16.423PRESENTATION

Conceptual Design of a Countermeasure for Intermittent Altitude-Induced Hypoxia

MAY 6, 2015

MORRIS VANEGAS • ALEXANDRA HILBERT • CEILI BURDHIMO • CONNIE LIU • KATHRINE BRETL

PROBLEM STATEMENT

- University of Tokyo Atacama Observatory (TAO) to be built in next couple years
- Located on summit of Cerro Chajnantor - altitude of 5,640 m (18,500 ft)
- Base camp at San Pedro - 2,400 m (7,900 ft)
- Continuous travel over 10,000 ft of elevation difference => intermittent hypoxia

How can scientists and workers live and work at the TAO site without experiencing large adverse health effects at the high altitude and when they readjust to life at the base camp?

HYPOXIAINCHILE

Background

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Hypoxia - decrease in amount of oxygen available to cells and tissues of the body

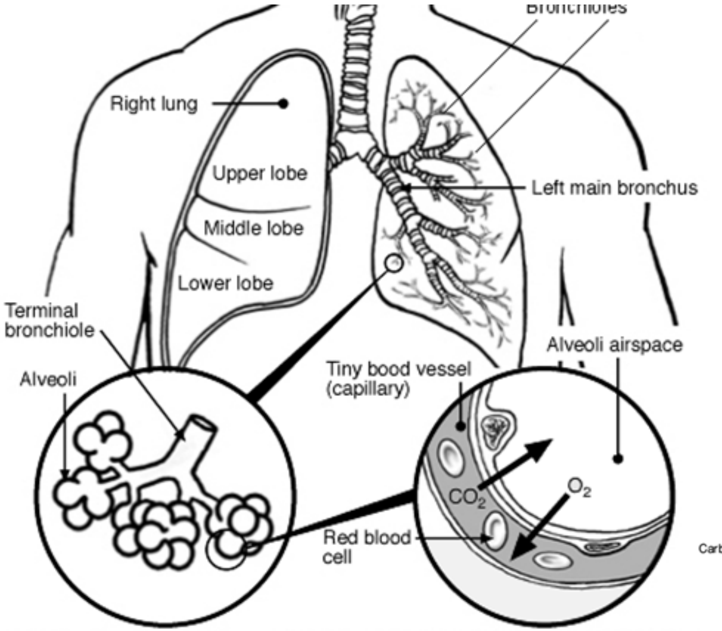
low inspired oxygen at high altitude (hypobaric hypoxia)

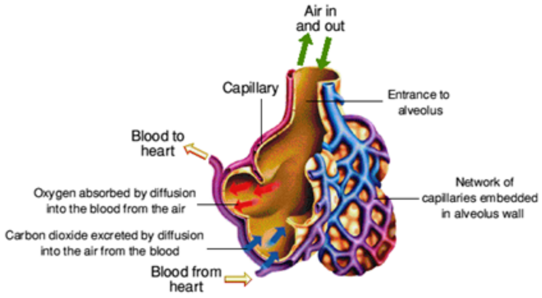
⇩

decreased oxygen in the blood (hypoxemia)

⇩

decreased oxygen in cells & tissues





(Image Sources: patient.co.uk, mcqueens.net)

