GE Aviation: Investing in the Future

Dr. Dale Carlson
April 3, 2013
The three questions:

(a) How GE maintains global awareness of what is happening in diverse areas of science, technology, and innovation?

(b) How GE builds mutually beneficial relationships and partnerships across the global S&T enterprise?

(c) How GE assesses the benefits and costs of conducting, as well as engaging in, global S&T?

Note: The material that follows is a high level, non-proprietary response by the General Electric Company to the aforementioned questions.
GE Aviation:
Legacy/marketplace
“I find out what the world needs, then I proceed to invent it.”

— Thomas Edison
GE Aviation portfolio ... $20B

Commercial engines $6.1\(^{a)}\)

Commercial engine services $7.0\(^{a)}\)

Military engines and services $3.9\(^{a)}\)

Systems $2.7

Business and general aviation/other $0.4

Largest provider of jet engines in the world

- 40,000 employees
- ~85 sites globally

\(^{a)}\) Includes GE’s share of revenue from CFM and EA engines

CFM is a 50/50 JV between GE and Snecma
EA is a 50/50 JV between GE and Pratt & Whitney
Technical innovation ...
Key to our past and future

U.S. jet engine
U.S. turboprop engine
Mach 2 engine
High bypass engine
Variable cycle turbofan engine
Unducted fan engine
Composite fan blade in airline service
120,000+ lb thrust engine
4D trajectory flight in revenue service
Modular power tile
FMS-controlled Unmanned Aircraft System
50 years of engine improvements

**Flight Safety**
- 90% improvement

**Thrust to Weight**
- 350% increase

**Fuel Efficiency**
- 45% improvement

**Engine Noise**
- 35 db decrease
Did you know? CFM56 Fleet of 22,000 Engines Accumulates 1 Million Hours Every 8.5 Days!

World’s Broadest, Most Modern Product Line
Leveraged Military Heritage

Did you know? CFM56 Fleet of 22,000 Engines Accumulates 1 Million Hours Every 8.5 Days!

F101 core to CFM

TF39 to CF6

TF34 to CF34
The Future:
Global forces/environment
### Commercial aviation growing steadily

<table>
<thead>
<tr>
<th>Airframe</th>
<th>Production rate ('12 → '14)</th>
<th>GEnx</th>
<th>CFM</th>
<th>CFM56</th>
<th>LEAP</th>
<th>CF34</th>
<th>GE90</th>
<th>GP</th>
</tr>
</thead>
<tbody>
<tr>
<td>A380</td>
<td>2.7 → 3.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>777</td>
<td>7 → 8.3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>787</td>
<td>3.5 → 10</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>737</td>
<td>38 → 42</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A320</td>
<td>40 → 42</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EJet</td>
<td>8.7 → 9.2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CRJ</td>
<td>2.5 → 2.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Traffic growth (Trillion RPKs)

- **CAGR**: 9.3%
- **5.4%**

### Highest production ramp rates in 3 decades... inconsistent with demand growth

Boeing and Airbus are increasing rates to ~40 / month. That means: 40 x 2 (Airbus & Boeing) x 11.5 mth. / yr. = 920 / yr. or ~1,000 including the other new single aisles. 1,000 x 5 years = 5,000 / 10 yrs. = 10,000 / 20 yrs. = 20,000 aircraft.

CFM, CFM56, LEAP and the CFM logo are trademarks of CFM International, a 50/50 joint company between Snecma and GE

EA is a 50/50 JV between GE and Pratt & Whitney
Our Industry-Specifically Propulsion

• Timescales of innovation long...safety demands technologies to be proven...strategic vision/commitment a must (Gamma TiAl, CMC, etc.)...multi-decade VISION

• Almost every flying technology started as a USG funded (NASA, DoD, etc.) early TRL level study, many driven to TRL 5 or 6. Changing dynamics/players...WTO agreement, sequestration, emerging funding sources

• Doubling of revenue miles every 13-15 years despite “shocks” such as 911

• Question: How many “tube/wing” iterations are left?
  ➢ 15% campaign/campaign FB improvement a must
  ➢ ICAO 2050 CO₂ commitment, other regs looming
Technology Readiness to Serve Today and Tomorrow
GE Aviation Engineering

Over 8000 engineers around the globe
3000 technologists at 5 Global Research Sites
Practical innovation ... GE’s model

Global resources teamed to advance technology

Idea creation + Technology maturation = Winning products

Idea creation:
- Internal
- Customers
- Government
- Universities (300+ relationships)

Technology maturation:
- Cross-disciplinary teams
- Technology roadmaps
- TRL/MRL maturation plans
- Long-term growth strategies
- Tactical funding

Winning products:
- 30+ new technologies by 2020
The Physics of “Readiness to Serve”

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

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

- Highly Loaded Compressors
- High OPR Low Emissions Combustors
- Adaptive cycles
- Constant Volume Combustion
- Hybrid Electric Propulsion
- Low Loss Inlets
- Variable Low Loss Exhausts
- Distributed Power Transmission
- Open Rotors
- Distributed Propulsion
- Wake Ingestion
- Very High BPR Turbofans
- Ultra High BPR Turbofans
- Advanced Engine Architectures
- Novel Alloys / MMC’s
- Non-metallics
Essential technologies ... keeping the pipeline filled

