

## Risk Assessment of Physiological Effects of Atmospheric Composition and Pressure in Constellation Vehicles

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**Introduction:** To limit the risk of fire and reduce denitrogenation time to prevent decompression sickness to support frequent extravehicular activities on the Moon, a hypobaric ( $P_B = 414$  mmHg) and mildly hypoxic ( $ppO_2 = 132$  mmHg, 32%  $O_2$  - 68%  $N_2$ ) living environment is considered for the Crew Exploration Vehicle (CEV) and Lunar Surface Access Module (LSAM). With acute change in  $ppO_2$  from 145-178 mmHg at standard vehicular operating pressure to less than 125 mmHg at desired lunar surface vehicular operating pressures, there is the possibility that some crewmembers may develop symptoms of Acute Mountain Sickness (AMS). The signs and symptoms of AMS (headache plus nausea, dizziness, fatigue, or sleeplessness), could impact crew health and performance on lunar surface missions. **Methods:** An exhaustive literature review on the topic of the physiological effects of reduced  $ppO_2$  and absolute pressure as may contribute to the development of altitude symptoms or AMS. The results of the nine most rigorous studies were collated, analyzed and contents on AMS and hypoxia symptoms summarized. **Results:** There is evidence for an absolute pressure effect *per se* on AMS, so the higher the altitude for a given hypoxic alveolar  $O_2$  partial pressure ( $P_{AO_2}$ ), the greater the AMS response. About 25% of adults are likely to experience mild AMS near 2,000 m altitude following a rapid ascent from sea level while breathing air (6,500 feet, acute  $P_{AO_2} = 75$  mmHg). The operational experience with the Shuttle staged denitrogenation protocol at 528 mmHg (3,048 m) while breathing 26.5%  $O_2$  (acute  $P_{AO_2} = 85$  mmHg) in astronauts adapting to microgravity suggests a similar likely experience in the proposed CEV environment. **Conclusions:** We believe the risk of mild AMS is greater given a  $P_{AO_2}$  of 77 mmHg at 4,876 m altitude while breathing 32%  $O_2$  than at 1,828 m altitude while breathing 21%  $O_2$ . Only susceptible astronauts would develop mild and transient AMS with prolonged exposure to 414 mmHg (4,876 m) while breathing 32%  $O_2$  (acute  $P_{AO_2} = 77$  mmHg). So the following may be employed for operational risk reduction: 1) develop procedures to increase  $P_B$  as needed in the CEV, and use a gradual or staged reduction in cabin pressure during lunar outbound; 2) train crews for symptoms of hypoxia, to allow early recognition and consider pre-adaptation of crews to a hypoxic environment prior to launch, 3) consider prophylactic acetazolamide for acute pressure changes and be prepared to treat any AMS associated symptoms early with both carbonic anhydrase inhibitors and supplemental oxygen.



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Constellation Vehicles***

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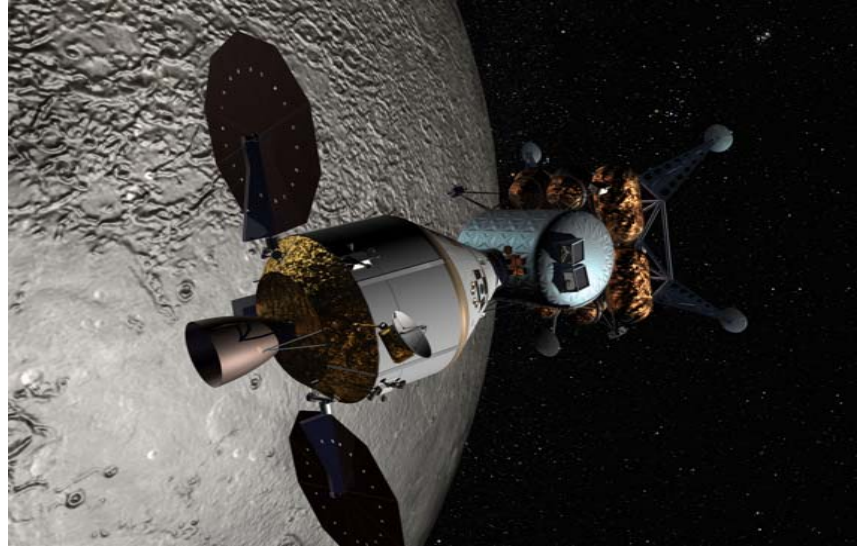
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## Acknowledgements

- ◆ **Johnny Conkin, PhD,  
Jeff Jones, MD, Mike  
Gernhardt, PhD**





## **Background**

### ◆ **Atmosphere Design Considerations:**

- Limit Hypoxia.
- Reduce Risk of Fire
- Prevent Decompression Sickness (DCS) and Venous Gas Emboli (VGE).
- Optimization of atmosphere(s) design to allow safe and efficient EVAs.

### ◆ **Risks addressed:**

- Mitigate risk of significant hypoxia.
- Mitigate / eliminate risk of serious DCS and VGE during EVA.
  - Better to prevent rather than treat DCS, or to constantly embolize the lung.

### ◆ **Underlying Assumptions:**

- Efficient and frequent EVAs drive the exploration initiative.
- Low pressure suit is always preferred to high pressure suit.
- There is an operational value to a short in-suit prebreathe.
- Vehicle atmosphere may not prevent risk of DCS during EVA.
  - Shuttle and ISS atmospheres are examples.
- Dedicated hyperbaric treatment capability may not be present.

## ***Historical Spacecraft Atmospheres*** *(From Lange, et al, 2005)*

<b>Program</b>	<b>Cabin Pressure, kPa (psia)</b>	<b>Cabin Oxygen Concentration, volume %</b>	<b>EVA Suit Pressure,<sup>(1)</sup> kPa (psia)</b>	<b>EVA O<sub>2</sub> Pre-breathe Time, minutes</b>	<b>EVA Prebreathe Conditions</b>
Mercury	34.5 (5)	100	-	-	-
Gemini/Apollo	34.5 (5)	100	25.8 (3.75)	0	-
Skylab	34.5 (5)	70	25.8 (3.75)	0	-
Shuttle	70.3 (10.2)	26.5	29.6 (4.3)	40	In-suit (after 36 hours at 70.3 kPa)
	101.3 (14.7)	21	29.6 (4.3)	240 <sup>(3)</sup>	In-suit
ISS/US	101.3 (14.7)	21	29.6 (4.3)	120-140	Mask and in-suit; staged w/exercise
				240 <sup>(3)</sup>	In-suit
Salyut, Mir, ISS/Russian	101.3 (14.7)	21	40.0 (5.8) <sup>(2)</sup>	30	In-suit

References: Carson, et al. (1975), McBarron, et al. (1993), Waligora, et al. (1993), NASA (2002), NASA (2003).

