<td><img src="image2" alt="Aerodynamic &amp; Engine Performance Improvements" /></td>
<td>- ATM</td>
</tr>
</tbody>
</table>

ATM: Air Traffic Management
Reducing Aviation Emissions

**Example of Aerodynamics Performance Improvement**

**Winglets**

The improvement depends on the individual mission.
Reducing Aviation Emissions

Examples of Structural Weight Reductions
Composite + Advanced Materials

1990 (10-12% *)

2005 (20-25% *)

2010 (40-50% *)

- wing: composite
- fuselage: composite or composite + advanced alloy

Materials Baseline

« Materials Baseline »

est. structural weight saving ≈ 8%

est. structural weight saving ≈ 12%

GFRP (Glass)
QFRP (Quartz)
CFRP (Carbon)
Metal
Glare
Reducing Aviation Emissions

**Examples of Combustor Technologies**

- **Rich-Quench-Lean Combustor:** Reduced NOx & HC Emissions
- **Lean Premixing Combustor:** Reduced NOx and Smoke Emissions
Reducing Aviation Emissions

CONTENTS

1. Overview
2. Background on Aviation Emissions
3. Progress in Reducing Aviation Emissions
4. Design & Technology to reduce Emissions
5. The Aviation Strands of Progress
6. Reducing Fuel Burn & Emissions in Operation
7. Epilogue
Reducing Aviation Emissions

Reducing Fuel Burn in Operation

• The Scope
  – Manufacturers minimize fuel burn in the **full aircraft life cycle**: design, manufacturing, transport, ground & flight operations, maintenance, refurbishment, end-of-life
  – All operational and maintenance procedures are subject to recommendations for potential fuel consumption reduction, well disseminated by the Manufacturers & ICAO
  – Current technologies are used to minimize fuel consumption in aircraft operation & induced airport activities
  – On-going research activities address the joint development of operational procedures & technologies

• The Way Forward
  – Extend Cooperation with all Stakeholders: Authorities, Manufacturers, Research Centers, ANSP’s, Airports, Operators, Pilots
  – Develop Synergies between Aircraft & Infrastructures / Ground Systems Technologies / Operations
Reducing Aviation Emissions

Reducing Fuel Burn in Operation

Dissemination of Best Practices

- Operating Procedures optimizing each phase of flight to minimize fuel consumption
  - Ground running and taxiing
  - Take-Off & Climb
  - Cruise
  - Descent, Holding & Approach

- Maintenance procedures to minimize Engine (SFC) or Aircraft performance (drag, weight) deterioration & restore it
Reducing Aviation Emissions

Reducing Fuel Burn in Operation

Airports - Prospects for the future

- Powered Gear / Electric Taxi
- Gate Power Supply (Electric or Alternate fuel GSE)
- Electrically powered PCA systems
- Gate Refuelling
- Airport Layout
- Airport Taxi management
- Operational towing
- Other Aircraft-related: Aircraft De-Icing, Tank Farm, Engine Test Stands, …
- Other Airport Stationary Sources
- Airport Ground Vehicles
- Airport Access & Road Traffic
Reducing Aviation Emissions

CONTENTS

1. Overview
2. Background on Aviation Emissions
3. Progress in Reducing Aviation Emissions
4. Design & Technology to reduce Emissions
5. The Aviation Strands of Progress
6. Reducing Fuel Burn & Emissions in Operation
7. Epilogue
Reducing Aviation Emissions

Example of EU Vision 2020 for Environment

- Reduce CO2 by 50% per passenger kilometre

**Potential for fast broad-based solutions to be taken into account!**

- Reduce Perceived Noise to one half of current average levels
- Reduce NOx emissions by 80%
- Minimise the impact of industries on the global environment

Similar Vision in the US
Reducing Aviation Emissions

Manufacturers and Environmental Protection

• Participate actively in elaborating a broad, global & long-term vision and apply it to programmes, products, investments & partnerships

• Work to meet ambitious environmental-related targets addressing climate change, community noise, local air quality & trade-offs

• Support research for better understanding of environmental impacts & benefits

• Participate in extensive research programmes to foster environmental advances for aviation (optimized combined scenarios)

• Ensure that environmental advances get continuously introduced into design & operating practices, and into products, balancing early introduction of mature technologies & long development & life cycles

• Expand cooperation, coordination and synergies at all levels with all actors involved in all relevant domains (using the ICAO platform)

Manufacturers despite facing multiple challenges are resolutely engaged in tackling environmental issues; they only hold some of the keys, but they are willing to work with others in order to best address these issues
Reducing Aviation Emissions

**Systems Approach to Environment**

- To maximize the benefits from the large investments in developing emission (and noise) reduction technologies, it is essential for all stakeholders to work together on the multiple, interdependent factors involved, in a global system approach.

- This implies a **permanent productive dialogue** and a **high level of cooperation** between all stakeholders.

- **Technology will not be enough** - All possible cost-effective means to improve the environmental situation should be explored, including operating procedures, land use management, airport infrastructure and equipment, ground systems and ATM.

*Technology Cannot Be Considered in Isolation*
Reducing Aviation Emissions

Emissions Technology in a global system perspective

- **Emissions Reduction at Source** (TM)
- **Flight & Ground Operating Procedures** (TM)
- **ATM - ATC (ANSPs)* (TN+TA+TM)**
- **Airport Infrastructure & Equipment** (TA+TN)

**Scientific knowledge**

**Systems Approach to Emissions**

**Cost-Benefit Analysis**

Reducing Aviation Emissions

ICAO/CAEP is a Unique Framework

• Provides an international forum for sharing and consolidating data, visions & prospects

• Provides & best uses resources to develop & maintain international policies, standards, databases, tools, models, practices & guidelines

• Brings together all stakeholders to balance their needs

• Brings together scientific and engineering resources to help finding & optimizing the environmental solutions, taking into account interdependencies and trade-offs

• Facilitates safe, coordinated, harmonized, efficient and consistent approaches & processes

Provides Global Coordination for a Global Industry
Reducing Aviation Emissions

In Conclusion,…

Efficient Solutions

Balanced Systems Approaches

Broad Vision
Cost-efficiency
Priorities

ICA O
Synergies Cooperation

High dedicated Investments & Resources

Knowledge-Models-Scenarios-Technology-Design-Operations
ATM-Airports Land use/Infrastructures/Equipment/Access

All Actors

All Fields
The future, you do not have to foretell it, but to enable it.

- Antoine de Saint Exupéry

Thank You