Technology

- Composites
- Lean combustion
- Advanced cooling
- High-temp materials
- Flight Management

2010

- Advanced turbofan
- Integrated engine and aircraft systems
- Adaptive cycles
- Advanced architectures

Architecture

- Integrated propulsion
- Integrated power generation
- Core efficiency
- New designs
Technology success takes commitment and opportunity

Commitment ... **$1-2 billion** continuous technology investment per year, despite 911 (01), SARS (02), Avian Flu (05), and financial meltdown (08)

Opportunity ... **10 new engines** proving and maturing technology
Propulsion R&D and/or S&T: 2005 to date, one of the best of times...what follows?

**DARPA**: VULCAN

**EU**: Clean Sky JTI (€1.6 B)

**FAA**: CLEEN, NextGen

**NASA**: ERA, Low NOx, N+1, N+2, N+3, RTAPS, SMAAART, etc

**VAATE**: AATE, ADVENT, AETD, FATE, HEETE, VCAT, etc

**SBIRs**: Numerous Opportunities
VAATE Propulsion Demo Programs
Despite F136 loss, helps GE preserve industrial base

<table>
<thead>
<tr>
<th></th>
<th>GE</th>
<th>Other OEM</th>
<th>Other OEM Team</th>
</tr>
</thead>
<tbody>
<tr>
<td>AATE (USA)</td>
<td>Win</td>
<td>Win</td>
<td></td>
</tr>
<tr>
<td>ADVENT (USAF)</td>
<td>Win</td>
<td>Win</td>
<td></td>
</tr>
<tr>
<td>AETD (USAF)</td>
<td>Win</td>
<td>Win</td>
<td></td>
</tr>
<tr>
<td>FATE (USA)</td>
<td>Win</td>
<td></td>
<td>Win</td>
</tr>
<tr>
<td>HEEETE (USAF)</td>
<td>Win</td>
<td>Win</td>
<td></td>
</tr>
<tr>
<td><strong>Total Wins</strong></td>
<td>5</td>
<td>2</td>
<td>1</td>
</tr>
</tbody>
</table>
# NextGen portfolio

**Potential military/commercial technology synergies**

<table>
<thead>
<tr>
<th>Technologies</th>
<th>Program goals</th>
<th>Segments</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>AATE</strong></td>
<td>25% better SFC</td>
<td>Attack/utility Helicopters</td>
</tr>
<tr>
<td><em>(Advanced Affordable Turbine Engine)</em></td>
<td>65% ↑hp/wt</td>
<td>Blackhawk</td>
</tr>
<tr>
<td><strong>FATE</strong></td>
<td>35% better SFC</td>
<td>Heavy lift Helicopters</td>
</tr>
<tr>
<td><em>(Future Affordable Turbine Engine)</em></td>
<td>80% ↑hp/wt</td>
<td>NextGen heavy lift</td>
</tr>
<tr>
<td><strong>ADVENT</strong></td>
<td>20-200+% better SFC</td>
<td>Combat aircraft</td>
</tr>
<tr>
<td><em>(Adaptive Versatile Engine Technology)</em></td>
<td></td>
<td>6th Generation</td>
</tr>
<tr>
<td><strong>HEETE</strong></td>
<td>35% better SFC</td>
<td>Tanker/Transport</td>
</tr>
<tr>
<td><em>(Highly Efficient, Embedded Turbine Engine)</em></td>
<td></td>
<td>KC-135</td>
</tr>
</tbody>
</table>
Technology demonstrator programs

Renewing our technology DNA for new products and upgrades of fielded products. Mostly USG funded, what comes next?
Global S&T relationships and partnerships

Emerging architectures, new thermodynamic cycles, hybrids, etc., concept studies good, but...cannot let others get there first!

➢ Organic capability never enough...build portfolio to meet the future via several approaches:
  ✓ Joint Technology Development Agreements (JTDAs)
    • Example: Meltless Ti
  ✓ Joint Ventures
    • Example: TAPS one piece fuel nozzle
  ✓ Business Development (BD) plays...acquisition
    • Example: Additive manufacturing

➢ Must participate in setting standards for the certification of emerging technologies:
  ✓ EU sent out draft electric cert rules for light sport aircraft in 2012 for comments, establish rules in 2013.
S&T value proposition…key items

Emerging global players, significant inducements from non-traditional sources:

- Canada (>48% R&D reimbursements), China (significant FTZ inducements, seeking partnerships), EU (Clean Sky I and II), and Singapore (A*STAR)...can offset high costs of TRL/MRL maturation of emerging technologies

- Background & new IP release requirements a key decision driver (Appears to be a key part of future DoD acquisition requirements)

- Campaigns and proposals for our products...linked to technology engagement/sharing
GE’s commitment ...

- Technology innovation for customer value
- Learning from the world’s largest installed fleet
- Focusing on people, processes, and tools across the globe
- To be prepared for, and shape, the future of flight