(1) 100% oxygen.

(2) In earlier versions of the Orlan suit, the pressure could be reduced to 26.5 kPa (3.8 psia) for short-duration work regime.

(3) Under emergency conditions, a minimum of 150 minutes of unbroken prebreathe is recommended.



# Future Spacecraft Atmospheres

Environment	P <sub>B</sub> psia mmHg		F <sub>I</sub> O <sub>2</sub> (%)	P <sub>I</sub> O <sub>2</sub> mmHg	P <sub>A</sub> O <sub>2</sub> mmHg	Actual Altitude m feet		Equivalent Air Altitude m feet	
	<u>CEV + LSAM</u>								
normal	8.0	414	32.0	117	77	4,877	16,000	1,829	6,000
<b>best case</b>	<b>8.2</b>	<b>424</b>	<b>34.0</b>	<b>128</b>	<b>86</b>	<b>4,816</b>	<b>15,800</b>	<b>1,158</b>	<b>3,800</b>
<b>worse case</b>	<b>7.8</b>	<b>403</b>	<b>30.0</b>	<b>107</b>	<b>68</b>	<b>5,029</b>	<b>16,500</b>	<b>2,438</b>	<b>8,000</b>
<u>HABITAT</u>									
normal	7.6	393	32.0	111	71	5,182	17,000	2,286	7,500
<b>best case</b>	<b>7.8</b>	<b>403</b>	<b>34.0</b>	<b>121</b>	<b>80</b>	<b>5,029</b>	<b>16,500</b>	<b>1,524</b>	<b>5,000</b>
<b>worse case</b>	<b>7.4</b>	<b>383</b>	<b>30.0</b>	<b>101</b>	<b>63</b>	<b>5,364</b>	<b>17,600</b>	<b>2,895</b>	<b>9,500</b>

P<sub>I</sub>O<sub>2</sub> is inspired O<sub>2</sub> partial pressure, computed as (P<sub>B</sub> mmHg – 47) \* F<sub>I</sub>O<sub>2</sub> (as decimal fraction).

PAO<sub>2</sub> is computed acute alveolar oxygen partial pressure from alveolar oxygen equation.



# Summary of Recommendations for Constellation Mission Systems

Vehicle	Nominal Total Pressure ( psia +/- 0.2 psia ) <sup>4</sup>	Nominal Oxygen Partial Pressure (mmHg) <sup>4</sup>	Nominal Oxygen Concentration ( % +/- 2.0 % ) <sup>4</sup>	Range of Total Pressure Capability (psia) <sup>1</sup>	Tissue Ratio ( R ) After 60 Minutes Prebreathing <sup>3</sup>
CEV to ISS	14.7 10.2 <sup>5</sup>	160 ( 0 ft ) 140 (3500 ft)	21 26.5	0-14.9	
CEV In-Space Suit	4.3	222	100	4.0-4.6	1.55 from 10.2 psia CEV to 4.3 psia suit
Lunar and Mars CEV	14.7 10.2	160 ( 0 ft ) 140 (3500 ft)	21 26.5	0-14.9	
Lunar and Mars Landers	10.2 8.0	140 (3500 ft) 132 (5000 ft)	26.5 32	0-14.9	
Lunar and Mars Surface Suits	4.3 6.0	222 310	100 100	3.5-8.0 <sup>2</sup>	1.13 from 8.0 psia Landers to 4.3 psia suit; 1.07 from 7.6 psia Surface Habitats to 4.3 psia suit
Lunar and Mars Surface Habitats	8.0 7.6	132 (5000 ft) 126 (6500 ft)	32 32	0-14.9	
Mars Transit	14.7 10.2	160 ( 0 ft ) 140 (3500 ft)	21 26.5	0-14.9	

**Note 1:** Range of total pressure capability covers Earth launch, Earth entry, and contingencies.

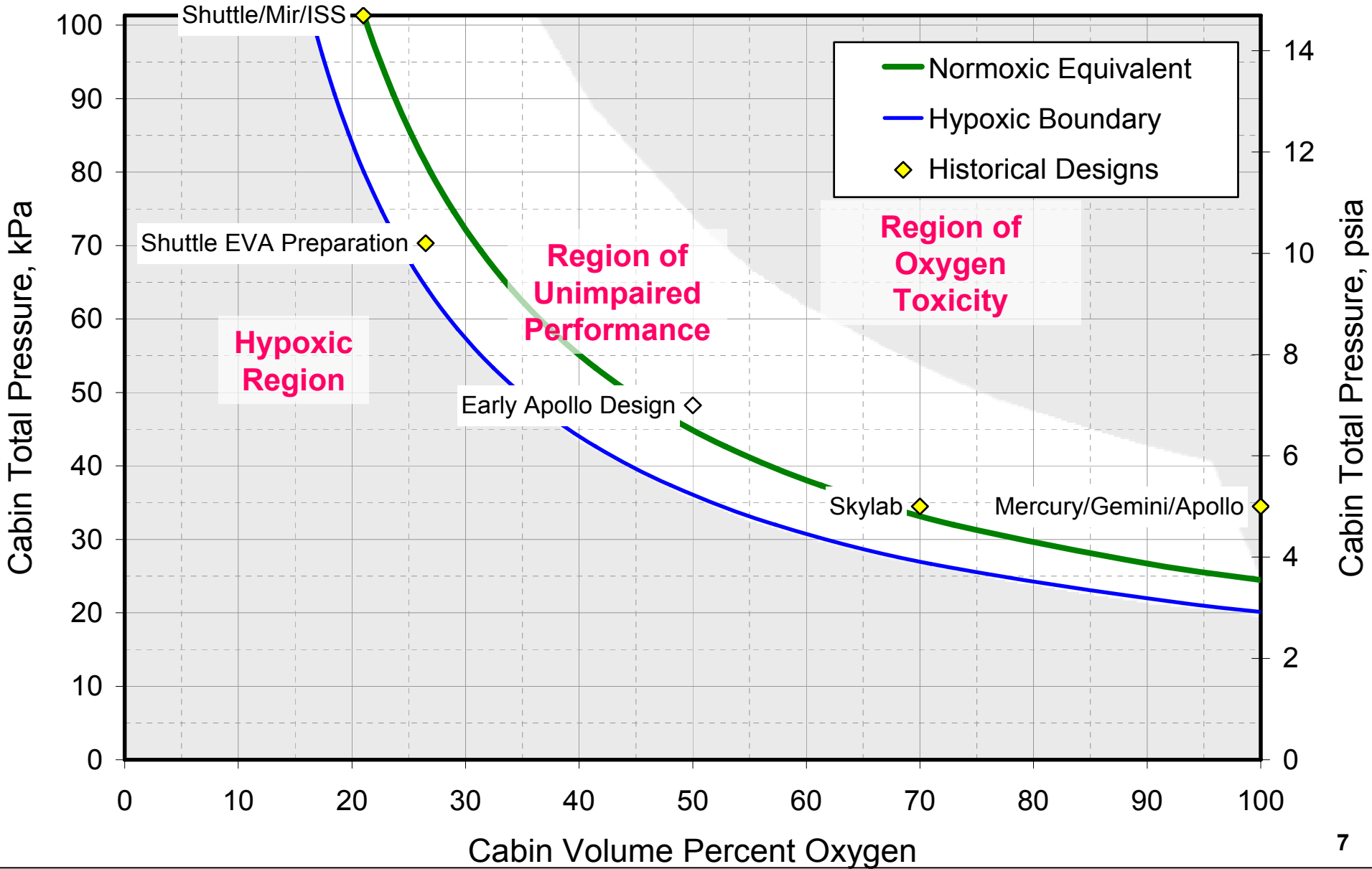
**Note 2:** Surface suit 3.5 psia capability for suit emergency operations, 8.0 psia for DCS treatment.

