A Primer: Aircraft Emissions & Environmental Impact

Alan Epstein
Vice President
Technology & Environment

Aviation and the Environment
Washington, DC, March 2008
Impact of Aviation on The Environment

**Ground Level:**
- NO\textsubscript{x} 
- O\textsubscript{3} 
- Particulates

**Troposphere:**
- NO\textsubscript{x} 
- CO\textsubscript{2} 
- H\textsubscript{2}O 
- Particulates 

~3,000 ft (~1000m)

~40,000 ft (12-17 km)

**Stratosphere:**
- NO\textsubscript{x} 
- Halogens

**Ozone Layer Change**

**Climate Change**

**Local Air Quality**

**Noise**
Engine Efficiency Vs. Combustor Technology
Engine Efficiency Vs. Combustor Technology

Set By Engine Efficiency
Carbon Dioxide - CO₂
Water Vapor - H₂O
Engine Efficiency Vs. Combustor Technology

Air

Fuel

Combustor

Set By Engine Efficiency
- Carbon Dioxide - CO₂
- Water Vapor - H₂O

Set By Combustor Technology
- Nitrogen Oxides – NOₓ
- Carbon Monoxide – CO
- Unburned Hydrocarbons – UHC
- Smoke

Combustion Products
Engine Efficiency Vs. Combustor Technology

Two Paths to Emission Reduction
• Reduce emissions per kg of fuel
• Reduce absolute amount of fuel

Set By Engine Efficiency
Carbon Dioxide - CO₂
Water Vapor - H₂O

Set By Combustor Technology
Nitrogen Oxides – NOₓ
Carbon Monoxide – CO
Unburned Hydrocarbons – UHC
Smoke
Improving Combustors to Reduce Emissions

Combustor Requirements

- Local Air Quality & Global Warming
- SAFETY
- Emissions
- Stability
- Altitude Re-light and Starting
- Endurance
Science Behind Low NO$_x$ Technology

NO$_x$ Up With Temperature and Time

Rich Quick Quench Lean (RQL) Combustor Design

EI – Emission Index, grams NO$_x$ per kg of fuel
Science Behind Low NO\textsubscript{x} Technology

NO\textsubscript{x} Up With Temperature and Time

Rich Quick Quench Lean (RQL) Combustor Design

EI – Emission Index, grams NO\textsubscript{x} per kg of fuel
Science Behind Low NO\(_x\) Technology

NO\(_x\) Up With Temperature and Time

Rich Quick Quench Lean (RQL) Combustor Design

EI – Emission Index, grams NO\(_x\) per kg of fuel
Science Behind Low NO$_x$ Technology

NO$_x$ Up With Temperature and Time

Rich Quick Quench Lean (RQL) Combustor Design

EI – Emission Index, grams NO$_x$ per kg of fuel
History of Regulated Emissions Reduction

% of CAEP2 limit

Year of Engine Certification

pre 76  | 76-80  | 81-85  | 86-90  | 91-95
---|---|---|---|---

HC  | CO  | NOx

Pratt & Whitney
A United Technologies Company
NO\textsubscript{x} Reductions Continue to be Mandated
Cannot compromise CO, UHC, and Smoke
Reducing Fuel Burn to Reduce Emissions
Thermal and Propulsive Efficiency Set Fuel Burn (SFC)
**NO\textsubscript{x} - CO\textsubscript{2} Engine Design Trade**

Improving Thermal Efficiency Can Increase NO\textsubscript{x}

---

**Graph Details:**
- **Y-axis:** Specific Fuel Consumption (SFC, lb/lb-hr)
- **X-axis:** Overall Compressor Pressure Ratio (Thermal Efficiency)
- **Lines:**
  - Red line: Improving Engine performance
  - Blue line: Improving Combustor Technology
  - Dashed blue line: NO\textsubscript{x} emissions
  - Dashed dark blue line: EI (grams NO\textsubscript{x}/kg fuel)

---

**Footer:**
Pratt & Whitney
A United Technologies Company
NO$_x$ - CO$_2$ Engine Design Trade
Improving Thermal Efficiency Can Increase NO$_x$

Improving Combustor Technology

SFC (lb/lb-hr)

Improving Engine performance

Overall Compressor Pressure Ratio (Thermal Efficiency)

