Future Trends in Aeropropulsion Gas Turbines

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Bechtel Corporation

ASME SW Texas Gas Turbine Technical Chapter
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Many flight crews will never face an engine failure during their career.

In the 1960s, on average, each engine failed once a year.

Today, on average, each engine fails every 30 years.
Bird Strikes
Gas Turbine Market

Value of Gas Turbine Production

Value of Gas Turbine Production by Sector

Source: Prof. Lee Langston, ME, May 2012
Growth of Air Travel

Passenger air travel trends by region

North America

China/ India

1 Data source: ICAO Scheduled Services of Commercial Air Carriers (through 2006), IATA Annual Traffic Growth Data for Year 2007 (Jan.-Oct.).
Growth over the next 20 Years – single aisle 70%

Market value of $3.2 trillion

20-year new deliveries of passenger and freighter aircraft

<table>
<thead>
<tr>
<th>Type of Aircraft</th>
<th>Percentage</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single-aisle aircraft</td>
<td>69%</td>
<td>17,870</td>
</tr>
<tr>
<td>Twin-aisle aircraft</td>
<td>17%</td>
<td>6,240</td>
</tr>
<tr>
<td>Very large aircraft</td>
<td>40%</td>
<td>1,740</td>
</tr>
<tr>
<td>% units</td>
<td>17%</td>
<td>7%</td>
</tr>
<tr>
<td>Passenger aircraft (≥ 100 seats) and freighter aircraft (&gt; 10 tons)</td>
<td>26%</td>
<td>18%</td>
</tr>
</tbody>
</table>

Source: Airbus
Crude Oil and Jet A Price

Crude and jet price history in the U.S. gulf coast region

http://tonto.eia.doe.gov/dnav/pet/pet_pri_spt_s1_d.htm.

United Airlines
Fuel cost:
$25,000 / minute
THE TURBOJET REVOLUTION

1912-1945 → PISTON ENGINE MAX POWER 120 HP TO 3000 HP

(UP X 25)

SPECIFIC WT 4.8 TO 0.82 LB/HP (DOWN X 6)

= EVOLUTIONARY CHANGE

TURBOJET = TECHNOLOGY REVOLUTION
The Turbojet Revolution - Technology Shift

August 27, 1939 – World’s First Jet Flight

May 15, 1941 First British Jet Flight
Whittle- First Flight of a British Turbojet – Whittle and Gerry Sayer

15 May 1941
Genealogy of Early Centrifugal Turbojets Derived from Whittle Designs

POWER JETS LTD
WU, W.1 X, W.2B

ROLLS ROYCE
W.2B, WELLAND, DERWENT
NENE, TAY

PRATT& WHITNEY
J-42, J-48 (Nene)

USSR---CHINA
VK ENGINES (Nene)

GENERAL ELECTRIC
I-A. J-31, J33
Thrust = 2000 lb, airflow = 46.6 lb/sec, pressure ratio = 3.14,
Turbine inlet temperature = 1427°F, fuel consumption = 1.4
(lb/hr)/lb-thrust,
Engine weight = 1650 lb, diameter = 30 in, length = 152 in,
< 5 lbs Chromium
Efficiencies: 78% compressor, 95% combustor, 79.5% turbine
Mid-span Aft Swept for High Efficiency,
Tip Forward Swept for Good Tip Efficiency & Stall Margin

Courtesy: Dr. Aspi Wadia, GEAE- AE Award Keynote at ASME Turboexpo 2009, Orlando
Historical Trends in Fuel Efficiency for Commercial Aircraft

Figure 11. Historical trends in fuel efficiency for commercial aircraft.39,46

MILITARY AVIATION AND THE ENVIRONMENT: HISTORICAL TRENDS AND COMPARISON TO CIVIL AVIATION

Ian A. Waitz,1 Stephen P. Lukachko,1 and Joosung J. Lee1
Near Future

Near Future N+1 - GTF
# P&W Geared Turbofan- Service Entry Plan (Thrust: 15,000-30,000 lbsf)

## Engine Specifications

<table>
<thead>
<tr>
<th>Engine Type</th>
<th>PurePower® PW1000G Engine Family</th>
</tr>
</thead>
<tbody>
<tr>
<td>Engine Program</td>
<td>geared turbofan™ (GTF) engine with scaled engine core current models from 10,000 to 40,000 pounds of thrust</td>
</tr>
<tr>
<td>Aircraft Family</td>
<td>Mitsubishi Regional Jet Bombardier CSeries Airbus A320neo Irkut MC-21</td>
</tr>
<tr>
<td>Aircraft Models</td>
<td>MRJ70 MRJ90 CS100 CS300 A319neo A320neo A321neo MC-21-200 MC-21-300 MC-21-400</td>
</tr>
<tr>
<td>Passenger Capacity</td>
<td>70-96 100-145 124-220 130-230</td>
</tr>
<tr>
<td>Engine Models (thrust in pounds-force)</td>
<td>PW1215G 15,000 lbs PW1521G 21,000 lbs PW1124G 24,000 lbs PW1127G 27,000 lbs PW1133G 33,000 lbs</td>
</tr>
<tr>
<td>Architecture</td>
<td>1-G-2-8-2-3 1-G-3-8-2-3 1-G-3-8-2-3 1-G-3-8-2-3</td>
</tr>
<tr>
<td>Bypass Ratio (BPR)</td>
<td>9:1 12:1 12:1 12:1</td>
</tr>
<tr>
<td>Fan Diameter</td>
<td>56 inches 73 inches 81 inches 81 inches</td>
</tr>
<tr>
<td>Entry into Service (EIS)</td>
<td>2014 2013 October 2015 2016</td>
</tr>
</tbody>
</table>
Geared Turbofan - Reduction Gearing
Deployment of PW1000G Geared Turbofan