**Note 3:** 60 minute in-suit prebreathe is defined as the time in the suit after purge and leak check until absolute pressure on the body reaches 4.3 psia after a nominal depressurization. Nitrogen is assumed diluent gas<sup>6</sup>

**Note 4:** All nominal values are centers of control boxes assumed +/-0.2 psia total pressure, +/-2% oxygen.

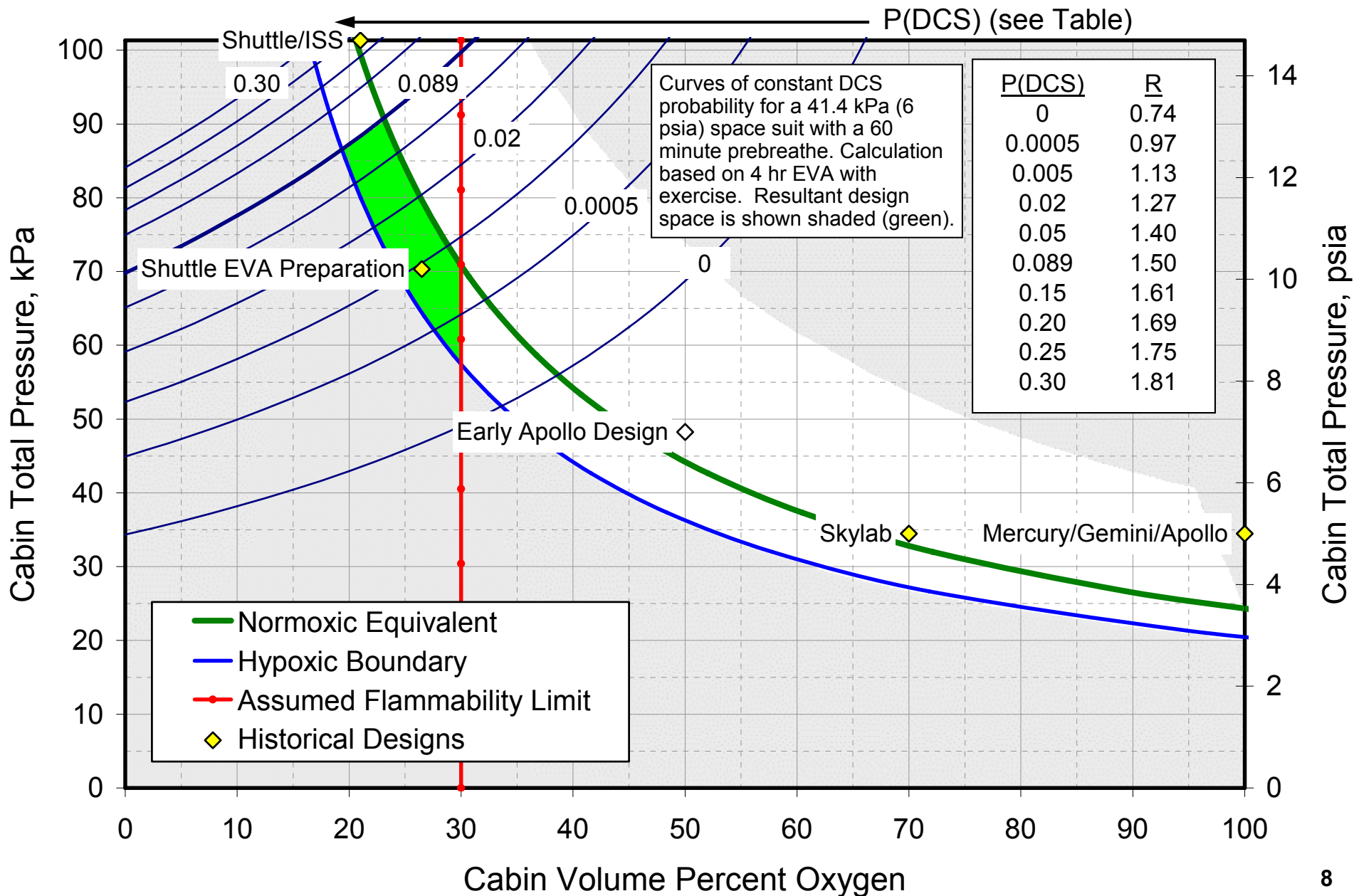
**Note 5:** 10.2 psia recommendation is based on Shuttle experience, for CEV contingency EVA preparation.

