New Technologies in Airframe and Engine Development

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April 5, 2011
Current Aviation Era

- Highest level of technological innovation and change since advent of commercial jet age.

- Key drivers:
  - Competitive pressure for cost reduction across the board.
  - Escalating and costly environmental restrictions.
Cost Reduction

- Fuel cost
- Life-cycle maintenance, repair and overhaul costs
- Flight operations cost other than fuel
- New-Product development costs
Environmental Restrictions

- Emission of CO\textsubscript{2} – directly proportional to fuel consumption. Carbon “taxes”.
- Emission of NO\textsubscript{x}
- Goal for 2030-2035 of NASA’s Future Vehicle Aircraft Research Program: 70% reduction in fuel consumption relative to today.
- Noise emissions
Impact on Airframes

- Composites for primary structure
- “More Electric Airplane” (MEA) technology
- Improved simulation and design tools
- Enhanced and synthetic vision systems
- Avionics for NextGen
Composite Airframes

- Composites for most of the airframe (e.g. fuselage, empennage, wing, wing-box, floor-support structure).

- Composites make up about 50% of B-787 and A350 airframes by weight.

- Metal structure legacy not yet completely cut: B-787 fuselage has Ti frames at large section joins. A350 employs some metal components and fuselage architecture (stringers, frames and panels) similar to metal structure.
Composite Airframes, contd.

- With better manufacturing technology:
  - more metal content replaced by composites.
  - design architecture optimized for composite material.
- Transitioning from “thinking in terms of metal structure” to “thinking in terms of composites”.
- Large potential for improvements before the advantages of composites are fully exploited.
- Composites: a key arena for competition.
Composites Production

- Production of a composite part: material and shape simultaneously created in one process. Metal parts: machined or cast into parts from raw stock.

- Composites: natural for making complex, monolithic parts, greatly reducing need for joining many small parts, as in metal structure. A key factor in making composites cost-competitive.
Composites Production, contd.

- Composites manufacturing processes not perfected yet. Large scope for improvement.

- Current composite parts over-designed and heavier than theoretically necessary due to manufacturing problems. (E.g. Porosity, delaminations)

- 100% non-destructive inspection required of all primary structural parts and components.
Composites Production, contd.

Production techniques

- Most primary structure: Automated Tape Layup (ATL) with autoclave curing. Most expensive.
- Less critical structure: Resin Transfer Molding (RTM). Faster, cheaper than ATL.
- Major effort to perfect RTM for primary structure.
- Automobile industry employing RTM for future light-weight cars. Spurs technology development.
Composites Production, contd.

Future improvements

• Tighter production tolerances (lighter parts).

• Full exploitation of composites technology.

• Cost reduction
  o Shorter autoclave curing times (e.g. microwave curing).
  o Wider use of RTM for primary structure.
  o Faster production processes.
  o Lower-cost fiber and matrix materials.
Benefits of Composites Structure

Cost benefits

• Monolithic composites structure: Lower manufacturing cost compared to metal structure.
• Composites structure essentially not subject to corrosion and fatigue cracking. Lower MRO costs.
• Lower fuel consumption, reduced operating costs and CO2 and NOx emissions. Boeing estimate for 787 -- 5% lower fuel consumption from composites.
Collateral benefits

- Greater passenger comfort level
  - Higher cabin pressure
  - Higher humidity level
- Health benefits for passengers with cardiovascular problems.
- May possibly become new cabin comfort standard over time.
Composites – A Changed Logistics Chain

- Design and manufacturing outsourced to risk-sharing partners in Japan, Italy, South Korea.

- New organizations in emerging nations without background in metal airplanes becoming suppliers. E.g. Mubadala Development Co., Abu Dhabi.
More Electric Airplane (MEA)

- Advances in electric generator and power-conditioning technology (light weight, compact size, efficiency) make MEA feasible.

- Airbus A380 first civil transport airplane to use some MEA technology.

- Boeing 787 taking it much further.
MEA on A380

- One of three central hydraulic circuits replaced by electro-hydrostatic actuators (EHAs) and back-up EHAs (EBHAs). Distributed hydraulic system. 1000 lb. weight saving.
- EHA brakes.
- Electrically-operated thrust reversers with electro-mechanical actuators (EMAs).
- Max. electric power-generating capacity: 600 KW
MEA on B-787

- Max electric power generating capacity: 1450 KW (2x250 for each engine + 2x225 for the APU)

- Electrically-driven Hydraulic Pumps: 2 of 3 hydraulic circuits have electric back-up pumps, one circuit entirely powered by electric pumps.

