Introducing the 787
- Effect on Major Investigations
- And Interesting Tidbits

Tom Dodt
Chief Engineer – Air Safety Investigation
ISASI  September, 2011
787 Size Comparison

<table>
<thead>
<tr>
<th></th>
<th>767-400</th>
<th>787-8</th>
<th>777-300</th>
</tr>
</thead>
<tbody>
<tr>
<td>~Pax 3-Class</td>
<td>245</td>
<td>250</td>
<td>368</td>
</tr>
<tr>
<td>~Span</td>
<td>170 ft</td>
<td>197 ft</td>
<td>200 ft</td>
</tr>
<tr>
<td>~Length</td>
<td>201 ft</td>
<td>186 ft</td>
<td>242 ft</td>
</tr>
<tr>
<td>~MTGW</td>
<td>450,000 lbs</td>
<td>500,000 lbs</td>
<td>660,000 lbs</td>
</tr>
<tr>
<td>~Range</td>
<td>5,600 NM</td>
<td>7,650 NM</td>
<td>6,000 NM</td>
</tr>
<tr>
<td>Cruise Mach</td>
<td>0.80</td>
<td>0.85</td>
<td>0.84</td>
</tr>
</tbody>
</table>
Composite Structure

By weight  | 787  | 777  
- Composites  | 50%  | 12%  
- Aluminum    | 20%  | 50%  

- Carbon laminate
- Carbon sandwich
- Fiberglass
- Aluminum
- Aluminum/steel/titanium pylons

Composites 50%
Titanium 15%
Aluminum 20%
Steel 10%
Other 5%
787 Wing Flex - On-Ground
787 Wing Flex - 1G Flight

1G Flight ~12 ft
On-Ground 0 ft
# Investigations with Composite Materials

- **Terms:**
  - **Composites**
    - disbond
    - delaminate
    - inter-laminar shear
    - water absorption
    - fiber architecture
  - **Aluminum**
    - fatigue
    - beach marks
    - striation counts
    - corrosion
    - metallurgical prop.

- **Material Forensics Techniques will be different**

- **On-Site with Exposed Composite Fibers**
  - Eyes - goggles or full face protection
  - Nose - HEPA filter
  - Hands - gloves
  - Exposed Skin - coveralls
787 Cabin Experience
Cleaner Cabin Air

HEPA (high efficiency particulate air) recirculation filters and gaseous air purification filters produce air that is essentially particle free and odor free. The HEPA filters are highly effective in removing bacteria, viruses, and fungi. The gaseous filtration system removes odors and volatile organic compounds.
Ride Quality - Smoother Ride

Vertical Gust Suppression

- Uses the flaperons and elevators
- Counters light to moderate turbulence to improve ride quality
- Passengers have a more comfortable flight

<table>
<thead>
<tr>
<th>Change in altitude (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>2</td>
</tr>
<tr>
<td>-1</td>
</tr>
<tr>
<td>-2</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Time (sec)</th>
<th>0</th>
<th>20</th>
<th>40</th>
<th>60</th>
<th>80</th>
<th>100</th>
<th>120</th>
<th>140</th>
<th>160</th>
<th>180</th>
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</thead>
<tbody>
<tr>
<td>Vertical Gust Suppression</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- With Enhanced Gust Suppression
- Without Enhanced Gust Suppression
787 Cabin Experience

- Windows - Larger
- Pressure - Lower
- Humidity - Higher
- Air Quality - Improved
- Ride Quality - Improved
- Food Service - Unchanged (sorry)
787 Pax Oxygen

