Powering the Next Generation of Flight

Technologies To Address Aviation Energy Efficiency and the Environment

NASA Technology Showcase
29 November 2012

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Business Development
GE Aviation
Historical Improvements

Flight Safety
(accidents per MFH)

90% Improvement

Thrust to Weight

350% Increase

Fuel Efficiency
(SFC)

45% Improvement

Engine Noise
(cum db’s)

35 db Decrease
Historical Fuel Burn Improvements

Fuel Efficiency
(SFC)

45% Improvement

GE CJ805-23

1940 1960 1980 2000

GEnX

OPR, Components & Materials

FPR / BPR

imagination at work
Propulsion Challenge

Industry Revenue/Profits

- Revenues
- Profits

Sources: Air Transport Association/Bureau of Transportation Statistics

Airline Operating Costs

- Fuel: 28%
- Labor: 23%
- Other Operating: 18%
- Transport-Related: 14%
- Professional Services: 7%
- Aircraft rents/ownership: 6%
- Non-aircraft rents/ownership: 4%

Source: A4A Quarterly Cost Index, US Airlines

Regulatory Challenges

- CAEP/6: 2008 / 2013
- CAEP/8: 2014 / 2018
- EU Carbon Trading: 2012
- ICAO CO₂ Standard: TBD

Sources: Air Transport Association, International Air Transport Association

Historical Fuel Prices

>15% Growth Rate

Sources: Air Transport Association, International Air Transport Association

Make airlines more profitable in an increasingly difficult environment
The suppliers’ broader task ...  
*Delivering customer value with technology - Clean, quiet, affordable and reliable systems*

More comprehensive than just lowering GHGs

- Fuel consumption
- Emissions
- Noise
- Ownership Cost
- Maintenance
- Disruptions
- Impact of new tech.

Our R&D investments
- Materials
- Aerodynamics
- Combustion
- Cycles / Planforms
- Architectures
- Fuels
Opportunities for the Future

\[ \text{Range} = \left( \frac{V_0}{SFC} \right) \times \left( \frac{L}{D} \right) \times \ln \left( \frac{W_{\text{initial}}}{W_{\text{final}}} \right) \]

\[ = (FHV \times \eta_{\text{thermal}} \times \eta_{\text{transfer}} \times \eta_{\text{propulsive}}) \times \left( \frac{L}{D} \right) \times \ln \left( 1 + \frac{W_{\text{fuel}}}{W_{\text{payload}} + W_{\text{empty}}} \right) \]

- N+1
  - Highly Loaded Compressors
  - High OPR Low Emissions Combustors
  - Adaptive cycles
  - Constant Volume Combustion
  - Hybrid Electric Propulsion

- N+2
  - Low Loss Inlets
  - Variable Low Loss Exhausts
  - Distributed Power Transmission

- N+3
  - Very High BPR Turbofans
  - Ultra High BPR Turbofans
  - Open Rotors
  - Distributed Propulsion
  - Wake Ingression

- Novel Alloys / MMC’s
- Non-metallics
- Advanced Engine Architectures

imagination at work
Composite development timeline

**Technology maturation and advancement**

- 80’s: Unducted, composite fan blades (UDF)
- 90’s: Composite fan blades
- 00’s: Composite fan blades and case (GE90)
- 10’s: High temp composites
- Moderate-temp composites
- Expanded low-temp composites

Turbine Blade
Core Nozzle

Image source: imagination at work
Vision for 2030 – 2050 Propulsion Systems

Revolutionary Ideas Required For Future Aviation

- Non-Brayton Cycle Propulsion (CVC, Electric, etc.)
- Distributed, Hybrid-Electric
- Open Rotor

Brayton Cycle Propulsion (Turbo Gas Generators)

Key Technologies to Bridge The Gaps
- High OPR Cores
- Advanced Propulsors (Open Rotor, etc.)
- Distributed Propulsion
- Electrical Systems (Fuel Cells, Batteries, Motors)
- Superconductivity / Cryo Systems

NASA N3-X

Timeframe

1950

GE-IA

2050
Evolution To All Electric Commercial Propulsion

Revolutionary Technologies Needed

Gas Turbine Engine Propulsion
- Engines ~15,000 lbs
- Fuel ~8,000 lbs
- Total ~ 23,000 lbs

Hybrid Turbo-Electric Propulsion
- Engines ~15,000 lbs
- Fuel ~5,000 lbs
- Motors + Converters~ 2000 lbs
- Batteries ~ 25,000 lbs
- Total ~47,000 lbs

All Electric Propulsion
- Fans + Nacelles ~ 6000 lbs
- Motors + Converters~ 11,000 lbs
- Batteries ~ 55,000 lbs
- Total ~72,000 lbs

Example for Narrow-Body Application

GE Aviation
Commercial Electric Propulsion

Coming….But When?

Traditional Hurdles
- “System-Level” benefits/impacts
  - Power/Weight/Volume, packaging
  - Impacts from production, operation and maintenance
- Commercial airframe integration timelines
- Electric Motor Ramp Rate/Impulse
- Prime reliability
- Certification
- Cost

What has changed?
- Increased environmental concerns: noise, emissions, fuel burn
- Fuel costs
- Electrical technology state-of-the-art and projected improvements
  - Batteries and Fuel cell invention

**Significant Advancements & Opportunities**
Future Engine Design Space

Advanced Airframes

Advanced Powerplant
- High OPR Brayton
- Fuel Cells
  - CVC
  - TEC

Thermal Efficiency

Advanced Power Transfer
- Gas Power
- Geared
  - Hydraulic
  - Electric
  - Conventional
  - Super Conducting

Transfer Efficiency

Propulsive Efficiency / Airplane Drag Reduction
- Ducted Propulsor
- Ducted Distributed Propulsor
- Un-ducted Propulsor
- Un-ducted Distributed Propulsor
  - Poded
  - Embedded
  - BLI / Wake Propulsion

Advanced Power Transfer and Wake Propulsion Enabling Concepts Target Untapped Performance Potential
### Key Pacing Items for Future Programs

**Increased Airframe Integration Needed Sooner in Process**

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**Need Balance of Evolutionary & Revolutionary Technologies**
Systems integration is a divergent-convergent-divergent process
- High level studies assess concept benefits then drive need for detailed studies
Fundamental understanding of advanced technology systems needed
- Systems integration requires understanding of technology trade factors
- Analytic studies and component tests needed to understand system interactions
Safely landing the world’s airline fleets

- Precise, optimal flight paths
- Less fuel, emissions
- Lower noise

GE's Performance-based Navigation (PBN) Services allow the aircraft to arrive at the airport using precise navigation to ensure optimal efficiency.

GE's TrueCourse℠ Flight Management Systems accurately predict and guide the aircraft to the efficient trajectory in all four dimensions.
Summary

Key challenge is minimizing fuel cost while meeting the constraints of the commercial aviation environment:

- Emissions
- Noise
- Reliability

Traditional fuel burn reduction strategies are beginning to yield diminishing returns – innovative technologies are required

- Light weight / high propulsive efficiency
- Highly integrated / distributed propulsion
- Non-Brayton cycles

Multiple paths needed…no “all in” on one innovation!

- From materials to integrated installations
- Near term to 2050+ architectures

Revolutionary Ideas Required For Future Aviation