- No bleed air and pneumatic systems
  - Electric Wing Ice Protection
  - Electric air cabin environmental system.
  - Bleed-air de-icing only for engine nacelles
  - Electric starter/generators

- Electric wheel brakes
MEA Benefits

- Reduced Fuel Consumption (~5% estimate on 787)
  - Minimal bleed-air losses
  - Electrically-powered hydraulic circuits: Power on demand during cruise.

- Reduced Maintenance Costs
  - Elimination of bleed-air and pneumatic systems.
  - Built-in test and self-diagnosing capability for preventive maintenance.

- Improved dispatch reliability and safety.
Improved Design Tools

- Computational fluid dynamics (CFD)-based simulation for aerodynamic and aero-acoustic design.
- Finite element analysis (FEA) for structural analysis.
- Future goal: Full dynamic simulation of aero-elastic behavior by combining CFD and FEA.
- Industry goal: reduce development time and cost by half.
Impact on Engines
More efficient, cleaner, quieter engines

Major innovations:
- P&W Geared Turbo Fan -- near term
- Magnetic bearings and all-electric fuel, oil and hydraulic pumps – mid term
- Open rotor (aka “un-ducted fan”) – mid term
- Adaptive cooling – mid term
- Intercooled core technology – long term
- Exhaust gas heat recuperation – long term
Impact on Engines, contd.
More efficient, cleaner, quieter engines

Continuous improvements in all details

- Optimized 3D aerodynamic shapes (CFD tools) for
  - compressor and turbine blades
  - stator blades
  - Intake and exhaust shapes
- Higher compressor ratio (goal of 70:1 for Air Force R&D)
- Higher combustion temperatures (advanced turbine alloys, thermal-barrier coatings).
Impact on Engines, contd.

Relevant U.S. Government R&D programs

- Adaptive Versatile Engine Technology – ADVENT (variable cycle engine – Air Force)
- Highly Efficient Embedded Turbine Engine – HEETE (Air Force)
  - Ceramic matrix composites
  - Advanced turbine alloys
  - Adaptive engine cooling
- Open rotor (NASA/GE)
Objective: Improved aircraft operations under poor visibility conditions. Greater situational awareness.

- Enhanced vision: IR sensors provide an actual image of the terrain ahead.


- Synthetic vision: Terrain image data creates a synthetic image. Improved situational awareness. No regulatory credit.
Enhanced and Synthetic Vision, contd.

Benefits

- Safe landing and take-off operations under very low visibility conditions. Fewer flight cancellations.
- Safe airport movement operations under very poor visibility conditions.
- Improved situational awareness of surrounding terrain (synthetic vision).
Avionics for NextGen

- Modular, integrated digital avionics for satellite-based navigation and communication.
- Goal: Automated Dependent Surveillance – Broadcast (ADS-B) out and in.
- Interim GPS-based advances:
  - Automatic oceanic reporting
  - Required Navigation (RNAV)
  - Required Navigation Performance (RNP)
GPS-based Avionics -- WAAS

- GPS-based en-route navigation throughout North America (all 50 states, Canada, Mexico)
- Category I landing at non-ILS equipped airports.
- GPS signal accuracy improved through signal-augmentation technology:
  - 38 ground-based Wide-area Reference Stations (WRFs) with precisely-known location information monitor GPS signals.
  - 3 Wide-area Master Stations (WMSs) receive WRF data, calculate corrections and transmit corrections to Ground Uplink Stations GUSs).
WAAS, contd.

- 2 pairs of GUSs transmit the correction signals to geostationary satellites.
- 2 satellites broadcast correction signals to aircraft avionics.
- Observed performance: 1 meter for position and 1.5 m for altitude accuracy. FAA requirement is 7.6 m for either.
- WAAS self-monitors GPS performance and warns pilot if performance degrades below acceptable level.
RNAV & RNP

- Both GPS-based navigation systems used for approaches to airports.
- Allow more flexible, fuel-efficient approach and departure routes.
- Require special avionics equipment on aircraft to receive, process and use GPS signal for precision navigation.
- RNP is RNAV with additional self-monitoring and pilot-alerting functions.
RNP

- Enables pilot to fly along a selected flight path with great precision. E.g. RNP 0.1, which is standard equipment on new Boeing and Airbus planes, keeps plane within a tunnel of 0.4 mile width and height along flight path with 99.99% reliability.
- Special FAA certification requirements for equipment and pilots.
- Self-monitoring and alerting functions detect any abnormality in GPS signal and alert pilots.