HIGH ALTITUDE HYPOXIA

Sea Level

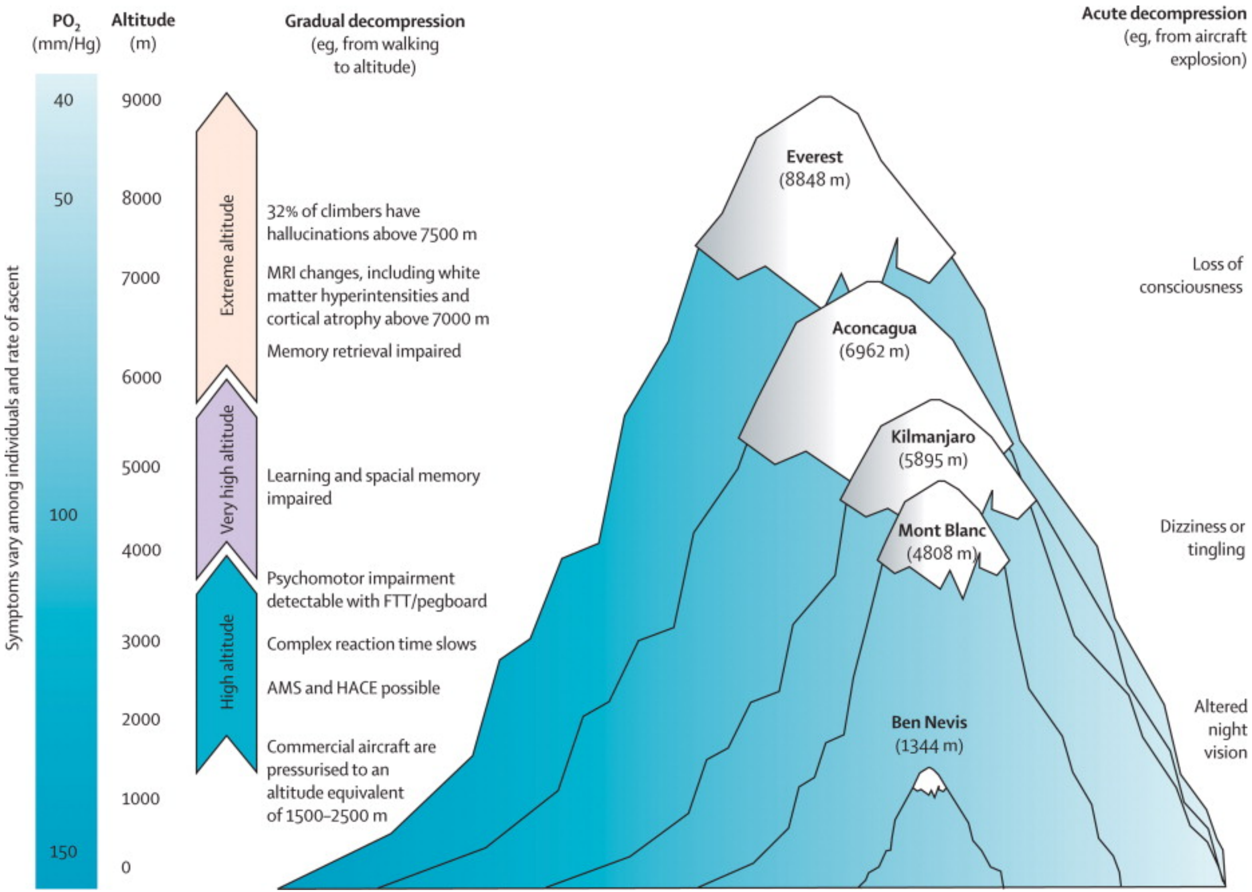
- Total barometric pressure = 760 mmHg
- Partial pressure of oxygen = 21%
- Partial pressure of arterial oxygen (PaO2) = (760 - 47) x 0.21 = 150 mmHg

Future Observatory Site – 5640 m

- Total barometric pressure = 375 mmHg
- Partial pressure of oxygen = 21%
- Partial pressure of arterial oxygen (PaO2) = (375 - 47) x 0.21 = 69 mmHg

→ ***Less than half of the typical amount!***

HIGH ALTITUDE HYPOXIA



(Image Source: pharmaceuticalintelligence.com)

PHYSIOLOGIC EFFECTS

Physical

- Hyperventilation
- Decreased VO2 max
- Increased fatigue
- Increased heart rate, blood pressure, cardiac output

Acute Mountain Sickness

- Headache
- Lightheadedness
- Breathlessness
- Fatigue
- Insomnia
- Nausea

Mental

- Increased arithmetic errors
- Reduced attention span
- Increased mental fatigue
- Impaired decision making
- Altered short term memory
- Lower productivity
- Mood changes

Sleep

- Periodic breathing and apnea
- Frequent waking, not feeling well-rested, unpleasant dreams

(Image Source: C. Behn)

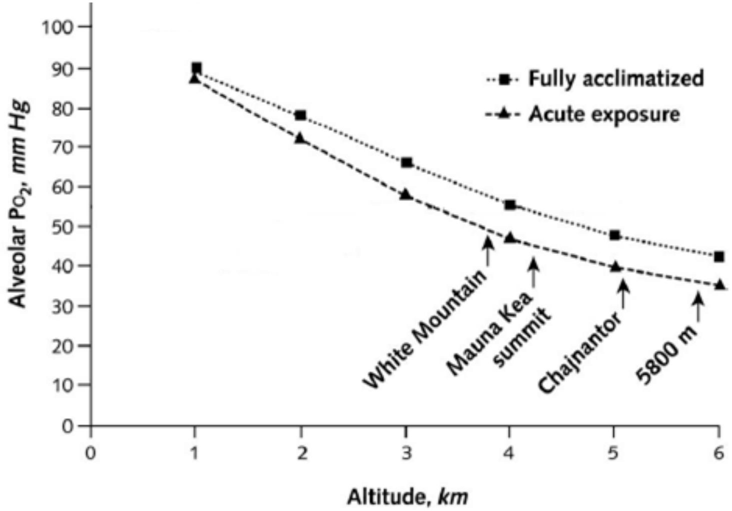
- **Acclimatization** - adaptive physiologic responses that increase oxygen delivery
  - Hyperventilation
  - Increased heart rate → increased cardiac output
  - Increased hemoglobin → increased oxygen carrying capacity of the blood

