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

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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>
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<tr>
<td>~Length</td>
<td>201 ft</td>
<td>186 ft</td>
<td>242 ft</td>
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<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>
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<tr>
<td>Cruise Mach</td>
<td>0.80</td>
<td>0.85</td>
<td>0.84</td>
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</table>
Composite Structure

By weight

<table>
<thead>
<tr>
<th>Material</th>
<th>787</th>
<th>777</th>
</tr>
</thead>
<tbody>
<tr>
<td>Composites</td>
<td>50%</td>
<td>12%</td>
</tr>
<tr>
<td>Aluminum</td>
<td>20%</td>
<td>50%</td>
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</tbody>
</table>

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

Composites 50%

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

1G Flight ~12 ft
On-Ground 0 ft

1G Flight
787 Wing Flex

Ultimate-Load ~26 ft
1G Flight ~12 ft
On-Ground 0 ft

Max-Load
787 Static Load Test @ Ultimate Load
Investigations with Composite Materials

• Terms: Composites
  disbonds
  delaminates
  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
787 Windows
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>
<th>Time (sec)</th>
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<tbody>
<tr>
<td>0</td>
<td>0</td>
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<tr>
<td>-1</td>
<td>20</td>
</tr>
<tr>
<td>1</td>
<td>40</td>
</tr>
<tr>
<td>2</td>
<td>60</td>
</tr>
<tr>
<td>-1</td>
<td>80</td>
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<td>140</td>
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<tr>
<td>1</td>
<td>160</td>
</tr>
<tr>
<td>0</td>
<td>180</td>
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</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)
787 Fuel Tank Inerting

Nitrogen Generation

VENT

AIR

CO₂

H₂O

AIR

N₂

N₂
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**
  - Wing LE Anti-Ice
  - Air Conditioning
  - Cabin Pressure
  - Engine start
  - **777**: bleed air
electric
generator
  - **787**: electric
  - electric
  - electric

- **Engine Generators**
  - **777**: 240 kVA
    - (2 @ 120 kVA)
  - **787**: 1000 kVA
    - (4 @ 250 kVA)
  - Generators
  - Starter/Gen’s
Variable Frequency Power Generation

**777**
- 115 VAC
- 400 Hz

**787**
- 230 VAC
- 360-800 Hz

**Integrated Drive Generator (IDG): Majority of In-Service Airplanes**

**Variable Frequency (VF): 787**

Variable frequency generation system is the simplest and the most reliable option.
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>SYS MENU</th>
<th>FLIGHT DECK CB</th>
<th>NON-NORMAL CB</th>
<th>CB BY STATE</th>
<th>CB SEARCH</th>
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<tbody>
<tr>
<td>CB BY ATA</td>
<td>CB BY BUS</td>
<td>CB BY LOCATION</td>
<td>RECENT USED CB</td>
<td>CB CUSTOM LIST</td>
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<tr>
<td>CE2100713 CIRCUIT BREAKER NAME 1</td>
<td>TRIPPED</td>
<td>DETAILS</td>
<td>CONTROL</td>
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<td>CE2100714 CIRCUIT BREAKER NAME 2</td>
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<td>CE2100717 CIRCUIT BREAKER NAME 8</td>
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<td>CE2100718 CIRCUIT BREAKER NAME 9</td>
<td>DO NOT CLOSE</td>
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<td>CE2100719 CIRCUIT BREAKER NAME 10</td>
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<td>CE2100722 CIRCUIT BREAKER NAME 13</td>
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<td>CK2100724 CONTACTOR NAME 15</td>
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<td>CE2100725 CIRCUIT BREAKER NAME 16</td>
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</tbody>
</table>
Overhead Panels - Circuit Breakers

787

777
Integrated FCE

Equivalent Channel of Flight Controls and High Lift
Common Core System

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

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

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

**Center System**
- 27 gpm
- Electric Motor Pump (EMP)
- 27 gpm
- Electric Motor Pump (EMP)
- 27 gpm
- Ram Air Turbine (RAT)

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

**OB Aileron – IB Flaperon**
- L Wing: OB & IB
- R Wing: IB
- L Wing: 3
- R Wing: 12

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

**Elevator**
- L: Left
- R: PCU

**Rudder**
- L: Left
- R: PCU

**Thrust Reverser**
- Left

**Trailing Edge Flaps**
- Left & Right

**Leading Edge Flaps**
- Left & Right

**Nose Landing Gear & Steering**
- Left & Right

**Main Landing Gear**
- Left & Right

**25 gpm**
- +/− 270V DC

**27 gpm**
- +/− 270V DC

VDC
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

- Heat Exchanger inlet
- Cabin Air Compressor Inlet (Deflector door shown deployed)
- 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
Flight Controls - 777 / 787 Common Functionality

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)

Voted AD & IR (777, 787)

Fault arbitration by CREW

Fault arbitration by SYSTEM

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
Objective: Reduce schedule interruptions and maintenance costs

Integrated data load and configuration reporting

Electronic Distribution of Software

Electronic link to maintenance manuals

Fault Prediction

Airplane level fault consolidation and correlation, and data collection

Media-less data transfer to/from ground stations

Coordinated airplane and ground processing approach
Sat Comm
747
Dream Lifter
Partners Across the Globe are Bringing the 787 Together

U.S.  
- Boeing
- Spirit
- GE
- Goodrich

Australia  
- Boeing

Canada  
- Fuji
- Mitsubishi
- Kawasaki
- KAL-ASD

Asia  
- Boeing
- Messier-Dowty

Europe  
- Messier-Dowty
- Rolls-Royce
- Latécoère
- Alenia
- Saab

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Wing tips  
Seoul, Korea

Fixed trailing edge  
Nagoya, Japan

Moveable trailing edge  
Melbourne, Australia

Tail fin  
Frederickson, WA

Wing  
Nagoya, Japan

Passenger entry doors  
Toulouse, France

Aft fuselage  
Charleston, SC

Center fuselage  
Grottaglie, Italy

Mid forward fuselage  
Nagoya, Japan

Forward fuselage  
Wichita, KS

Cargo access doors  
Linköping, Sweden

Wing/body fairing  
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
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