Atmosphere Selection for Long-duration Manned Space Missions

David B. Hirsch
NASA Johnson Space Center White Sands Test Facility

NASA/JAXA Technical Interchange Meeting
Tsukuba, Japan
June 4-8, 2007

Slide 1

d2

The environment of spacecraft for future human space exploration missions will play a critical role in the ultimate safety, productivity, and cost.

There are a multitude of factors involved in selection of spacecraft environments. During my presentation I will review some of the factors.

dhirsch, 1/15/2006

d5

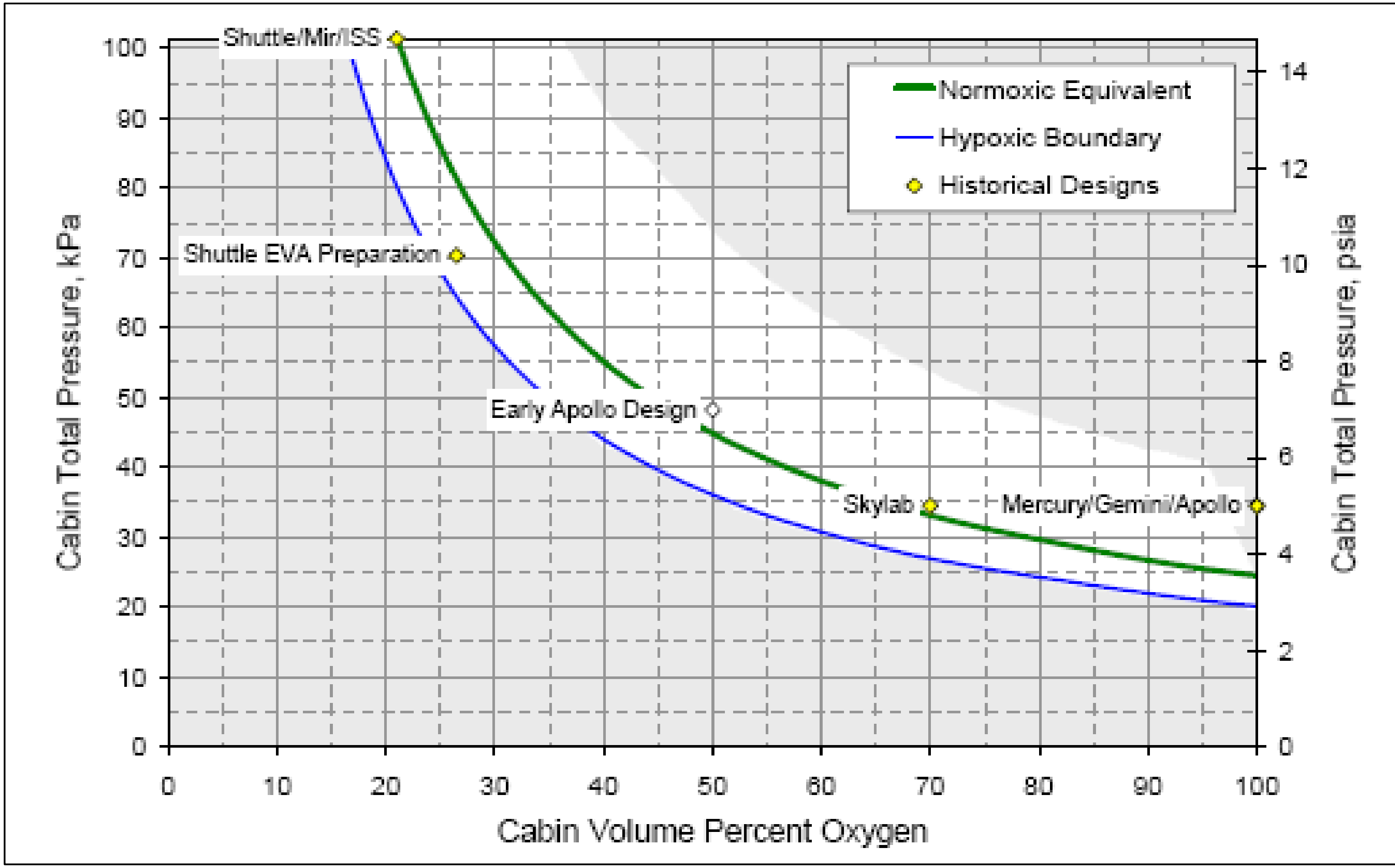
Longer mission duration drive reuse and recycling of materials to reduce consumables and expandebles supplies.