PurePower® PW1000G Engine Selected to Power:

AIRBUS A320neo

<table>
<thead>
<tr>
<th>Aircraft</th>
<th>A319neo, A320neo, A321neo</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thrust capability</td>
<td>24,000-33,000 lbs</td>
</tr>
<tr>
<td>Engines</td>
<td>PW1126G, PW1127G, PW1133G</td>
</tr>
</tbody>
</table>

BOMBARDIER CSeries

MITSUBISHI REGIONAL JET
NASA Programs

NASA N+3 Program for Subsonic Aircraft
### NASA Programs - Performance, Noise and Environmental Goals

<table>
<thead>
<tr>
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</tr>
</thead>
<tbody>
<tr>
<td>Noise (cum below Stage 4)</td>
<td>-32 dB</td>
<td>-42 dB</td>
<td>-71 dB</td>
</tr>
<tr>
<td>LTO NOx Emissions</td>
<td>-60%</td>
<td>-75%</td>
<td>better than -75%</td>
</tr>
<tr>
<td>(below CAEP 6)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Performance Aircraft Fuel Burn</td>
<td>-33%**</td>
<td>-50%**</td>
<td>better than -70%</td>
</tr>
<tr>
<td>Performance Field Length</td>
<td>-33%</td>
<td>-50%</td>
<td>exploit metroplex* concepts</td>
</tr>
</tbody>
</table>

*** Technology Readiness Level for key technologies = 4-6  
** Additional gains may be possible through operational improvements  
* Concepts that enable optimal use of runways at multiple airports within the metropolitan areas

Studies done by four teams + NASA In house team to project scenarios for the 2030-2035 timeframe
Boeing N+3 concepts, (a) Refined SUGAR, (b) SUGAR Ray, (c) SUGAR High, and (d) SUGAR Volt.
MIT concepts, Double Bubble and Hybrid Wing Body

Boundary Layer Ingestion

Two adjoining fuselages of Double Bubble
MIT D8 “Double-Bubble” Design Concept
MIT: Hybrid Wing Body (HWB) Design Concept
Northrop Grumman SELECT concept

Advanced tube and wing configuration
advanced engine BPR = 18
Special airframe materials
63% Fuel burn reduction
Advanced Turboprop, 20 passenger Aircraft (point to point transport between regional airports) meets the N+3 goals for noise, fuel burn, emissions

Use of composite structures
NASA Glenn TeDP concept- Turboelectric Distributed Propulsion

Superconducting electrically driven, distributed low-pressure-ratio (1.35) fans power provided by two remote superconducting electric generators based on a conventional turbofan core engine design
Relative Weights of Technologies wrt. N+3 goals and concepts

- Electric Motors: 13.8
- Advanced Combustors: 11.2
- Alternative Fuels: 10.8
- BLI/DTF: 10.2
- Composites: 10.0
- Distributed Propulsion: 9.8
- Gearbox: 8.0
- Acoustic Liners: 5.7
- Computational Tools: 5.5
- Variable Geometry: 4.1
- Sensors: 3.7
- Clearance Control: 3.1
- SMA: 1.9
- Batteries: 1.4
- Fuel Cells: 0.9

Relative weights of technologies w.r.t. N+3 goals and concepts

NASA/TM—2011-217239
Advanced Combustors

multipoint array of lean direct injectors integrated into a sector combustor

Combined instability control strategy

Combustion Instability

Controller

Sensor

Actuator

Natural feedback process

Closed-loop set-excited system

Combustion Process

Combustor Acoustics

Fuel/air mixture system
Growth of % Composites in Commercial Aircraft
CONCLUDING REMARKS
Concluding Remarks

Greatest opportunity for improvements involve airframe, engine integration to reduce L/D ratio

No single approach can be used- a wide range of technologies will be deployed

Trade off between fuel burn, emissions and noise will be dominant

Engines will be high bypass ratio (Low FPR)

Aeroengine industry partnerships will be key to meeting goals.
Airbus Concepts

- Longer slimmer wings - reduce drag
- U tail (Noise shielding)
- Semi - Embedded Engines
- Adv. Health Monitoring
- Lightweight Materials/ Composites
Concluding Remarks
Future Aircraft Configurations

Blended wing aircraft may offer up to 30% reduction in fuel consumption - 40% if combined with electric engine concepts.
Classic Swept Wing Aircraft A380

Boeing BWB

BWB Model 450-1U

- Thrust: 63K (SLS)
- Payload: 98,280 lb.
- Design Range: 7750 nmi
- Engine Type: BPR 11 Direct Drive Fan