NASA's Global Green Challenge

Alan Epstein
Vice President
Technology & Environment

NASA Green Engineering Masters Forum
San Francisco, September 2009
NASA’s Green Challenge: Outline of Talk

Green Aerospace – Opportunity for Innovation

• Green Engineering: processes, products

• Green Aviation

• Green Space

• A New Global Endeavor
Context of Discussion

Aerospace is the largest manufacturing export of US

- Emphasis on what’s important to the nation
- Answering society’s need for transportation, defense & science
What Are We Trying to Accomplish?

Measuring progress – United Aircraft Co., 1930

*San Francisco* 1850

*New York* 1930

1860

1876

1928

1930

24 DAYS

10½ DAYS

100 HOURS

85 HOURS

32 HOURS

**Diminishing Distance Across the Continent**

- What we do now but at lower environmental cost?
- Enable new capabilities, new economics?
UTC Revenues

<table>
<thead>
<tr>
<th>Year</th>
<th>International</th>
<th>US</th>
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<tbody>
<tr>
<td>72</td>
<td>0.5 (24%)</td>
<td>1.5 (76%)</td>
</tr>
<tr>
<td>08</td>
<td>37 (64%)</td>
<td>21 (36%)</td>
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2008 UTC World Presence
SOA of Engineering & Manufacturing in 1969
B-747 Designed and Built in the USA
SOA of Engineering & Manufacturing in 2009
Boeing 787 Designed & Built Around the World

- **U.S.**
  - Boeing
  - Spirit
  - Vought
  - GE
  - Goodrich

- **Canada**
  - Boeing
  - Messier-Dowty

- **Australia**
  - Boeing

- **Japan**
  - Kawasaki
  - Mitsubishi
  - Fuji

- **Korea**
  - KAL-ASD

- **Europe**
  - Messier-Dowty
  - Rolls-Royce
  - Latecoère
  - Alenia
  - Saab

**Diagram Details:**
- **WING TIPS:** Korea
- **MOVABLE TRAILING EDGE:** Australia
- **TAIL FIN:** Fredrickson, Washington
- **HORIZONTAL STABILIZER:** Foggia, Italy
- **AFT FUSELAGE:** Charleston, S.C.
- **WING:** Nagoya, Japan
- **MOVABLE TRAILING EDGE:** Chula Vista, CA
- **ENGINE NACELLES:** Grottaglie, Italy
- **ENGINE:** GE-Evenendale, Ohio
- **FIXED TRAILING EDGE:** Nagoya, Japan
- **CARGO/ACCESS DOORS:** Sweden
- **FORWARD FUSELAGE:** Nagoya, Japan
- **FORWARD FUSELAGE:** Wichita, Kansas
- **WING/BODY FAIRING LANDING GEAR DOORS:** Winnipeg, Canada
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P&W And The Environment
Why Do We Care?

• Responsibility
  – To our customers
  – To our people
  – To society

• Opportunity
  – Changes to markets can create new opportunities
  – Innovation in products & processes can fuel growth

• Climate change concerns will shape aerospace
Engine Company Impact On The Environment

What is new?

Suppliers

Materials of concern
Solid & liquid waste
Gaseous emissions
Direct & Indirect CO₂

Processes

Materials of concern
Solid & liquid waste,
Gaseous emissions
Direct & Indirect CO₂

Products

Scrap, Noise,
NOₓ, Particulates,
Direct & Indirect CO₂

Red denotes a concern for climate change
Engine Company Impact On Climate Change
Relative CO$_2$ Annual Production

- Suppliers
- Processes
- Emerging Understanding
- EH&S Responsibility
- Products
Impact of Aviation on The Environment

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

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

~3,000 ft
(1000m)

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

~40,000 ft
(12-17 km)

Ozone Layer Change

Climate Change

Local Air Quality
Noise
Aeronautical Challenges in 1911

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PurePower® Engine Significantly Reduces Noise

LaGuardia Noise Footprint

Current B-737/A-320

LaGuardia Noise Footprint

PurePower® Engine Engine (77% reduction)
The Climate Change Challenge

“The world can not regulate its way out of global warming, it must innovate”

Tom Friedman,
New York Time Columnist
Author, *The World Is Flat*
The Innovation Challenge
The Aviation Climate Debate Is Intensifying

“Flying — the worst thing to do ... The dirtiest industry in the world”
- B. Sewill, *Fly Now, Grieve Later*, 2005
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“Passengers face new tax to halt rise in air travel”
*Times Online* Sept 9, 2009
Are Airplanes Green?
Aircraft As Low Carbon Transportation

<table>
<thead>
<tr>
<th>Mode</th>
<th>CO₂ (g/pkm)</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Train</td>
<td>184</td>
<td>Predominantly electric-powered</td>
</tr>
<tr>
<td>Car</td>
<td>51 – 113</td>
<td>Predominantly diesel-powered</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Small diesel car</td>
</tr>
<tr>
<td>Petrol Sedan</td>
<td>81 – 113</td>
<td></td>
</tr>
<tr>
<td>787</td>
<td>61 – 95</td>
<td>3-class, low density</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3-class, high density</td>
</tr>
</tbody>
</table>

- Equivalent grams CO₂ / passenger kilometers, assuming average modal load factors (1.6 passengers for SUV and cars, 38.7% for diesel train, 47.6% for electric trains, 70% for low density 787 and 90% for high density 787).
- Electric trains are assumed to have typical CO₂/kWh electrical generation factors, reflecting a mix of fossil fuels, nuclear and hydroelectric sources.