# NASA Spacecraft Atmosphere Design Space

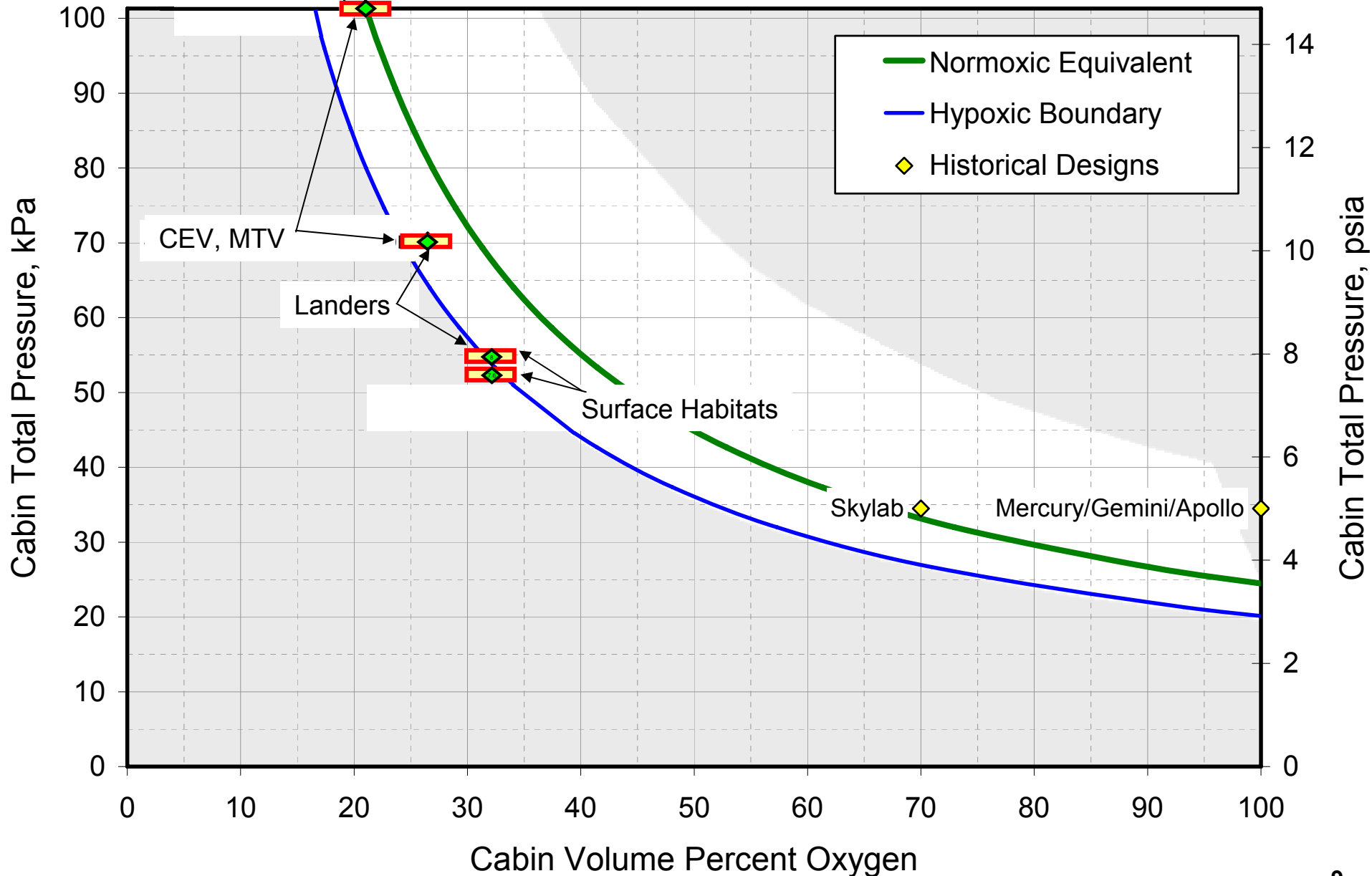




# NASA Spacecraft Atmosphere Design Space



# Current EAWG Recommended Constellation Atmospheres





## ***Background and Rationale for Atmosphere Recommendations***

### ▪ **Hypoxia:**

- Aviation experience:
  - Commercial airline cabins up to 8000 ft without supplemental oxygen
  - Military operations up to 10000 ft without supplemental oxygen
- Space experience:
  - All previous NASA programs were at 6000 ft or lower
  - ISS excursions per Flight Rule with time duration limits
- US Air Force research:
  - Recently reported Brooks data show 8000 feet has minimal cognitive effect

### ▪ **Decompression sickness:**

- Space experience: no reported in-flight DCS for Shuttle/ISS (Apollo ascent report by one crewmember).
- Much zero-g experience, but little in hypogravity environments
- NASA ground testing shows higher DCS incidence than zero-g
- Expect that lunar gravity ambulation will have significantly higher risk than zero-g

### ▪ **Flammability:**

- Space experience: Apollo, Mir, Shuttle fire events
  - Apollo-1: catastrophic outcome
  - Mir-22 and Shuttle: non-catastrophic (materials usage controls, larger vehicles, much lower oxygen concentrations)
- Flammability threshold testing will give better materials characterization versus current pass/fail<sup>10</sup> testing (NASA STD-6001 standard test). Characterization of pyrolysis products is also needed. 10



- ◆ **Ascent causes a decrease in  $P_aO_2$  sensed by the peripheral and central chemoreceptors, leading to increased rate of pulmonary ventilation ( $V_E$ ).**
- ◆ **Hyperventilation in response to hypoxia increases  $P_AO_2$  and subsequently decreases alveolar carbon dioxide ( $P_ACO_2$ ) and leads to a transient alkalosis.**
- ◆ **There is also a hypoxia-induced diuresis as the kidney attempts to return to a balanced pH with the excretion of bicarbonate.**



Altitude		Pressure		Ambient	$P_{A_{O_2}}$	$P_{A_{CO_2}}$	$P_{H_2O}$	Respiratory
(m)	(ft)	(PSIA)	(mm Hg)	$P_{O_2}$ (mm Hg)	(mm Hg)	(mm Hg)	(mm Hg)	Exchange Ratio (R)
<b>Breathing Air</b>								
0	0	14.69	759.97	159.21	103.0	40.0	47.0	0.85
305	1000	14.17	733.04	153.57	98.2	39.4	—	—
610	2000	13.66	706.63	148.04	93.8	39.0	—	—
914	3000	13.17	681.23	142.72	89.5	38.4	—	—
1219	4000	12.69	656.34	137.50	85.1	38.0	—	—
1524	5000	12.23	632.46	132.50	81.0	37.4	47.0	0.87
1829	6000	11.77	609.09	127.60	76.8	37.0	—	—
2134	7000	11.34	586.49	122.87	72.8	36.4	—	—
2438	8000	10.91	564.64	118.29	68.9	36.0	—	—
2743	9000	10.50	543.31	113.82	65.0	35.4	—	—
3048	10,000	10.10	522.73	109.51	61.2	35.0	47.0	0.90
3353	11,000	9.72	502.92	105.36	57.8	34.4	—	—
3658	12,000	9.34	483.36	101.26	54.3	33.8	—	—
3962	13,000	8.99	464.82	97.38	51.0	33.2	—	—
4267	14,000	8.63	446.53	93.55	47.9	32.6	—	—
4572	15,000	8.29	429.01	89.88	45.0	32.0	47.0	0.95
4877	16,000	7.96	411.99	86.31	42.0	31.4	—	—
5182	17,000	7.65	395.73	84.50	40.0	31.0	—	—
5486	18,000	7.34	379.73	79.55	37.8	30.4	—	—
5791	19,000	7.05	364.49	76.36	35.9	30.0	—	—
6096	20,000	6.76	349.50	73.22	34.3	29.4	47.0	1.00
6401	21,000	6.48	335.28	70.24	33.5	29.0	—	—
6706	22,000	6.21	321.31	67.31	32.8	28.4	47.0	1.05
7010	23,000	5.95	307.85	64.49	32.0	28.0	—	—
7315	24,000	5.70	294.89	61.78	31.2	27.4	—	—
7620	25,000	5.46	282.45	59.17	30.4	27.0	47.0	—
<b>Breathing 100% Oxygen*</b>								
10,058	33,000	3.81	197.10	197.10	109	40	47.0	—
10,973	36,000	3.30	170.94	170.94	85	38	47.0	—
11,887	39,000	2.86	148.08	148.08	64	36	47.0	—
12,192	40,000	2.73	141.22	141.22	—	—	—	—
12,802	42,000	2.48	128.27	128.27	48	33	47.0	—
13,716	45,000	2.15	111.25	111.25	34	30	47.0	—
14,021	46,000	2.05	105.92	105.92	30	29	47.0	—



