Aircraft Environmental Control Systems (ECS) with Case Studies

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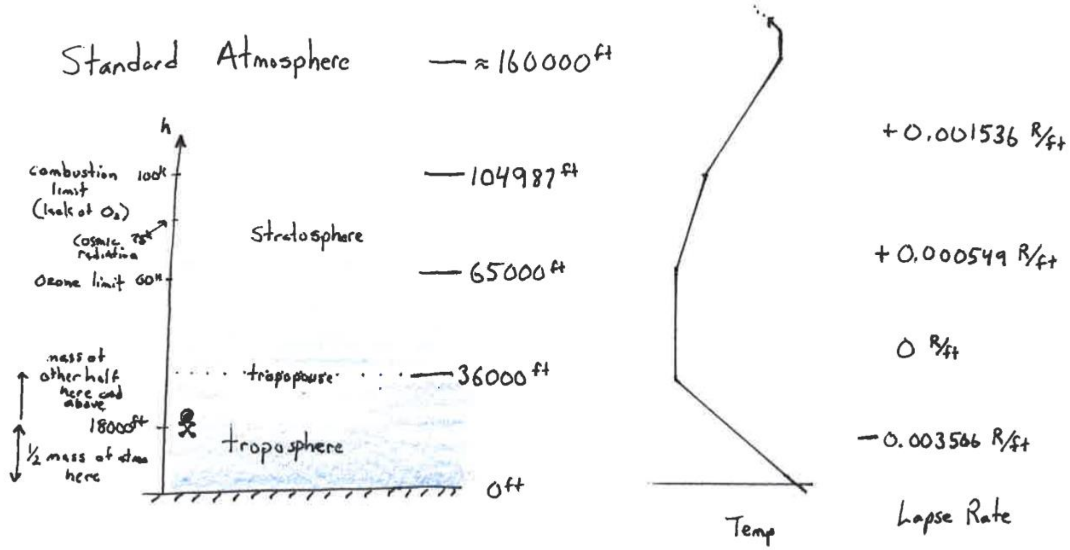
It’s the man, not the machine.
– Chuck Yeager

The objective of an Environmental Control System (ECS) is to sustain and nourish the pilot, humans, and other lifeforms aboard the vehicle. Aerospace ECS is a **life critical** requirement for aircraft and spacecraft.

By Master Sgt. Andy Dunaway - This Image was released by the United States Air Force with the ID 080610-F-BC606-048

Standard Atmosphere



We are lucky to live at the bottom of an ocean of protective air.

- Death zone for humans begins around 20^{kft} or so...
- Half the mass of air is below 18^{kft}
- Ozone above 60^{kft} prevents use of outside air for humans.
- Cosmic radiation becomes significant around 75^{kft}.
- Normal jet combustion fails around 100^{kft}. (Not enough O_2)
- The positive lapse rate around 65^{kft} makes the atmosphere stable. Convection is minimal.

Non-dimensional P, T, ρ ratios

$$\delta = \frac{P}{P_{ssl}} \qquad \theta = \frac{T}{T_{ssl}} \qquad \sigma = \frac{\rho}{\rho_{ssl}} = \frac{\delta}{\theta}$$