Long duration will require greater housekeeping and support activities, including cooking, laundry, and trash management. Regular maintenance operations on equipment and spacesuits, such as cleaning and part replacement will be necessary. The capability for local part fabrication may also be required.

Advanced life support systems wil linclude food production and waste recycling systems. Drying processes are considered to recover water from solid waste, and high temperature processes are considered to decompose wates and microbial stabilization. These operations will inevitably involve increased handling and materials processing that could include flammable items

dhirsch, 1/17/2006

Historical Spacecraft Atmospheric Conditions



d1

Mercury/Gemini/Apollo
100% oxygen, 5 psia
Space suit 100% oxygen, 3.75 psia
No EVA prebreathe time required but prior to lunch the astronauts were exposed tp 100% oxygen for 3 hrs
Skylab 70 oxygen, 5 psia, same suit as above
No EVA prebreath required
Shuttle/ISS US 21% oxygen, 14.7 psia; suit at 4.3 psia
two operation modes:
36 hrs at 26.5% oxygen, 10.2 psia in spacecraft followed by 40 min 100% oxygen in suit
if no 36 hrs preconditioning, than 4 hrs in 100% oxygen in the suit (2.5 hrs on emergency)
ISS/Russia suit at 5.8 psia, 30 minute 100% 0xygen in suit
dhirsch, 1/15/2006

d4

Spacecraft Environment Selection

d6

- What drives spacecraft environment selection?
  - Crew Health and Safety Requirements
  - Materials Requirements
  - Program Requirements
  - Mission, Vehicle, and Space Suit Optimization

Slide 3

d4 Crew health: respiratory physiology, decompression sickness prevention directly affect atmosphere selection
radiation protection affects indirectly
dhirsch, 1/15/2006

d6 Program and mission requirements
Number of EVA planned - complexity of space architecture -
Capability for emergency EVA
Rapid cabin depressurization response
dhirsch, 1/17/2006

Physiological Response

The impact of the second of these requirements on the atmosphere design space is shown in Figure 2-1. For different combinations of atmosphere total pressure and oxygen concentration, a region of unimpaired performance exists that is bounded by regions of hypoxia (oxygen deficiency) and oxygen toxicity.

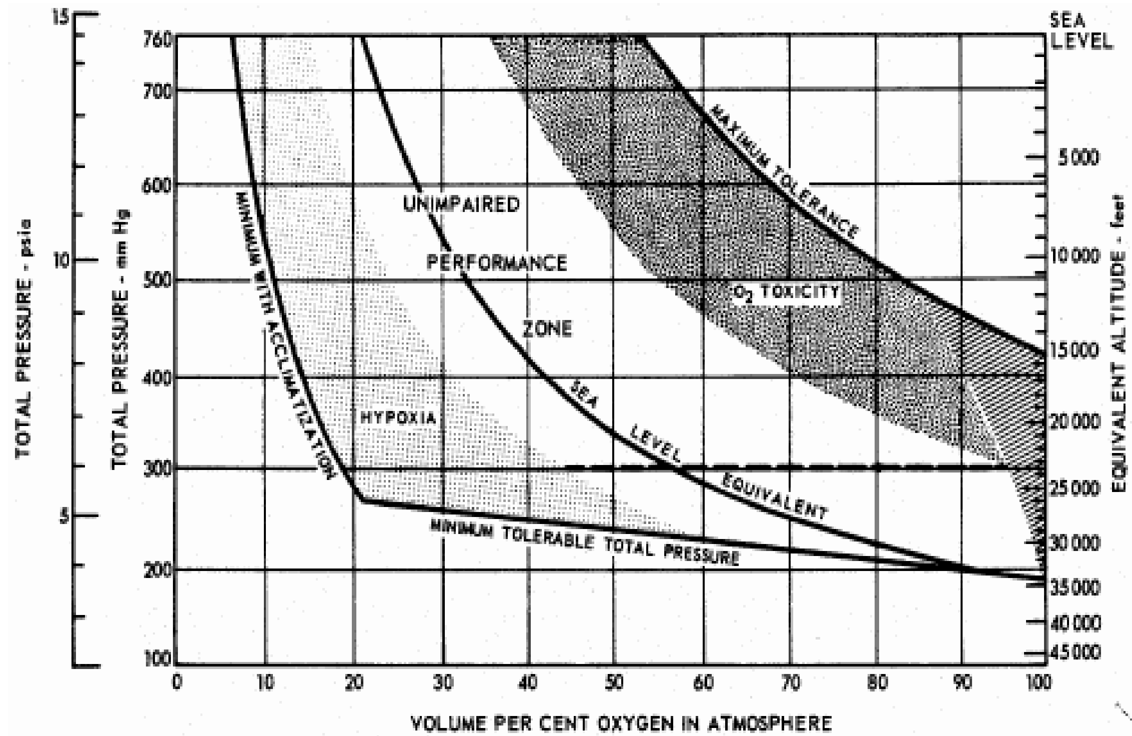


Figure 2-1. Physiological response to atmospheres of different total pressure and oxygen concentration (from Webb (1964); also NASA (1995)).