- **787** - Gaseous Oxy @ 3000 psi
  - Steel cylinder

- **777** - Chem Oxy Generators (2x)
Quiet for Airport Communities

85 dB Noise Contours at Heathrow

- 85 dBA contours
- 3,000 nmi mission

787 noise footprint stays in the airport property
Engine Technology Advancements

• No-engine-bleed-air systems architecture

• Higher bypass ratio

• Low-noise nacelles with chevrons
## Airplane/Engine Architecture

### No-engine-bleed-air systems

<table>
<thead>
<tr>
<th>System</th>
<th>777</th>
<th>787</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wing LE Anti-Ice bleed air</td>
<td>electric</td>
<td>electric</td>
</tr>
<tr>
<td>Air Conditioning bleed air</td>
<td>electric</td>
<td>electric</td>
</tr>
<tr>
<td>Cabin Pressure bleed air</td>
<td>electric</td>
<td>electric</td>
</tr>
<tr>
<td>Engine start bleed air</td>
<td>electric</td>
<td>electric</td>
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</table>

### Engine Generators

<table>
<thead>
<tr>
<th>System</th>
<th>777</th>
<th>787</th>
</tr>
</thead>
<tbody>
<tr>
<td>Generators</td>
<td>240 kVA</td>
<td>1000 kVA</td>
</tr>
<tr>
<td>(2 @ 120 kVA)</td>
<td>(4 @ 250 kVA)</td>
<td></td>
</tr>
<tr>
<td>Starter/Gen’s</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Variable Frequency Power Generation

**777**
115 VAC
400 Hz

**787**
230 VAC
360-800 Hz
EE vs Pneumatic Power Distribution
Electronic Circuit Breakers

- No physical CBs in Flight Deck
- CB control and state indication are display based.
- Accessible on Multi-Function Display (MFD) and maintenance access devices
- A few Thermal CB are located in the Fwd EE-Bay

<table>
<thead>
<tr>
<th>CB BY ATA</th>
<th>CB BY BUS</th>
<th>CB BY LOCATION</th>
<th>CB BY STATE</th>
<th>CB SEARCH</th>
<th>CB CUSTOM LIST</th>
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<tbody>
<tr>
<td>CE2100713</td>
<td>CIRCUIT BREAKER NAME 1</td>
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<td>CONTROL</td>
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<td>DETAILS</td>
<td>CONTROL</td>
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</tbody>
</table>
Overhead Panels - Circuit Breakers
Integrated FCE

Equivalent Channel of Flight Controls and High Lift

777

787
Common Core System

- **Common Computing Resource**
  - High integrity computing resources for hosted systems applications

- **Common Data Network**
  - High Integrity Network
  - Open industry standard interfaces A664

- **Remote Data Concentrators**
  - 21 RDCs
  - Remote I/O capability
  - Reduces airplane wiring
CCS Hosted Functions

- Avionics Communication and Audio
- Avionics Flight Management and Navigation
- Avionics Thrust Management and Auto-throttle
- Avionics Primary Display Function
- Avionics Crew Alert/Warning and Surveillance
- Avionics Crew Information Services
- Avionics Maintenance and Data Loading
- Cabin Management and Air Show
- Data Interface to Flight Controls Electronics (FCE)
- Interface to Flight Deck Panels and Switches
- Fuel Management and Fuel Quantity Indication
- Hydraulics Control
- Mechanical System Interface Functions in Brakes, Landing Gear, Nose Wheel Steering
- Payloads Interface Functions in Galleys, Water & Waste, Emergency Lighting
- Data Interface to Propulsion Controls in EEC, Engine Fire Detection/Protection, Thrust Reverser
- Specific functionality supported by the CCS is described in the CCS SDD (Ref. 4) as well as in individual 787 CCS hosted function System Description
- Documents (SDDs) identified in their respective certification plans listed in Ref. 4.)
Hydraulic System Architecture

5000 psi systems

Left System
- Left Engine
- Engine Driven Pump (EDP)
- Electric Motor Pump (EMP)
- 25 gpm