- ◆ **Increased catecholamines**
  - ↑HR
  - ↑CO
  - ↑Venous Tone
- ◆ **↓ Plasma Volume**
- ◆ **↓ Stroke Volume**
- ◆ **Transient ↑ in Pulmonary artery pressure**
- ◆ **↑ Hgb / HCT, viscosity**
- ◆ **Shift of O<sub>2</sub> / HgB curve to left**
- ◆ **cellular changes**



## *The Spectrum Of Hypoxia*

- ◆ **There is some confusion and overlap among the high altitude syndromes.**
- ◆ **A sudden ascent to high altitude can result in a rapid death from Acute Hypoxia while a more gradual ascent to the same altitude can result in AMS or no symptoms at all.**
- ◆ **Symptoms of AMS generally take a longer period of time to develop (hrs-days) and there is great variability among the population of those who are susceptible.**
- ◆ **Severe and prolonged forms of AMS may lead to High Altitude Pulmonary Edema (HAPE) and High Altitude Cerebral Edema (HACE) and death.**



- ◆ **Based on this committee's recommendations:**
  - A diagnosis of AMS is based on a recent gain in altitude, at least several hours (>2) at the new altitude, and the presence of headache and at least one of the following symptoms: gastrointestinal upset, fatigue or weakness, dizziness or lightheadedness and difficulty sleeping.
- ◆ **A score of three points or greater on the AMS Self-Report questionnaire alone or in combination with the clinical assessment score is diagnostic of AMS.**





# Self Report questionnaire

•Each question asked and the sum is calculated as the AMS self report score

<b>1. Headache</b>	<b>0</b>	<b>No headache</b>
	<b>1</b>	<b>Mild Headache</b>
	<b>2</b>	<b>Moderate Headache</b>
	<b>3</b>	<b>Severe Headache, incapacitating</b>
<b>2. Gastrointestinal Symptoms</b>	<b>0</b>	<b>No gastrointestinal symptoms</b>
	<b>1</b>	<b>Poor appetite or nausea</b>
	<b>2</b>	<b>Moderate nausea or vomiting</b>
	<b>3</b>	<b>Severe nausea &amp; vomiting, incapacitating</b>
<b>Fatigue and/or Weakness</b>	<b>0</b>	<b>Not tired or weak</b>
	<b>1</b>	<b>Mild fatigue/weakness</b>
	<b>2</b>	<b>Moderate fatigue/weakness</b>
	<b>3</b>	<b>Severe fatigue/weaknes, incapacitating</b>
<b>Dizziness/lightheadedness</b>	<b>0</b>	<b>Not Dizzy</b>
	<b>1</b>	<b>Mild dizziness</b>
	<b>2</b>	<b>Moderate dizziness</b>
	<b>3</b>	<b>Severe dizziness, incapacitating</b>
<b>Difficulty sleeping</b>	<b>0</b>	<b>Slept as well as usual</b>
	<b>1</b>	<b>Did not sleep as well as usual</b>
	<b>2</b>	<b>Woke many times, poor night's sleep</b>
	<b>3</b>	<b>Could not sleep at all</b>



## Clinical Assessment

The interviewers ratings of three signs:

Added to the self-report score (Roach 1993)

<b>6. Change in Mental Status</b>	<b>0</b>	<b>No Change in Mental Status</b>
	<b>1</b>	<b>Lethargy/lassitude</b>
	<b>2</b>	<b>Disoriented/confused</b>
	<b>3</b>	<b>Stupor/semiconsciousness</b>
	<b>4</b>	<b>Coma</b>
<b>7. Ataxia (heel to toe walking)</b>	<b>0</b>	<b>No Ataxia</b>
	<b>1</b>	<b>Maneuvers to maintain balance</b>
	<b>2</b>	<b>Steps off line</b>
	<b>3</b>	<b>Falls down</b>
	<b>4</b>	<b>Can't stand</b>
<b>8. Peripheral Edema</b>	<b>0</b>	<b>No peripheral edema</b>
	<b>1</b>	<b>Peripheral edema at one location</b>
	<b>2</b>	<b>Peripheral edema at two or more locations</b>

This system helped to standardize the diagnosis of AMS.



- ◆ **Despite over a century of research there remains a vigorous debate on the etiology and pathophysiology of AMS.**



## Paul Bert (1833-1886)

- ◆ A French Physiologist considered the founder of Aerospace Medicine.
- ◆ Demonstrated, that the symptoms of AMS could be prevented or relieved by oxygen breathing and so “Proved” that it was the decrease in partial pressure of oxygen & subsequent hypoxia at high altitude, that caused AMS.
- ◆ This doctrine that hypoxia alone is the cause for AMS has held true for 150 years.