Ei (grams NOx/kg fuel)
NO$_x$ - CO$_2$ Engine Design Trade

Improving Thermal Efficiency Can Increase NO$_x$

![Graph showing the relationship between Specific Fuel Consumption (SFC), Emissions Index (EI), Overall Compressor Pressure Ratio, and NO$_x$. The graph illustrates how improving engine performance and combustor technology can affect these parameters.](image)
• Lower fuel consumption so
  - Lower CO₂
  - Lower NOₓ

Evolution in By-Pass Ratio & Efficiency

- **TURBOJET** – B707 (JT3C)
- **TURBOFAN Low by-pass** – B707-320 (JT3D), B727 (JT8D)
- **TURBOFAN High by-pass** – B747 (JT9D), B777 (PW4084)
- **Ultra high by-pass**

## History of 70-100 PAX Class Air Transport

<table>
<thead>
<tr>
<th></th>
<th>DC-3</th>
<th>Boeing 377 Stratocruiser</th>
<th>Electra</th>
<th>ATR 72</th>
<th>CRJ1000</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Entry into Service</strong></td>
<td>1936</td>
<td>1948</td>
<td>1958</td>
<td>1998</td>
<td>2009</td>
</tr>
<tr>
<td><strong>MTOGW (lbs)</strong></td>
<td>25,200</td>
<td>145,800</td>
<td>116,000</td>
<td>49,600</td>
<td>91,800</td>
</tr>
<tr>
<td><strong>Fuel Capacity (gals)</strong></td>
<td>720</td>
<td>6900</td>
<td>6535</td>
<td>1645</td>
<td>2900</td>
</tr>
<tr>
<td><strong>Passengers</strong></td>
<td>28</td>
<td>89</td>
<td>85</td>
<td>68</td>
<td>100</td>
</tr>
<tr>
<td><strong>Wing Span (ft)</strong></td>
<td>95</td>
<td>141</td>
<td>99</td>
<td>89</td>
<td>86</td>
</tr>
<tr>
<td><strong>Cruise Altitude (ft)</strong></td>
<td>6,000</td>
<td>20,000</td>
<td>20,000</td>
<td>17,000</td>
<td>41,000</td>
</tr>
<tr>
<td><strong>Cruise/Max Speed (KCAS)</strong></td>
<td>150 cruise</td>
<td>260/325</td>
<td>325/352</td>
<td>250/275</td>
<td>447 / 470</td>
</tr>
<tr>
<td><strong>Range (NM)</strong></td>
<td>1450</td>
<td>3700</td>
<td>3500</td>
<td>890</td>
<td>816</td>
</tr>
<tr>
<td><strong>Fuel Efficiency</strong></td>
<td><strong>20</strong></td>
<td><strong>23</strong></td>
<td><strong>38</strong></td>
<td><strong>83</strong></td>
<td><strong>70</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Engine</strong></th>
<th>Pratt &amp; Whitney Twin Wasps</th>
<th>Pratt &amp; Whitney Wasp Major</th>
<th>Allison 501-D13 Turboprop</th>
<th>PW127 Turboprop</th>
<th>CF-34 Turbofan</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Diameter (in.)</strong></td>
<td>138” prop</td>
<td>199” prop</td>
<td>162” prop</td>
<td>155” prop</td>
<td>46” fan</td>
</tr>
<tr>
<td><strong>Takeoff Power</strong></td>
<td>1200 HP</td>
<td>3500 HP</td>
<td>3750 HP</td>
<td>2475 HP</td>
<td>13,600 lbf</td>
</tr>
</tbody>
</table>
Summary of Aircraft Emissions Primer

• Aircraft engines have unique requirements
  – Safety, weight, life in addition to low emissions

• Regulated emissions
  – Smoke, HC, CO are well in hand
  – NOX will stay a challenge as rules tighten & efficiency up

• Climate change concerns may add new constraints
  – CO₂ is a concern
  – H₂O may be a player if contrails important
This document is the property of United Technologies Corporation (UTC). You may not possess, use, copy, or disclose this document or any information in it, for any purpose, including without limitation to design, manufacture, or repair parts, or to obtain FAA or other government approval to do so, without UTC’s express written permission. Neither receipt nor possession of this document alone, from any source, constitutes such permission. Possession, use, copying, or disclosure by anyone without UTC’s express permission is not authorized and may result in criminal and/or civil liability.