Courtesy the Boeing Company

Pratt & Whitney
A United Technologies Company
Life Cycle Analysis of Transportation
An Emerging Environmental Field
Evolution of Gas Turbine Efficiency
A $2B Investment in Technology Innovation

25 Years to PurePower® Engines

1990
Flight weight design

1990
Gear Test Rigs

2000
11K Demo engine

2000
30K Ground demo

2008
40K Demo engine

2008
30K Flight demos

2013
Entry Into Service

Entry Into Service
Biojet Fuel
What is it & Why Should I Care?
Carbon Neutral Growth – Carbon Free Flight?
Only Possible with a Fuel Based Solution

Courtesy the Boeing Company
## Fuel Energy Per Unit Mass

<table>
<thead>
<tr>
<th></th>
<th>MJ / kg</th>
<th>$ / MJ</th>
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<tbody>
<tr>
<td>Beef</td>
<td>4.0</td>
<td>2.0</td>
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<tr>
<td>Whole Milk</td>
<td>2.8</td>
<td>0.32</td>
</tr>
<tr>
<td>Honey</td>
<td>14</td>
<td>0.29</td>
</tr>
<tr>
<td>Sugar</td>
<td>15</td>
<td>0.07</td>
</tr>
<tr>
<td>Peanut Butter</td>
<td>27</td>
<td>0.15</td>
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<tr>
<td>Bacon</td>
<td>29</td>
<td>0.14</td>
</tr>
<tr>
<td>Vegetable Oil</td>
<td>36</td>
<td>0.06</td>
</tr>
<tr>
<td>Kerosene</td>
<td>42</td>
<td>0.010</td>
</tr>
<tr>
<td>Natural Gas</td>
<td>45</td>
<td>0.005</td>
</tr>
<tr>
<td>Hydrogen</td>
<td>117</td>
<td>0.05</td>
</tr>
</tbody>
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(from *The Simple Science of Flight*, by H. Tennekes)
Chemical Energy Sources For Flight
Practical Energy Density Of Fuels

- Diesel/jet at 60% eff.
- Diesel/jet at 40% eff.
- Diesel/jet at 20% eff.
- Methanol (DMFC at 30% eff.)
- H$_2$ for fuel cells
- Primary batteries

Fuel & Container Only
How Does a Biofuel Help?
Reduces Net CO$_2$ Into Atmosphere

Conventional Fuel

Bio Fuel
Environmental Life Cycle Analysis
“Well-to-Wake” Life-cycle Emissions & Energy
Crop Yields Set Land Requirements
Significant Use Requires Greatly Improved Yields

<table>
<thead>
<tr>
<th>Oil Yield gal/acre/yr</th>
<th>Current Tech</th>
<th>Future ?</th>
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<tbody>
<tr>
<td>Soybeans ~70</td>
<td>100 gal/acre</td>
<td>10,000 gal/acre</td>
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<tr>
<td>Camelina 100</td>
<td>= 7% US Planted Land</td>
<td>= 7% US Planted Land</td>
</tr>
<tr>
<td>Jatropha 200</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Palm Oil 400</td>
<td></td>
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<tr>
<td>Algae 1000?</td>
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Is NASA’s Access to Orbit Green?
Which Launch Vehicles Are Climate Friendly?

Not Green
1100 tons of Chlorinated Exhaust

Green
Just adds water
Innovation vs. Novelty

• Innovation
  – “the alteration of what is established by the introduction of new elements or forms”*

• Novelty:
  – “An...amusing object...relying for its appeal on the newness of its design”*

(*Source: OED)
Impressive Novelties
Technical tour de forces

Human Power

Solar Power

Boutique aircraft can be fun & fascinating but where’s the (economic) beef?
Scientific uncertainty can lead to poor decisions
A Global Challenge For NASA
Climate Change and Aviation

Only NASA has all the deep, world class expertise need:
Expert in climate change, earth observation, and aeronautics
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Some Technology Challenges For NASA
Helping the Environment, Realistic but hard

• Eliminate aircraft noise as community concern

• Reduce aircraft climate change impact by 50-80%

• Reduce the cost of access to space
  – On a mass basis ($/kg)
  – On a mission basis ($/mission)