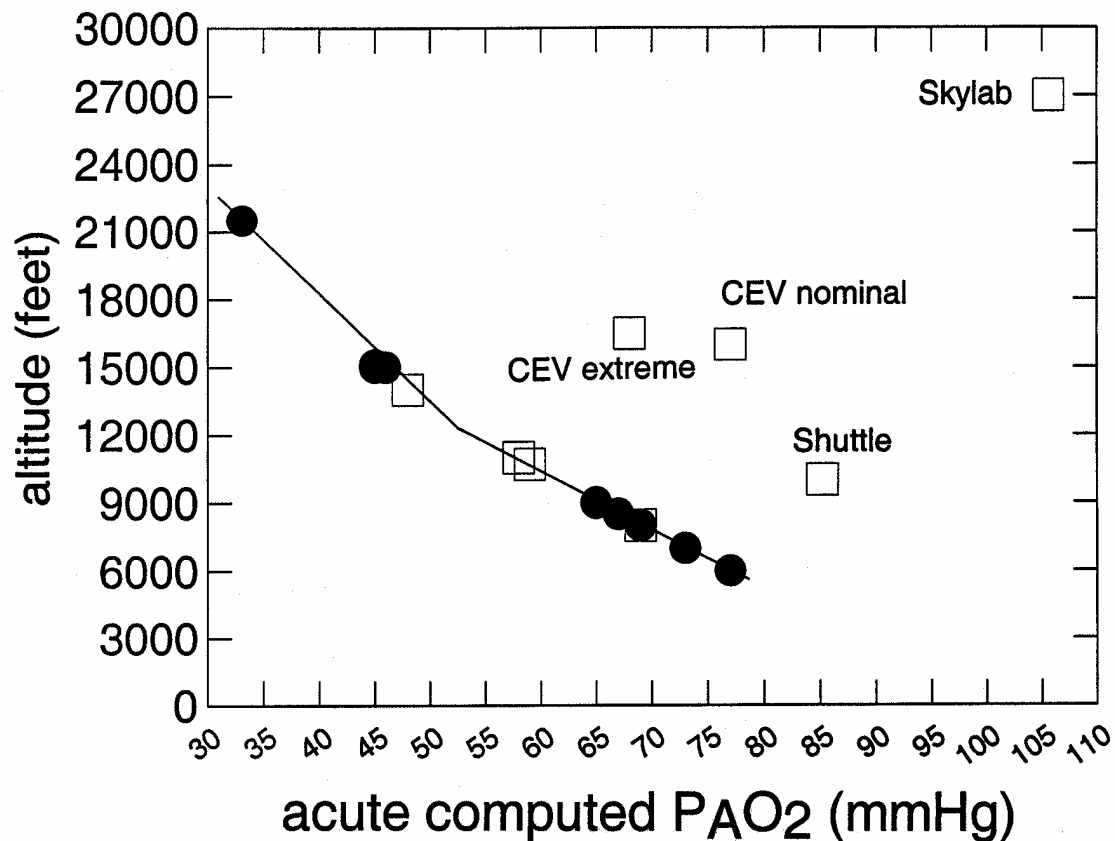


**But over the last thirty years, a new group of researchers have begun to question the conventional wisdom that the symptoms of AMS are solely due to hypoxia.**



**“the diminution of barometric pressure acts upon the living beings only by lowering the oxygen tension in the air, in the breath, and in the blood which supplies their tissues.... The increase in barometric pressure acts only by increasing oxygen tension in the air and blood....” Paul Bert, 1878.**

- ◆ **Consequently, maintaining sea level equivalent partial pressures of O<sub>2</sub> at any and all altitudes we “assume” no signs and symptoms of AMS should be seen.**



Solid circles connected by the curve are studies done where HH was induced by ascent to altitude on air, but are HH exposures without simulated  $\mu\text{G}$ . The open boxes are exposures where  $\mu\text{G}$  adaptation through simulation or actual exposure is present as part of the HH. The two least stressful points along the curve at 6,000 and 7,000 feet are from Ge (2002) where he shows a slight increase in plasma EP concentration. The third point at 8,000 feet from Ge (2002) is within the open box from Waligora (1982).



## Variable Pressure with Supposedly Equivalent Normoxia

<u>A</u>	<u>B</u>	<u>C</u>
21% O <sub>2</sub> @ 760mmHg	31% O <sub>2</sub> @ 523 mmHg	49% O <sub>2</sub> @ 349mmHg
Sea Level	10,000 ft	20,000 ft
P <sub>A</sub> O <sub>2</sub> = 104 mmHg	P <sub>A</sub> O <sub>2</sub> = 103 mmHg	P <sub>A</sub> O <sub>2</sub> = 104 mmHg

Equivalent normoxic air altitudes: A= B = C

no AMS is expected?

## Variable Pressure with Supposedly Equivalent Hypoxia

<u>A</u>	<u>B</u>	<u>C</u>
14% O <sub>2</sub> @ 760mmHg	21% O <sub>2</sub> @ 523 mmHg	32.5% O <sub>2</sub> @ 349mmHg
Sea Level	10,000 ft	20,000 ft
P <sub>A</sub> O <sub>2</sub> = 61 mmHg	P <sub>A</sub> O <sub>2</sub> = 61 mmHg	P <sub>A</sub> O <sub>2</sub> = 61 mmHg

Equivalent hypoxic altitudes: A = B = C

all equal time-course and incidence of AMS symptoms?



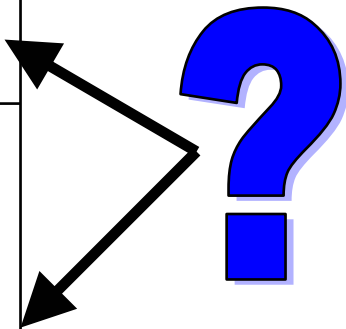
◆ **Evaluate multiple hypotheses of cardiopulmonary changes associated with AMS.**

	<b>Normoxic, <math>P_{A}O_2 = 103</math> mmHg</b>	<b>Hypoxic, <math>P_{A}O_2 &lt; 103</math> mmHg</b>
<b>Normobaric, <math>P_B = 760</math> mmHg</b>	<p>Altitude 1520  <math>P_{A}O_2 = 77</math>                      No AMS symptoms</p>	<p>Altitude 1520 m  <math>P_{A}O_2 = 47.1</math>                      Mean AMS Score: 3.2</p>
<b>Hypobaric  <math>P_B &lt; 760</math> mmHg</b>		<p>Altitude 4570 m  <math>P_B = 430</math> mmHg  <math>P_{A}O_2 = 45</math>                      Mean AMS Score: 6.75</p>

\*\* Environmental Symptoms Questionnaire (ESQ)

◆ Document the effect of hypobaria on the pathophysiology of AMS.

	Normoxic, $P_{A}O_2 = 103$ mmHg	Hypoxic, $P_{A}O_2 < 103$ mmHg
Normobaric, $P_B = 760$ mmHg	Altitude 1520 m $P_{A}O_2 = 76$ No AMS symptoms	Altitude 1520 m $P_{A}O_2 = 47.1$ Mean AMS Score: 2.0
Hypobaric $P_B < 760$ mmHg	Altitude 4570 m $P_{A}O_2 = 74.5$ Mean AMS score: 0.4	Altitude 4570 m $P_{A}O_2 = 46$ Mean AMS Score: 3.7



“we found that simulated altitude induces AMS to a greater extent than either normobaric hypoxia or normoxic hypobaria, although normobaric hypoxia induced some AMS.”