OB Aileron – IB Flaperon
- L Wing: OB & IB
- R Wing: IB

Spoilers IB & OB
- L Wing: 3
- R Wing: 12

Elevator
- Left

Rudder
- PCU

Thrust Reverser
- Left

Trailing Edge Flaps

Leading Edge Flaps

Nose Landing Gear & Steering
- Left & Right

Main Landing Gear

Center System
- Electric Motor Pump (EMP)
- 27 gpm

- Electric Motor Pump (EMP)
- 27 gpm

OB Aileron – IB Flaperon
- L Wing: OB & IB
- R Wing: IB

Spoilers IB & OB
- L Wing: 1, 7
- R Wing: 8, 14

Elevator
- Left & Right

Rudder
- PCU

Thrust Reverser
- Normal

Trailing Edge Flaps

Leading Edge Flaps

Nose Landing Gear & Steering
- Left & Right

Main Landing Gear

Right System
- Electric Motor Pump (EMP)
- 27 gpm

OB Aileron – IB Flaperon
- L Wing: IB
- R Wing: OB

Spoilers IB & OB
- L Wing: 2, 6
- R Wing: 9, 13

Elevator
- Right

Rudder
- PCU

Thrust Reverser
- Normal

Trailing Edge Flaps

Leading Edge Flaps

Nose Landing Gear & Steering
- Left & Right

Main Landing Gear

5000 psi systems

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Landing Gear Systems
New Control-by-Wire

• Landing Gear Actuation
  - Electronic control and sequencing of landing gear and doors

• Brake System
  - Control-by-wire brakes, autobrake and anti-skid
  - Electric Brake Actuators

• Nose Gear Steering
  - Control-by-wire (pedals & dual tillers)
  - Hydraulic actuation
Cabin Air Conditioning System

Cabin Air Compressor Inlet
(Deflector door shown deployed)

Heat Exchanger inlet

Heat Exchangers

Cabin Air Compressors

Electric Ram Fan
External Air Sources

- Heat Exchanger Inlet
- Cabin Air Compressor Inlet
- Heat Exchanger Exhaust Doors
787 EAFR
Enhanced Airborne Flight Recorder

• Dual-Combi Architecture
• Both recorders are same P/N
  - self contained acquisition function
  - FRED file in memory (Flight Rec. Elec. Doc. - ARINC 647)
  - flight data 25 hours minimum
  - voice - 2 hours
  - datalink

• FWD EAFR
  - RIPS for voice recording only

• AFT EAFR
  - no RIPS
Forward EAFR & RIPS
Aft Recorder
Recording Format

• EAFR Flight Data recording format
  - ARINC 767
  - raw data file size ~800 MB (zips to 200 MB)
  - Approx equivalent to 5000+ WPS recorder

• The 787 “QAR”
  - called "Continuous Parameter Logging" (CPL)
  - stored on the mass storage devices (server)
  - ARINC 767 recording format
Common 777 / 787 Fly-by-wire Functionality

- Stall Protection
- Overspeed Protection
- Bank Angle Protection
- Tail Strike Protection
- Thrust Asymmetry Compensation
- Yaw Damping, Over-yaw Protection
- Gust Load Alleviation
- Fin Load Alleviation
- Flap Load Relief & Autogap
- Lateral Gust Suppression
- Modal Suppression
Flight Controls - 787 New Features

• P-Beta control law

• Vertical Gust Suppression (turbulence)

• Enhanced Stall Protection
  - Limits high angles of attack

• Enhanced Thrust Asymmetry Compensation
  - Adds inertial yaw detection on ground
  - Generates rudder & steering for yaw disturbances
**P – Beta Control Law**

- Wheel commands roll rate (P)
- Pedals command sideslip angle (Beta)
- Opposes disturbances
- Coordinates lateral and directional control
- Automatic aileron & rudder trim
  - No aileron trim switch
Air Data System Design Philosophy

**Federated AD & IR**
(all previous models)

- AD ➔ PFD
- AD ➔ Stby
- AD ➔ PFD

Federated AD & IR Fault arbitration by CREW

**Voted AD & IR**
(777, 787)

- AD ➔ AD/IR ➔ Stby
- AD ➔ AD/IR ➔ Stby

Voted AD-IR Fault arbitration by SYSTEM

**Abbreviations**
- AD = Air Data
- IR = Inertial Reference
- FDI = Fault Detection & Isolation
- PFD = Primary Flight Display

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Air Data System - Common Mode Vulnerability