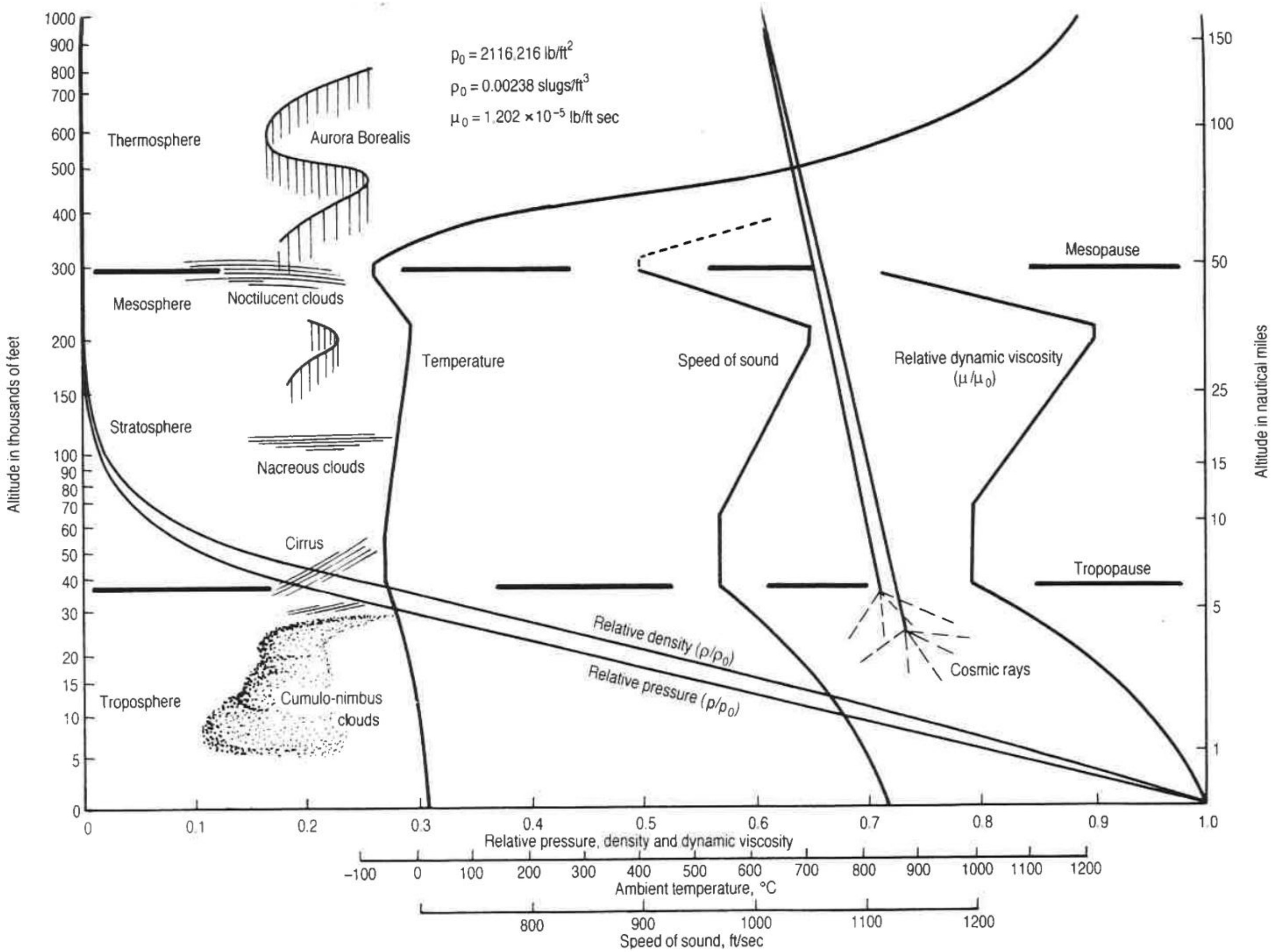
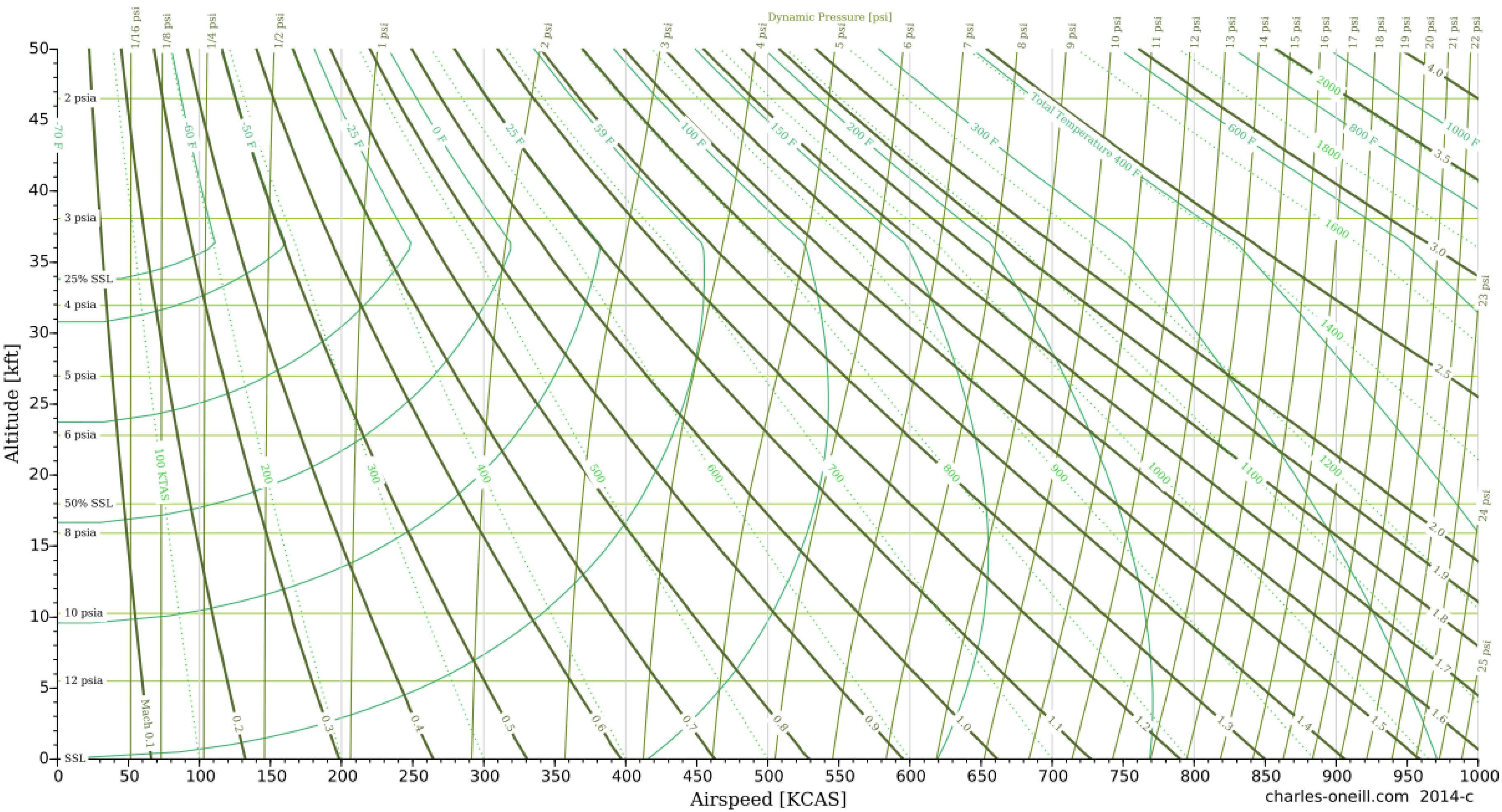


Fig. 1.2 General characteristics of the atmosphere (based upon ICAO and US Standard Atmosphere 1962).

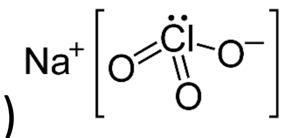
Source: The Anatomy of the Airplane
Stinton

Flight Envelope

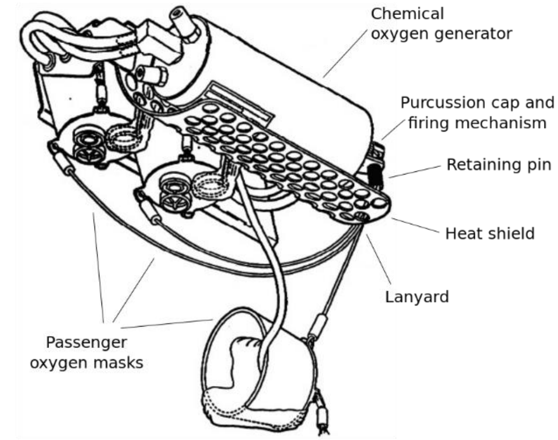


Oxygen: “take it or make it”

Take it
- Bottle: Limited supply, simple
- Chemical: (e.g. Sodium Chlorate)
  1 time use (10-20 minutes)