\*Lake Louise scoring system



## *The Pressure Effect!*

- ◆ **There are few other direct studies on the incidence of AMS in normal versus hypobaric hypoxia.**
- ◆ **Additional research has attempted to define the physiological differences that can be directly related to barometric pressure alone.**
- ◆ **Many of these have left us with more questions than answers.**

- ◆ **A variety of explanations have been proposed for AMS and the effect of barometric pressure.**





## *Hypobaric Hypoxia versus Normobaric Hypoxia*

- ◆ **Decreased gas density relative to 1 ATA**
- ◆ **Decreased quantity of gas in solution relative to 1 ATA**
- ◆ **Increased insensible water loss relative to 1 ATA**
- ◆ **Transient N<sub>2</sub> gradient out of tissues**
- ◆ **Potential for VGE**
- ◆ **Gas density at 1 ATA**
- ◆ **Gas in solution at 1 ATA**
- ◆ **Insensible water loss at 1 ATA**
- ◆ **Transient N<sub>2</sub> gradient into tissues**
- ◆ **No potential for VGE**



- ◆ **NASA's past habitats and vehicles rarely exposed the astronaut to hypobaric and hypoxic conditions.**
- ◆ **Staged decompression protocols taking many hours to days with very high O<sub>2</sub> levels were used in the past.**
- ◆ **Likelihood of AMS almost nil.**



- ◆ **Specifies the development of human missions to Earth's moon, Mars and beyond.**
- ◆ **In order to accomplish this task NASA will be required to build an array of vehicles including interplanetary spacecraft, planetary landers, space suits, rovers and surface habitats.**





- ◆ **Due to the technical, financial and mission operational constraints, the most likely atmospheres of this constellation of habitats, vehicles, suits and rovers will likely be well below standard pressure ( $P_B$ ).**
- ◆ **Future moon and mars missions with CEV, LSAM and lunar habitat amongst other issues will require efficient EVA egress with minimal prebreathe time while still avoiding DCS and venous gas emboli (VGE).**
- ◆ **This combination of hypobaria with a concomitant hypoxia simulates the conditions encountered by high altitude climbers.**







**SO.....**

**Are we putting future astronauts at an increased risk for AMS and all it's associated symptoms?**



## ***Incidence Of AMS***

- ◆ **The incidence of AMS as reported in the literature is highly variable.**
- ◆ **Most agree that some people may show mild AMS symptoms as low as 1,981-2,438m (6,500-8,000 ft).**
- ◆ **One report claims that as much as 25% of people may be affected with quick ascent to 1,891m, with 90% of symptoms resolving in 3 – 4 days.**
- ◆ **Houston C.S. claims that 25-30% of people ascending to 3,048m (10,000 ft) will experience some type of AMS, this figure will double at 4,200m and almost all people will show some signs of AMS by 5,486m (18,000 ft).**
- ◆ **Roach et al 1998 that a small percentage, 5% of people who develop AMS at 3,962m (13,000 ft) will go on to develop life threatening HAPE and/or HACE.**



## *What Happens If Future Astronauts Develop AMS?*

- ◆ **Based on extrapolation of current research it does not seem likely that one may experience severe AMS.**
- ◆ **The bigger issue is likely Performance.**
- ◆ **The bigger issue is a mitigation plan.**





- ◆ **Will the performance of future astronauts be effected?**
- ◆ **Can we still maintain a quick egress for EVA while safely balancing engineering, mission control, DCS, and AMS with minimal prebreathe times?**
- ◆ **What minimum  $P_A O_2$  can we maintain to satisfy all the above?**



- ◆ There have been almost no direct studies on the effect of AMS on performance.
- ◆ Montgomery in 1989 stated that the incidence of AMS at 1,981m (6,500 ft) was approximately 12% and further stated that 50% of these subjects took medication for relief of symptoms.
- ◆ He did not go as far as to quantify a decrease in effective performance during this study.



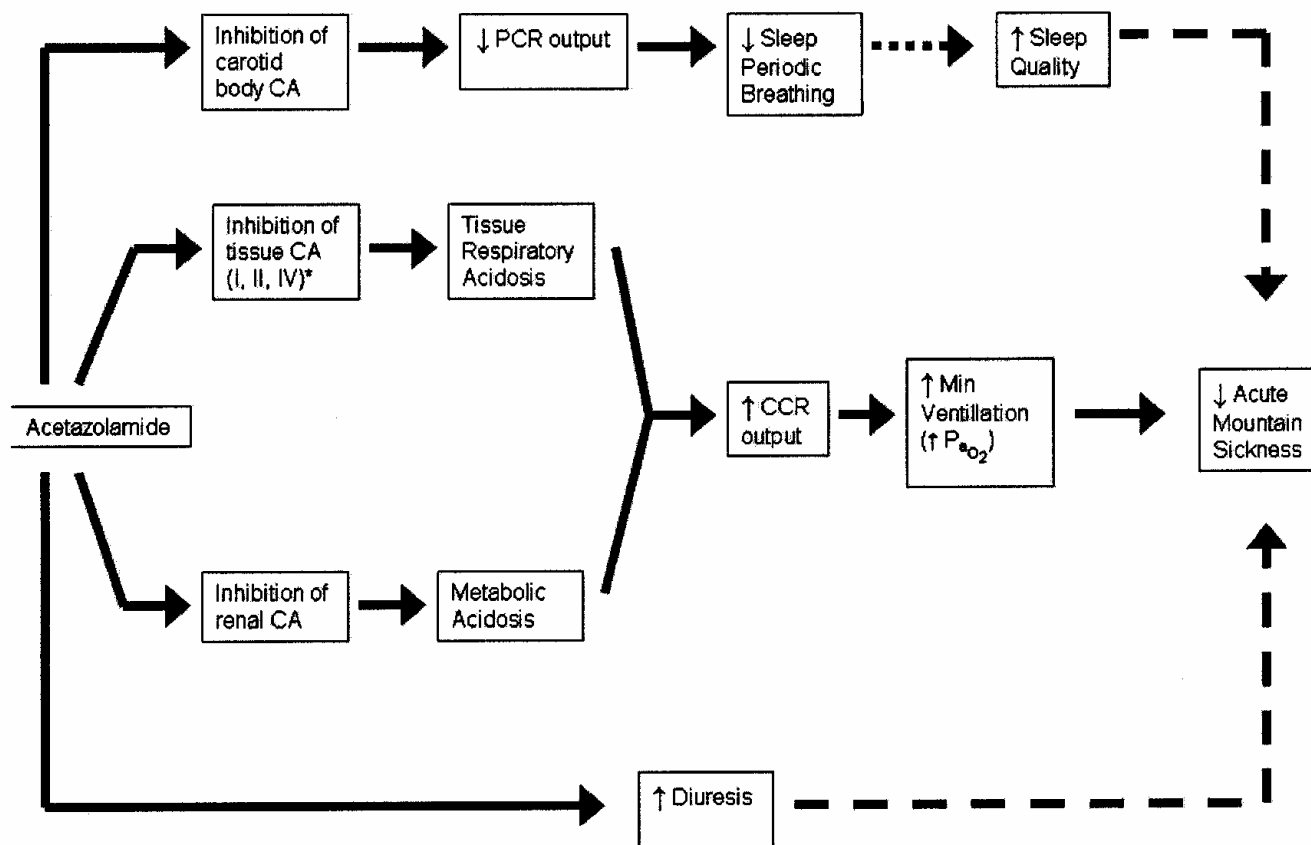
- ◆ **If it is determined that AMS is an acceptable risk for future space flight, a plan of treatment must be established.**
  