• **Common Mode Hazards to Pitot-Static sensors**
  - Mud Daubers
  - Volcanic Ash
  - Radome failure
  - Pitot covers
  - Maintenance errors (pneumatic plumbing)
  - Icing
  - Hail
  - Birds
  - Taped Static Ports

• **787 new capabilities for protection**
  - Synthetic airspeed
  - GPS altitude
  - Common Mode Monitor
787 Synthetic Airspeed

• Calculated from angle of attack and inertial data
  - AOA – voted dual sensors plus inertial data
  - Accurate Coefficient of Lift ($C_L$)
  - Airplane Mass from FMC - Validated after Takeoff

• Algorithm developed for enhanced stall protection

• Avoid displaying data known to be bad
  - Loss of valid voted $V_{CAS}$ = Display synthetic airspeed $V_{SYN}$
  - Loss of valid voted $P_{STATIC}$ = Display GPS altitude
Onboard Health Management

Objective: Reduce schedule interruptions and maintenance costs

Integrated data load and configuration reporting

Airplane level fault consolidation and correlation, and data collection

Electronic Distribution of Software

Media-less data transfer to/from ground stations

Electronic link to maintenance manuals

Coordinated airplane and ground processing approach

Fault Prediction
Sat Comm
747
Dream Lifter
Partners Across the Globe are Bringing the 787 Together

<table>
<thead>
<tr>
<th>Region</th>
<th>Partners</th>
</tr>
</thead>
<tbody>
<tr>
<td>U.S.</td>
<td>Boeing, Spirit, GE, Goodrich</td>
</tr>
<tr>
<td>Australia</td>
<td>Boeing</td>
</tr>
<tr>
<td>Canada</td>
<td>Boeing, Mitsubishi, Kawasaki, KAL-ASD</td>
</tr>
<tr>
<td>Asia</td>
<td>Fuji, Mitsubishi, Rolls-Royce, Latecoère, Alenia, Saab</td>
</tr>
<tr>
<td>Europe</td>
<td>Messier-Dowty, GE, Rolls-Royce, Latécoère, Alenia, Saab</td>
</tr>
</tbody>
</table>

- **Wing tips**: Seoul, Korea
- **Fixed trailing edge**: Nagoya, Japan
- **Moveable trailing edge**: Melbourne, Australia
- **Tail fin**: Frederickson, WA
- **Passenger entry doors**: Toulouse, France
- **Aft fuselage**: Charleston, SC
- **Horizontal stabilizer**: Foggia, Italy
- **Mid forward fuselage**: Nagoya, Japan
- **Forward fuselage**: Wichita, KS
- **Cargo access doors**: Linköping, Sweden
- **Wing/body fairing**: Landing gear doors, Winnipeg, Canada
- **Main landing gear wheel well**: Nagoya, Japan
- **Center wing box**: Nagoya, Japan
- **Landing gear**: Gloucester, UK
- **Fixed and moveable leading edge**: Tulsa, OK
- **Engines**: GE – Evandale, Ohio, Rolls Royce – Derby, UK
Dreamlifter Route Structure

Worldwide operations, less work in process

Section 41
Wichita, KS to Everett, WA

Joined Section 43-46
Charleston, SC to Everett, WA

Section 44
Grottaglie, Italy to Charleston, SC

Joined Section 47-48
Charleston, SC to Everett, WA

Section 46
Grottaglie, Italy to Charleston, SC

Horizontal Stabilizer
Foggia, Italy to Charleston, SC

Section 11/45
Nagoya, Japan to Charleston, SC

Wing
Nagoya, Japan to Everett, WA

Section 43
Nagoya, Japan to Charleston, SC
Dreamlifter Enables Global Operations

- Efficient transport of 787 major sub-assemblies from international partners

- Main deck is 65,000 cubic feet
  - 3x capacity of 747-400 Freighter

- Reduced transportation times versus surface transportation
  - Dramatically reduced final assembly flow times
  - Less inventory
787 Structure from Asia

International partners providing key 787 structure
787 Structure from Europe

International partners providing key 787 structure
787 Structure from North America

International partners providing key 787 structure