→ ***Body is able to adapt to the environment!***

BUT

Intermittent nature of the exposure makes acclimatization take years instead of months

(Richalet et al., 2002; Jimenez, 2003; Farias et al., 2012)



(Image Adapted from J. West, 2004)

ADDRESSING ALTITUDE-INDUCED INTERMITTENT HYPOXIA

Countermeasures

Address oxygen levels

- Breathe 100% oxygen

Address hypobaria

- Descent to lower altitude
- Hyperbaric Gamow bag
- Habitat to simulate lower altitude

(Image Source: iwls.com)

Previous Literature

Acclimatization

- Several studies monitoring physiologic parameters found similar adaptations (physical and mental) to chronic hypoxia (Antezana 2003, Richalet 2002, Brito 2007, Leon-Velarde 2010, etc.)

- Monitoring arterial oxygen saturation and heart rate at high site (Sakamoto 2006)

Effects of ascent and descent

- Rapid transitions may lead to arrhythmias, especially in younger workers (Behn 2014)

Telescopes/antennas need to be at high altitudes

- thinner atmosphere
- drier
- less light pollution

+

Frequent travel between telescope and base camp increases exposure to intermittent hypoxia

- fatigue, insomnia, stress, dangerous work environment
- heart rhythm alterations during descent

+

Individual susceptibility to hypoxia is difficult to screen for or predict

Proposed Solution - A habitat that maintains higher barometric pressure, thereby decreasing the frequency of exposure to intermittent hypoxia

- Must still be able to enter and exit to perform field work
- Must still monitor health of crew