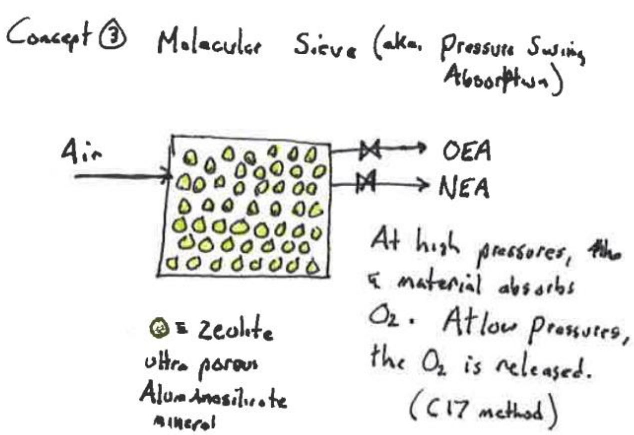


Ben Mills



Valujet 592 Crash (NTSB)

Make it
- Pressurize existing air: Common
- OBOGS (Onboard Oxygen Generating System):



Luke Air Force Base extends cancellation of F-35 flight operations

By: Valerie Insinna June 12, 2017

Since May 2, five 56th Fighter Wing pilots have reported symptoms of oxygen deprivation while flying the U.S. Air Force version of the joint strike fighter, including two incidents that occurred last week. In all cases, the

https://www.defensenews.com/air/2017/06/12/luke-air-force-base-extends-cancellation-of-f-35-flight-operations/

ALL U.S. F/A-18 HORNET MODELS AFFECTED BY OXYGEN DEPRIVATION AND CABIN DECOMPRESSION ISSUES

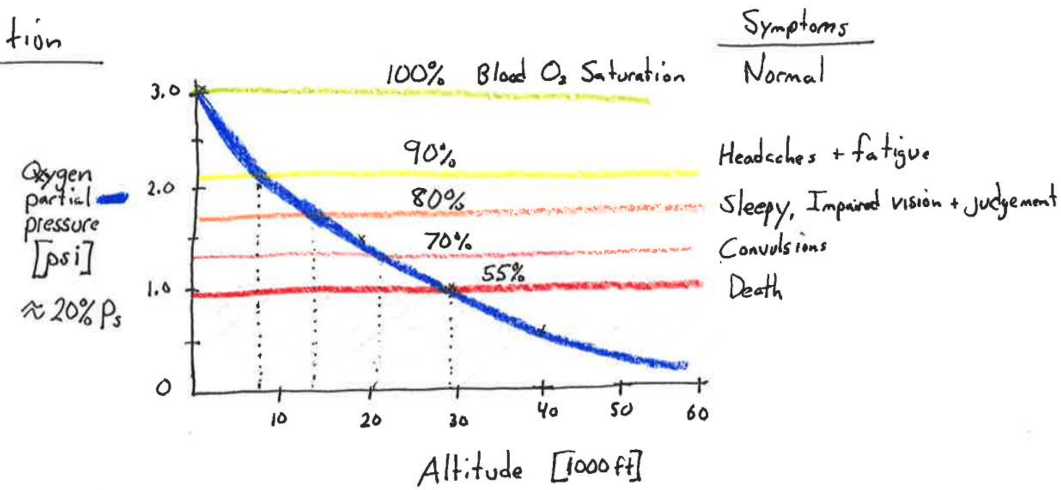
https://theaviationist.com/2017/03/29/all-u-s-fa-18-hornet-models-affected-by-oxygen-deprivation-and-cabin-decompression-issues/

F-22 grounding continues as oxygen safety probe widens

16 JUNE, 2011 | SOURCE: FLIGHT INTERNATIONAL | BY: STEPHEN TRIMBLE | WASHINGTON DC

https://www.flightglobal.com/news/articles/f-22-grounding-continues-as-oxygen-safety-probe-wide-358103/

pressurization



Federal Aviation Regulations

- Cabin must operate at an 8000 ft equivalent pressure or below if pressurized
  (≈ 90% O_2 Sat or above)

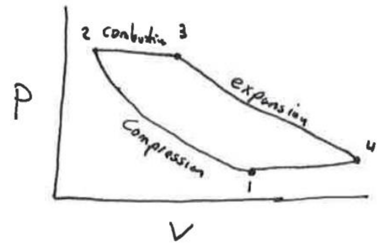
- 25000 ft Decompression for no more than 2 minutes
  40000 ft Never
  } this effectively drives the speed brake size on business jets

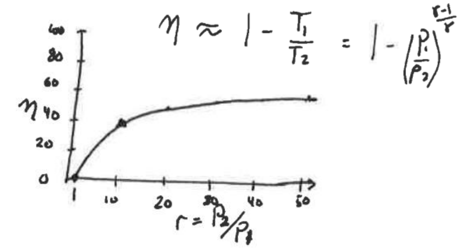
- Private aircraft (not for hire) can operate:
  >12500 ft for less than 30 min without Oxygen
  >14000 with oxygen

Mask or cannula

Bleed Air

Brayton Cycle





Compressor Combustion Turbine

Inlet Flow

Outlet Flow

Low P Bleed

High P Bleed

Bleed air is used for pressurization, power production, de-icing, starting, cooling, etc.

The price to pay is less mass flow rate available as thrust.

