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.

SWAP-C: Size, Weight, Access, Power, Cost?
Standard Atmosphere  

\[ h = 160000 \text{ ft} \]
\[ h = 104987 \text{ ft} \]
\[ h = 65000 \text{ ft} \]

Stratosphere

Troposphere

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

- Death zone for humans begins around 20,000 ft or so...
- Half the mass of air is below 18,000 ft
- Ozone above 60,000 ft prevents use of outside air for humans.
- Cosmic radiation becomes significant around 75,000 ft.
- Normal jet combustion fails around 100,000 ft. (Not enough O₂)
- The positive lapse rate around 65,000 ft makes the atmosphere stable. Convection is minimal.

Non-dimensional \( P, T, \rho \) ratios

\[ \mathcal{D} = \frac{P}{P_{\text{est}}} \quad \Theta = \frac{T}{T_{\text{est}}} \quad \sigma = \frac{\rho}{\rho_{\text{est}}} \]
Fig. 1.2 General characteristics of the atmosphere (based upon ICAO and US Standard Atmosphere 1962).

Source: The Anatomy of the Airplane, Stanton
Flight Envelope
Oxygen: “take it or make it”

Bottle: Limited supply, simple

Take it

Chemical: (e.g. Sodium Chlorate)
1 time use (10-20 minutes)

Make it

Pressurize existing air: Common

OBOGS (Onboard Oxygen Generating System):

Valujet 592 Crash (NTSB)

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

F-22 grounding continues as oxygen safety probe widens
16 JUNE, 2011 | SOURCE: FLIGHT INTERNATIONAL | BY: STEPHEN REYNOLDS | WASHINGTON DC
Federal Aviation Regulations

- Cabin must operate at an 8000 ft equivalent pressure or below if pressurized
  \( \approx 90\% \text{ O}_2 \text{ Sat or above} \)

- 25000 ft Decompression for no more than 2 minutes
  40000 ft Never

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

  Mask or cannula
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.
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 entry for the explosion could not be determined with certainty, but, at 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 wires associated with the fuel quantity indication system.

Contributing factors to the accident were the design and certification concepts 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 non-flammable.
Case St’: Boeing 737

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

Air conditioning

Pnuematics

http://www.b737.org.uk
Port A/C Bay
Starboard A/C Bay
Flush
Inlet
Vent
Tail
Landing Gear

Source: FAA
http://www.b737.org.uk
Pressurization:

Failure Mode? Loss of Pressurization

Helios 522

Payne Stewart
The Future?

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