- ◆ **Mild AMS is treated by:**
  - Halting ascent
  - Await acclimatization
  - Acetazolamide (125-250 mg BID)
  - O<sub>2</sub> therapy; .05-1.0 l/min mask or cannula:



- ◆ The best predictor of AMS is history of prior episode
- ◆ Acetazolamide has proven effective for AMS prophylaxis
- ◆ Roach et al. 1998 showed “development of AMS was significantly and negatively correlated with  $S_aO_2\%$ ” ....  
“subjects with  $S_aO_2\%$  above 84% appear immune to developing AMS at the altitudes tested.”



# Actions of acetazolamide



**Figure 5.** Proposed model for acetazolamide's reduction of AMS. Solid lines represent well-established connections; broken lines represent less-well established connections. \*CA I and II are located intracellularly in RBCs and tissues; CA IV is located on the luminal aspect of nearly all capillary beds. PCR=Peripheral Chemoreceptor; CCR=Central Chemoreceptor.





- ◆ **Potential negative synergy between mild hypoxia and adaptation to mG.**
- ◆ **Does mG change the incidence of AMS?**
  - redistribution of lung fluid
  - increased interstitial edema
  - altered incidence of HAPE?



# Optimum HCT for O<sub>2</sub> transport

## Relationship between haematocrit and blood viscosity

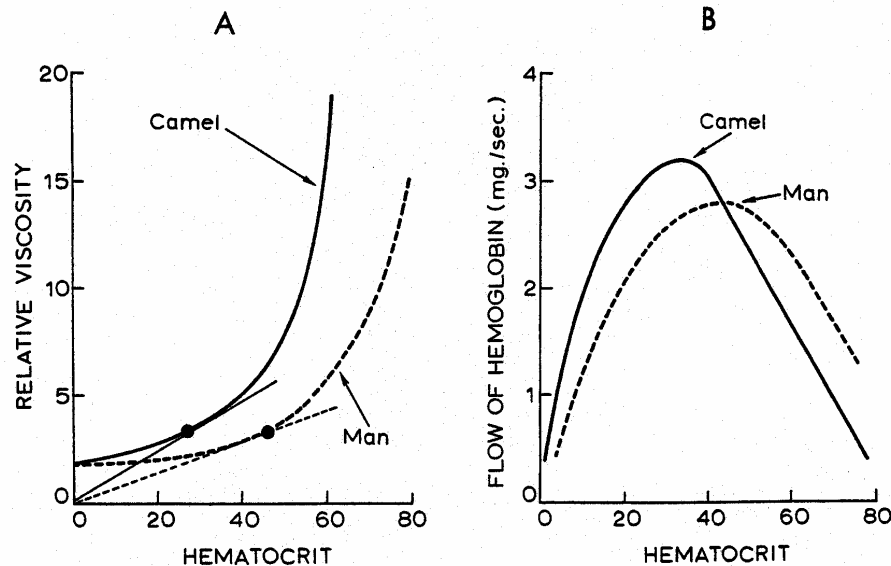
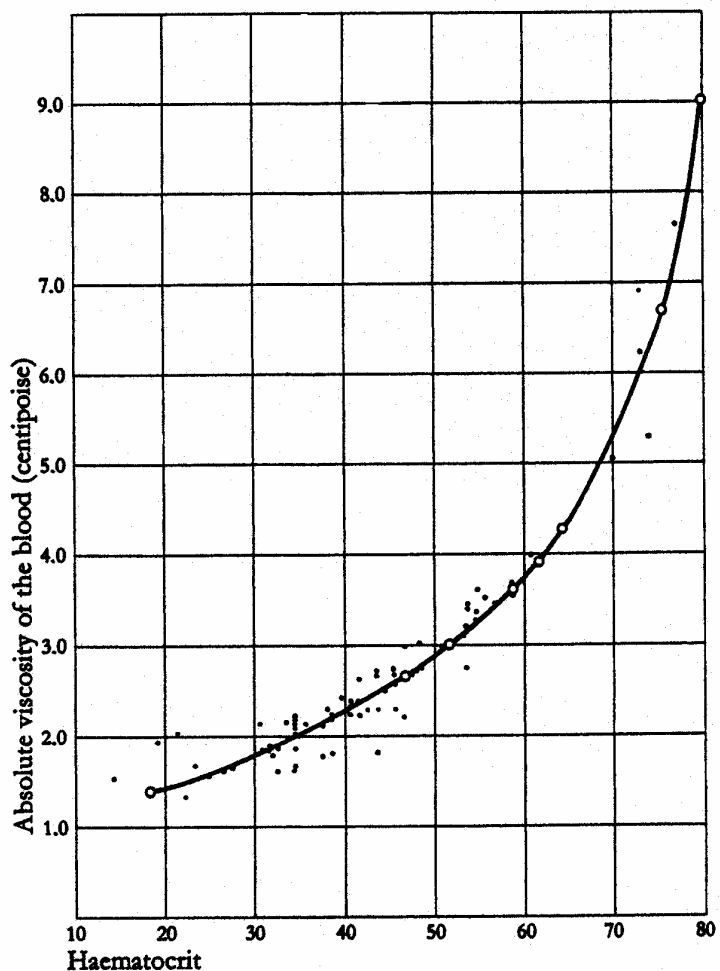


Fig. 5-5.—**A**, relative viscosity vs hematocrit for human blood and camel blood. **B**, the transport of oxygen through a glass tube vs hematocrit, with a constant driving pressure.



- ◆ **Unique experiments duplicating the atmospheres and conditions for the proposed CEV, LSAM, Habitats and EVA suits.**
- ◆ **Determine who may be at risk for developing AMS and it's effects on that individual.**
- ◆ **Current knowledge does not allow us to predict those that are at risk for AMS, the best predictor is previous episodes.**
- ◆ **Do we select future astronauts based on criteria to reduce the risk?**



# Thank You