Case Study: TWA 800 (Boeing 747)

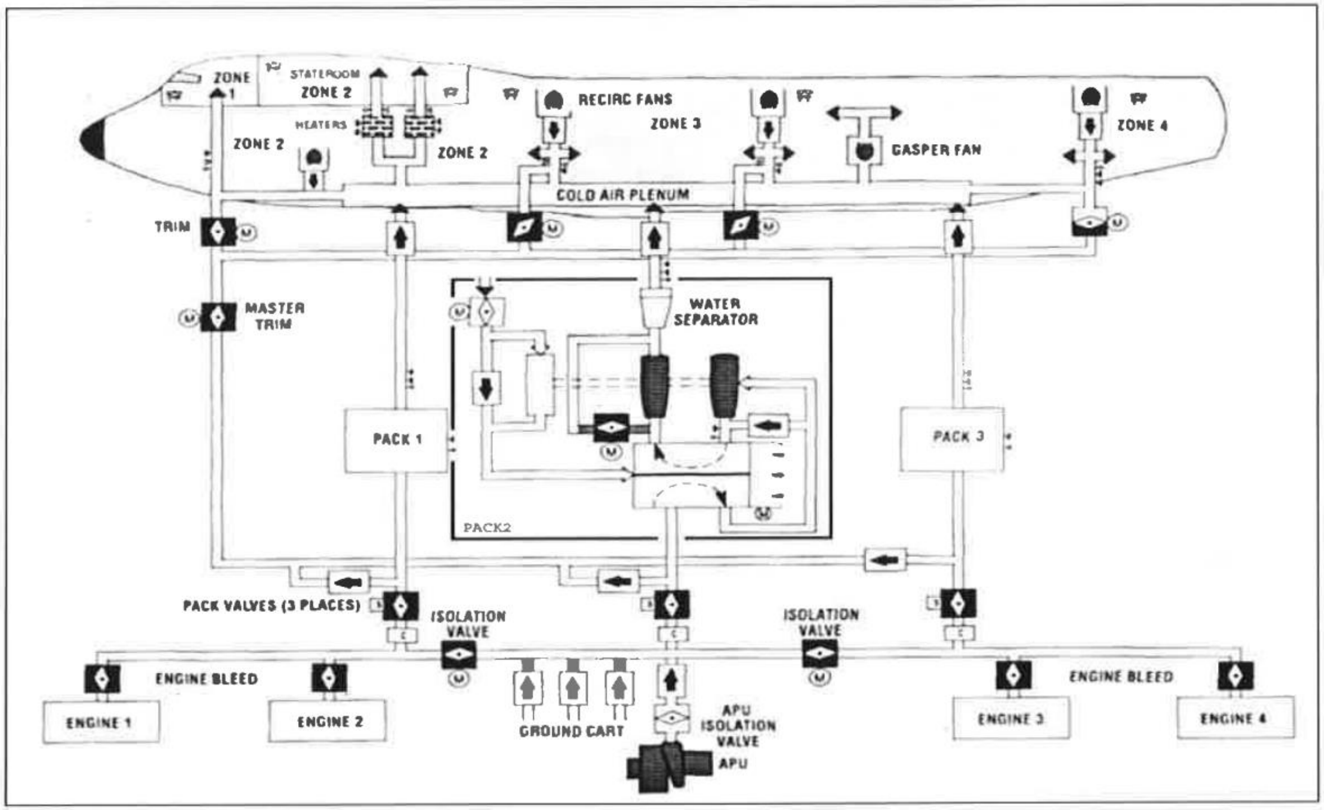
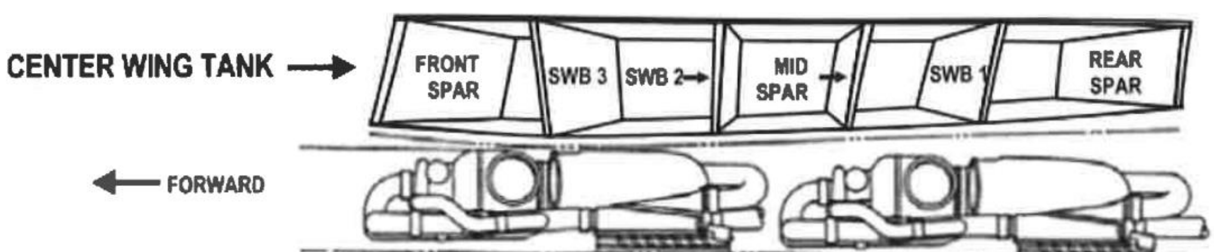


Figure 6. A schematic diagram of the 747-100's air conditioning system.



NTSB

TWA 800 B 747 1996

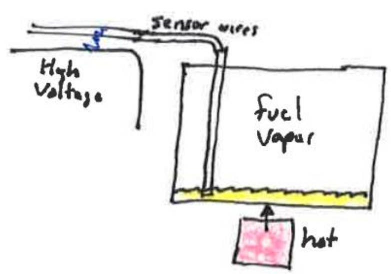
Aircraft destroyed in crash off the coast of Long Island NY after takeoff from JFK.

An unusual flight path and multiple fireballs contributed to speculation of ....

The NTSB report says: "An explosion of the center wing fuel tank (CWT), resulting from the ignition of the flammable fuel/air mixture in the tank. The source of ignition energy for the explosion could not be determined with certainty, but, of the sources evaluated by the investigation, the most likely was a short circuit outside of the CWT that allowed excessive voltage to enter it through electrical wiring associated with the fuel quantity indication system.

Contributing factors to the accident were the design and certification concept that fuel tank explosions could be prevented solely by precluding all ignition sources and the design and certification of the Boeing 747 with heat sources located beneath the CWT with no means to reduce the heat transferred into the CWT or to render the fuel vapor in the tank nonflammable.

Visual translation



Case St’: Boeing 737

Huge success: 10000+ delivered over 50 years
Up to 200+ seats, twin engine, efficient