Physiological response to atmospheres of various total pressures and oxygen concentrations

d3

Provide sufficient total pressure to prevent boiling of body fluids (>0.9 psia)
Provide sufficient oxygen partial pressure to prevent hypoxia but not so high to cause oxygen toxicity
Provide a neutral gas to prevent atelectasis
dhirsch, 1/17/2006

d8

Decompression Sickness Prevention

- Conditions of occurrence
- Symptoms: Pain, chokes, circulatory collapse, neurological disorders; potentially debilitating and life-threatening condition
- The occurrence and severity of DCS correlates with R, the ratio of the final nitrogen partial pressure in the body tissue to the final ambient total pressure.
- Maximum prebreathe time

d8

The internal pressure in spacesuits is low (4.3 psia for current EVA suits). The lower pressure allows increased glove mobility and reduces physical efforts. Reduced pressures require higher oxygen concentrations for breathing. Transition from a higher pressure to a reduced pressure may result in absorbed-nitrogen in tissues going into the gas phase.

Final R values of at least 1.65 are required in current spacecraft, but in fact we go to as low as 1.3

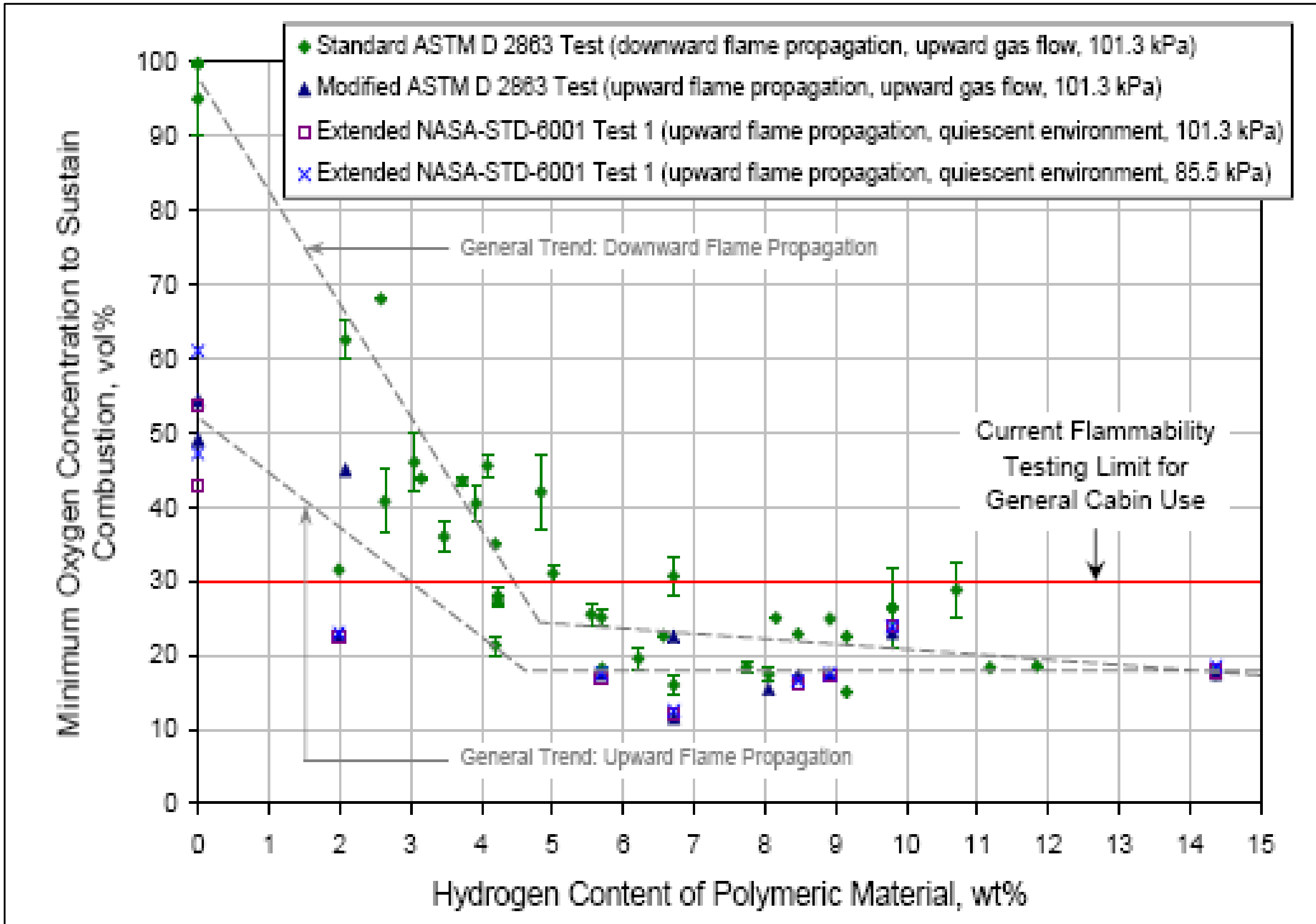
DCS incidence is lower in microgravity than forecasted. There may be increased physical efforts in partial gravity imposed by ambulation.