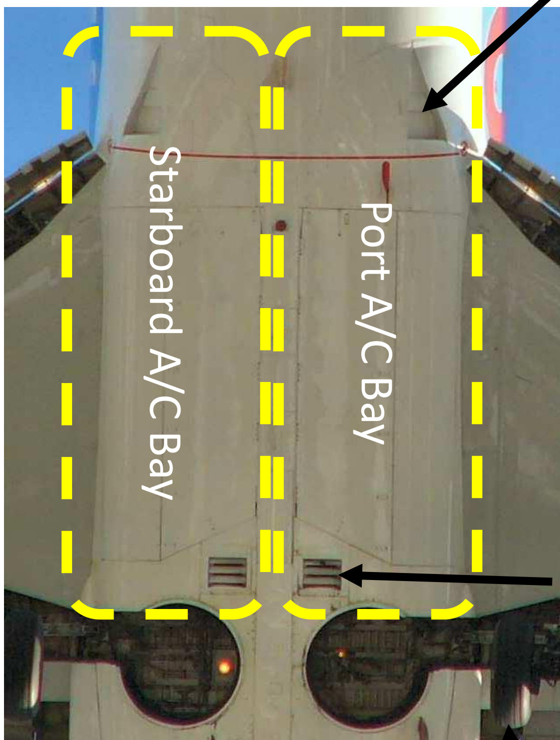
By Konstantin von Wedelstaedt

Air conditioning

Pnuematics

http://www.b737.org.uk

Flush Inlet

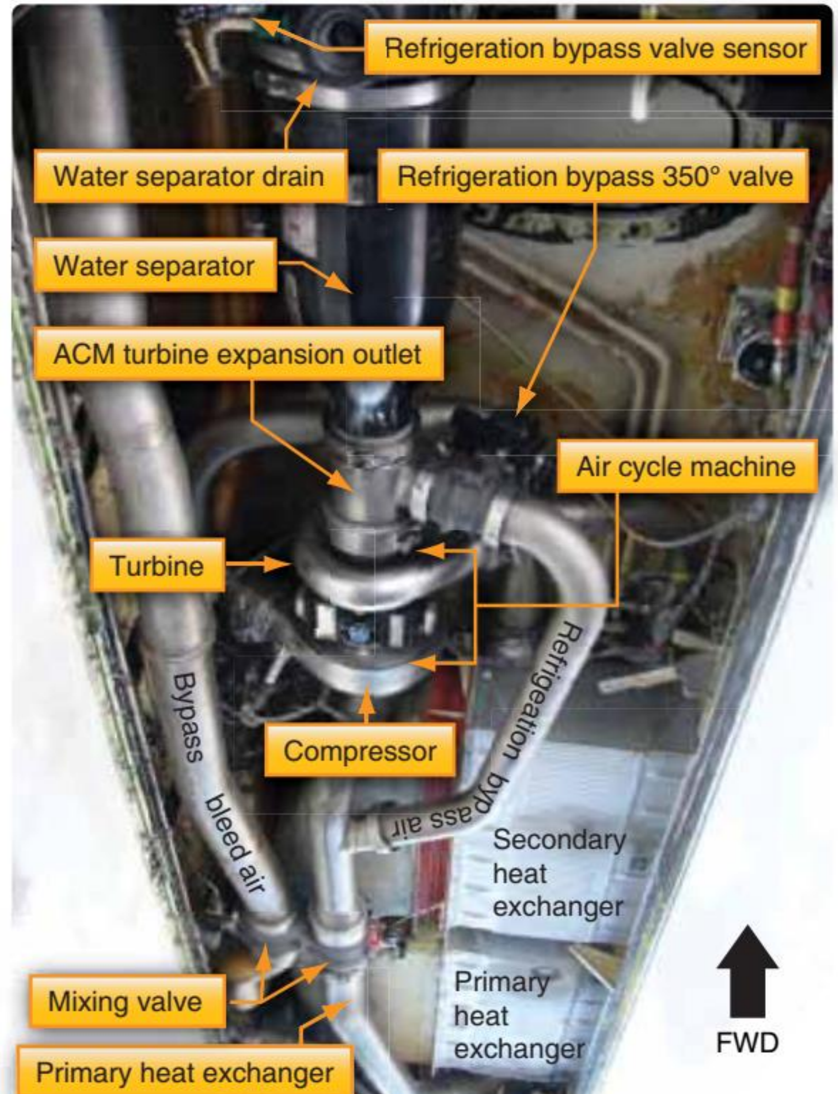


Vent

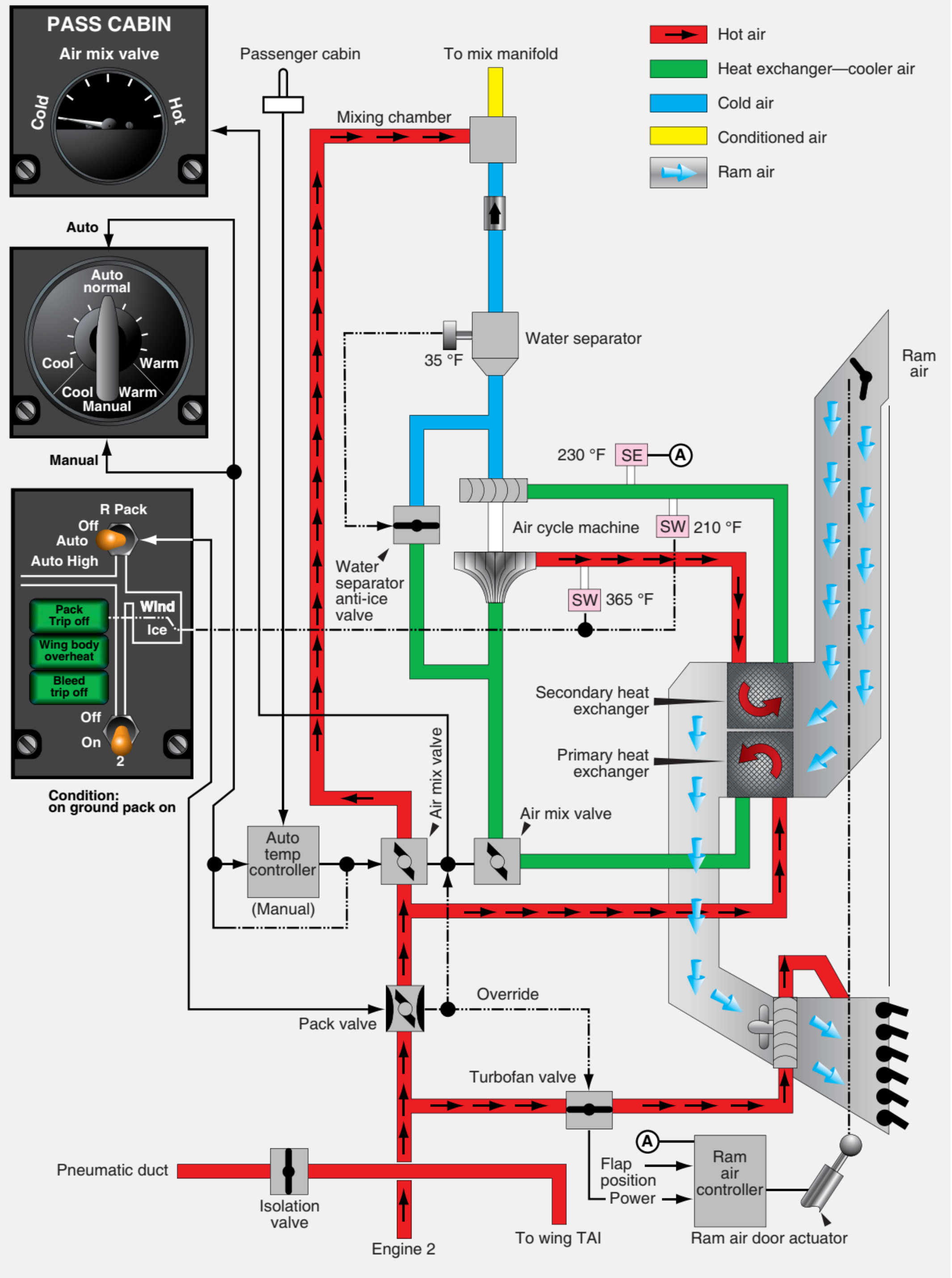
Tail ↓

Landing Gear

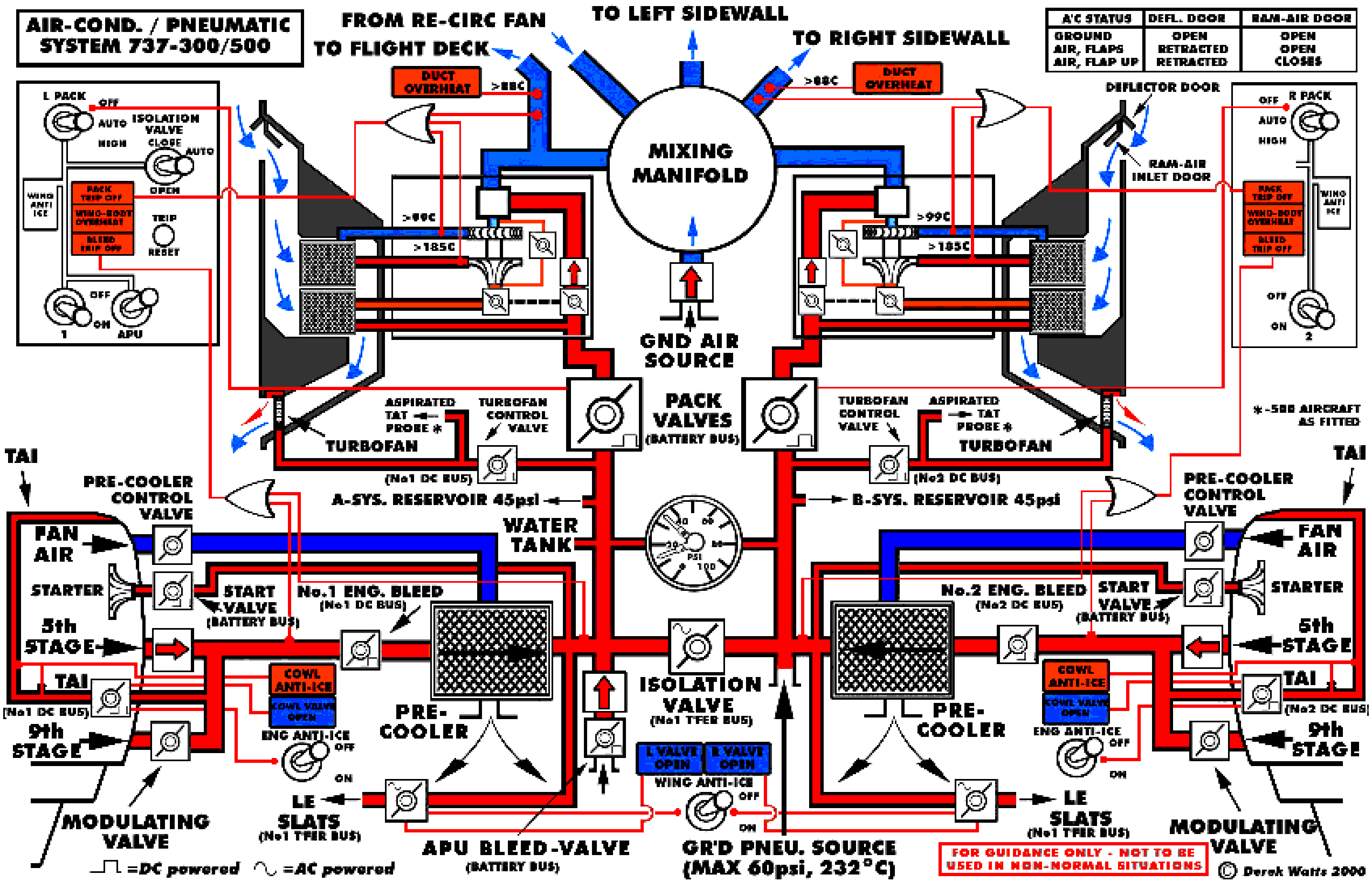
http://www.b737.org.uk



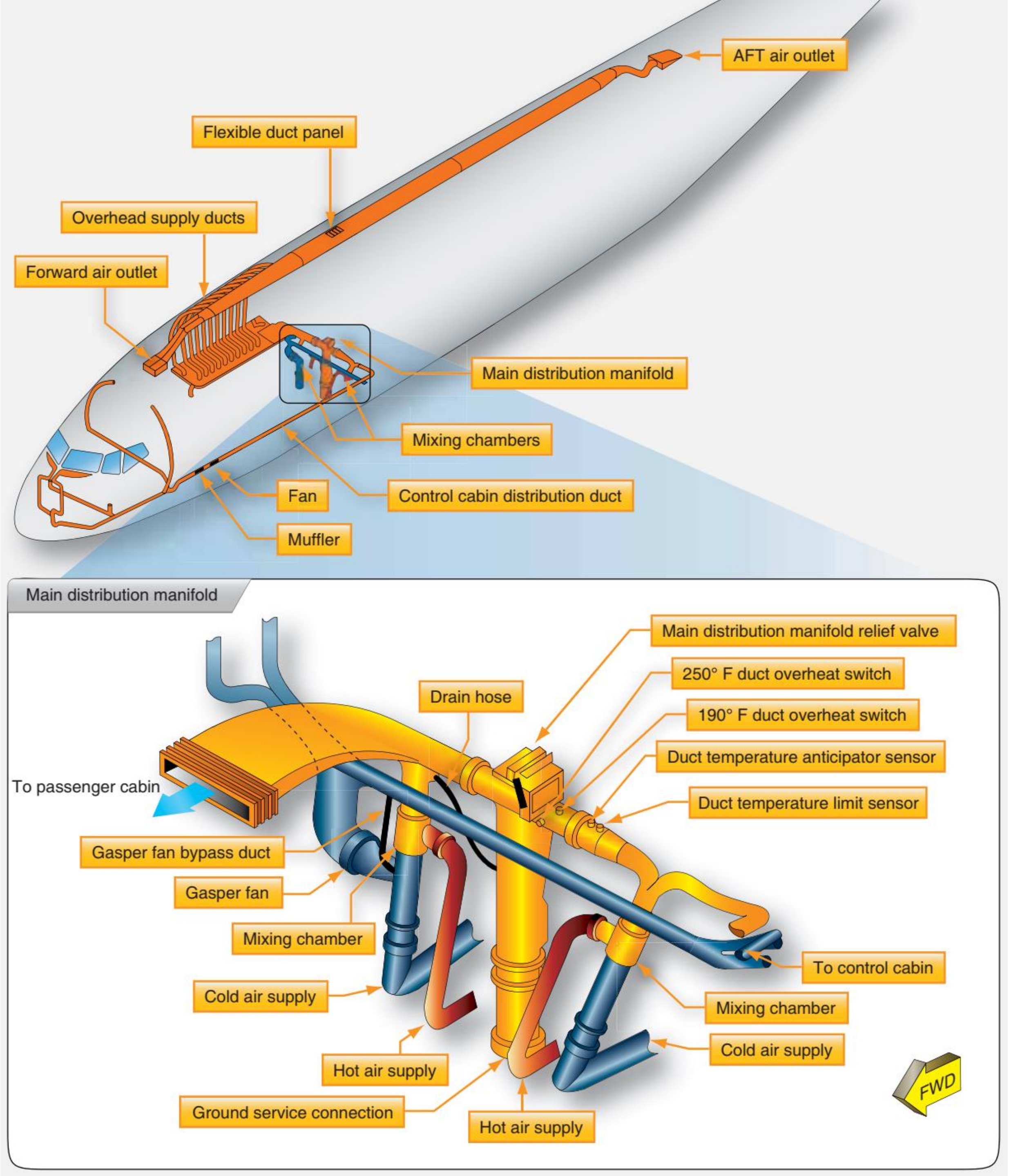
Source: FAA


PASS CABIN
Air mix valve
Cold
Hot
Auto
Auto normal
Cool
Warm
Cool
Warm
Manual
Manual
R Pack
Off
Auto
Auto High
Pack Trip off
Wing body overheat
Bleed trip off
Wind
Ice
Off
On
2
Condition: on ground pack on
Passenger cabin
To mix manifold
Mixing chamber
Hot air
Heat exchanger—cooler air
Cold air
Conditioned air
Ram air
Water separator
35 °F
Ram air
230 °F
SE
A
Air cycle machine
SW
210 °F
Water separator anti-ice valve
SW
365 °F
Secondary heat exchanger
Primary heat exchanger
Air mix valve
Air mix valve
Auto temp controller
(Manual)
Override
Pack valve
Turbofan valve
Pneumatic duct
Isolation valve
Engine 2
To wing TAI
A
Flap position
Power
Ram air controller
Ram air door actuator

Source: FAA



http://www.b737.org.uk



AFT air outlet
Flexible duct panel
Overhead supply ducts
Forward air outlet
Main distribution manifold
Mixing chambers
Fan
Control cabin distribution duct
Muffler
Main distribution manifold
Main distribution manifold relief valve
250° F duct overheat switch
Drain hose
190° F duct overheat switch
Duct temperature anticipator sensor
To passenger cabin
Duct temperature limit sensor
Gasper fan bypass duct
Gasper fan
Mixing chamber
To control cabin
Cold air supply
Mixing chamber
Cold air supply
Hot air supply
FWD
Ground service connection
Hot air supply

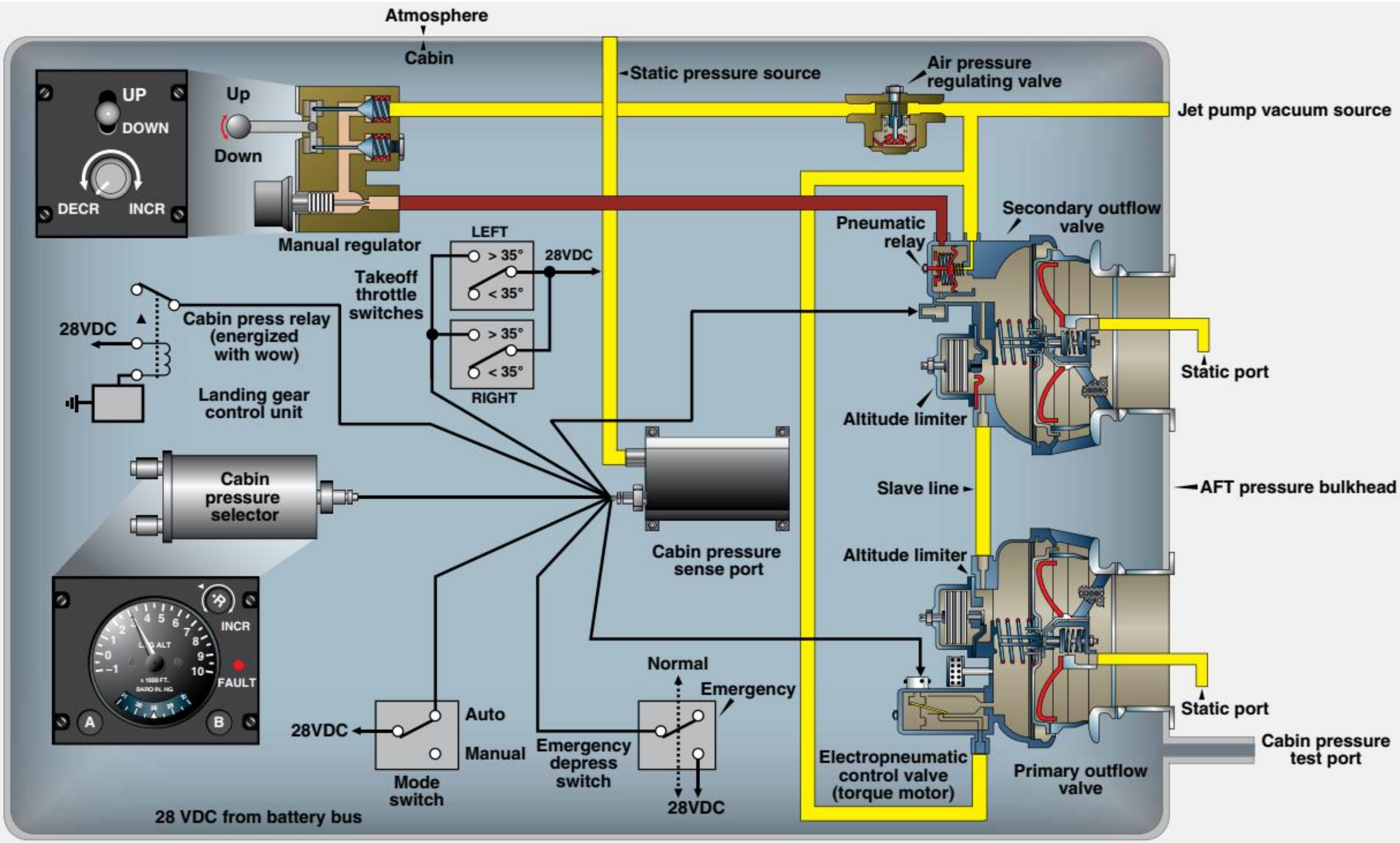
Source: FAA

Pressurization:

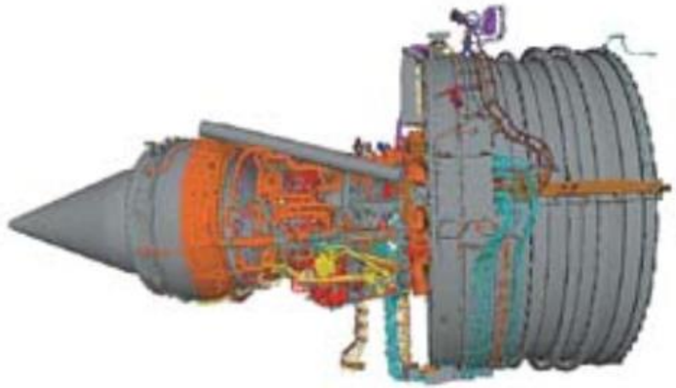
Failure Mode? Loss of Pressurization

Helios 522

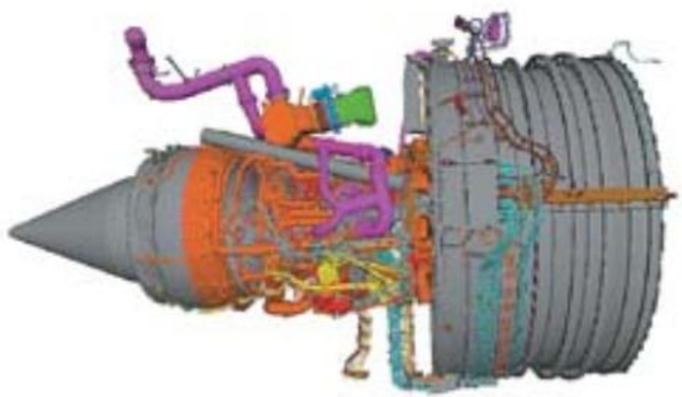
Payne Stewart


Atmosphere
Cabin
Static pressure source
Air pressure regulating valve
Jet pump vacuum source
UP
DOWN
DECR
INCR
Up
Down
Manual regulator
LEFT
> 35°
< 35°
28VDC
> 35°
< 35°
RIGHT
Takeoff throttle switches
Pneumatic relay
Secondary outflow valve
28VDC
Cabin press relay (energized with wow)
Landing gear control unit
Static port
Altitude limiter
Cabin pressure selector
Slave line
AFT pressure bulkhead
Cabin pressure sense port
Altitude limiter
INCR
FAULT
A
B
Normal
Emergency
Static port
28VDC
Auto
Manual
Emergency depress switch
Mode switch
28VDC
Electropneumatic control valve (torque motor)
Primary outflow valve
Cabin pressure test port
28 VDC from battery bus

The Future?



No bleed system



Traditional Bleed System

787 No-Bleed Systems: Saving Fuel and Enhancing Operational Efficiencies

by Mike Sinnett,
Director, 787 Systems

The primary differentiating factor in the systems architecture of the 787 is its emphasis on electrical systems, which replace most of the pneumatic systems found on traditional commercial airplanes.

One of the advantages of the no-bleed electrical systems architecture is the greater efficiency gained in terms of reduced fuel burn — the 787 systems architecture accounts for predicted fuel savings of about 3 percent. The 787 also offers operators operational efficiencies due to the advantages of electrical systems compared to pneumatic systems in terms of weight and reduced lifecycle costs.

In the no-bleed architecture, electrically driven compressors provide the cabin pressurization function, with fresh air brought onboard via dedicated cabin air inlets. This approach is significantly more efficient than the traditional bleed system because it avoids excessive energy extraction from engines with the associated

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Slides Posted at: http://tiny.cc/ECSLecture