dhirsch, 1/17/2006

Materials Selection

- Two major issues:
  - Flammability
  - Offgassing

Influences on LOI



Influence of polymer hydrogen content and test conditions on the LOI

d7

Commonly Used Polymers

- Some polymers commonly used in American spacecraft and their flammability limits:
  - PTFE
  - Kapton
  - Nomex HT 9040
  - Graphite epoxy composite
  - Silicones
  - Viton
  - PU and PE
  - Solimide
  - Kynar
  - Polycarbonate
  - Nylon
  - Cotton
  - Paper
  - PVC and ABS
  - Delrin
  - Kevlar
  - Epoxy fiberglass with PI

d7 PTFE (49); Kapton (>30); Nomex (aramide) - stowage containers (22.6); Nomex flight suits, never used
Graphite epoxy composite - ISS racks
Silicone adhesives and sealants (23.5 as foam)
Viton (22.5); PU (15.3) and PE (17.5) stowage foam (usually covered with Nomex)
Solimide, not used much (55.1); Kynar (pvdF);
PC (25-30)-camera and laptop cases
Nylon (23) hook and loop fasteners; running shorts; cotton (clothing, towels); paper
PVC (49.3) and ABS (16) in off-the-shelf hardware; Kevlar (aramid fabric) (25.6), internal webbing
dhirsch, 1/16/2006

Achieving Lower Cabin Oxygen Concentration

- Increasing the spacesuit pressure
- Accepting a higher value for R and the associated DCS risk
- Accepting a longer prebreathe time
- Allowing a more hypoxic atmosphere

d9

A variable spacecraft environment is considered. For transit vehicles with few EVA's , a longer prebreathe time may be acceptable, allowing an Earth-normal spacecraft atmosphere. This include vehicles that dock with the ISS. It is desirable to avoid the airlock operations during crew transfer.

The hypoxic boundary is defined by an oxygen partial pressure equivalent to an altitude of 6000 ft. About 130 million people live at altitudes from 6500 to 8200 ft, indicating that higher equivalent altitudes are acceptable for short duration space travel.

dhirsch, 1/17/2006

d10

Engineering Factors

- Cabin structural mass
  - Drivers: thickness to contain internal pressure, structural integrity to withstand launch and re-entry loads, radiation shielding, meteoroid protection
- Thermal control systems
- Life support systems
- Airlocks for EVA

d10

At cabin pressures below 5 to 7 psia launch loads determine the minimum wall thickness, whereas at higher pressures than 7 psia, the internal pressure dictates the thickness. For lunar vehicles, the launch loads dictate the wall thickness at pressures up to 14.7 psia.

TCSystems - The total pressure has an impact on the duct and fan sizing. For equivalent heat transfer, when reducing pressures, the mass flow rate has to stay the same. Consequently, the volumetric flow rate has to increase. The power penalty to the air cooling subsystem due to reduced pressures puts a practical minimum on cabin pressure of 7.35 psia.

LSSystems: the carbon dioxide and trace contaminants reduction are not affected by reduced pressures. The aerobic biological waste processing systems may have to be modified if oxygen concentrations other than air are used.

There are two types of airlocks: venting to outside and pumping the environment back to the spacecraft. If at least 6 EVA are conducted, pumping back pays off. The power required is much less at higher pressures.

dhirsch, 1/17/2006