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Habitat Design

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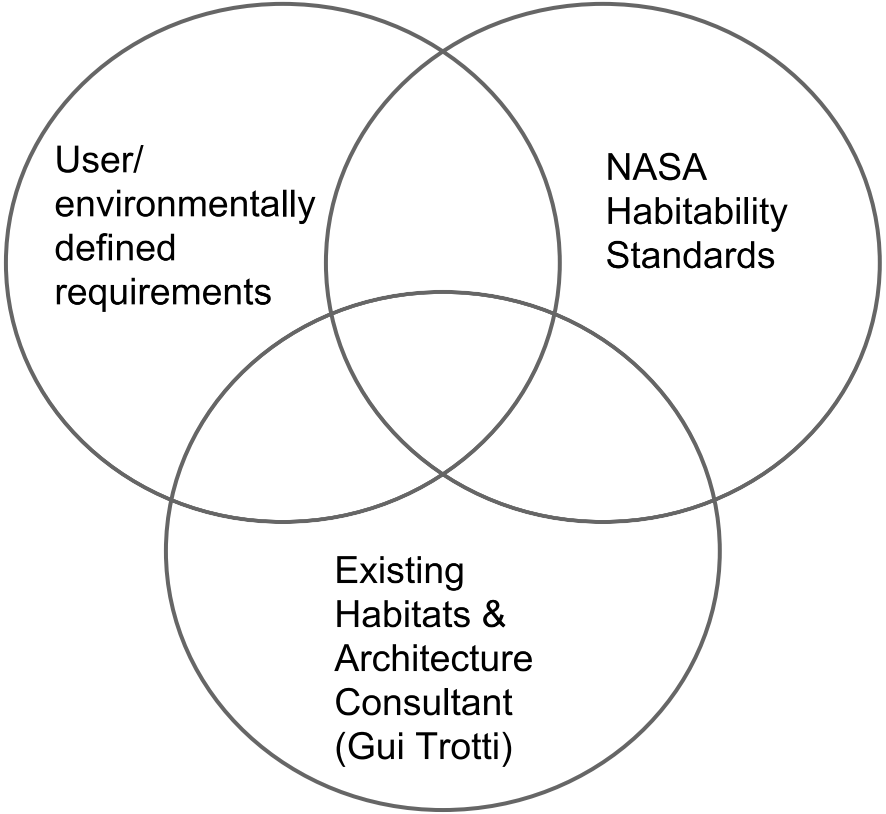
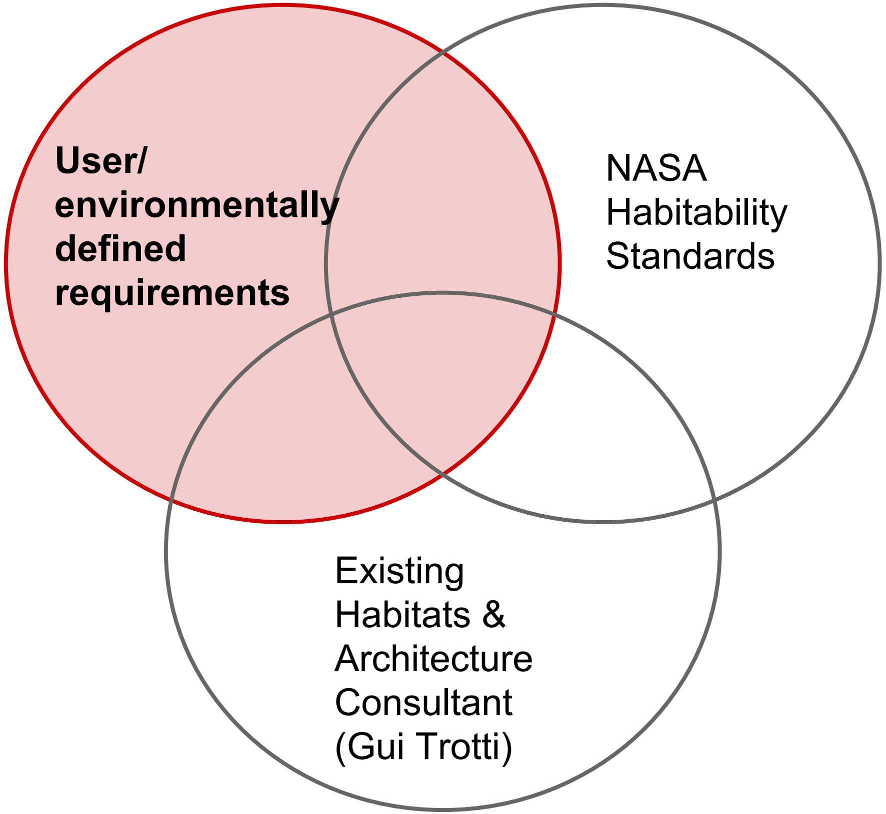
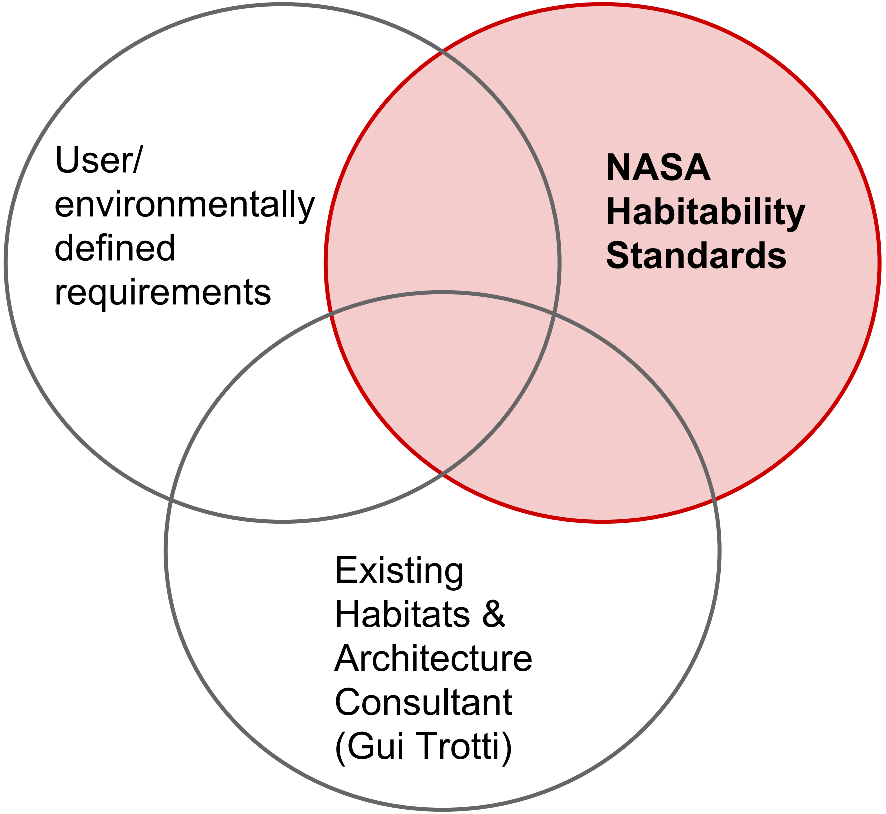

User/ environmentally defined requirements
NASA Habitability Standards
Existing Habitats & Architecture Consultant (Gui Trotti)



- Maintain 850 millibar (Equivalent to San Pedro de Atacama)
- 5 people in the habitat (with ability to expand to 15)
- 3 < number of days < 14
- 2 hour commutes up to summit from San Pedro on 4 person 4x4 jeeps
- Ability to go in and out of habitat (5x in and out per person)
- Must be removable (cannot damage terrain)
- Radio must be in ~60 Mhz range to avoid frequency pollution



NASA Life Support Baseline Values and Assumptions Document
NASA Human Integration Design handbook

Top-Level Design Variables
- # people, # days, total volume,

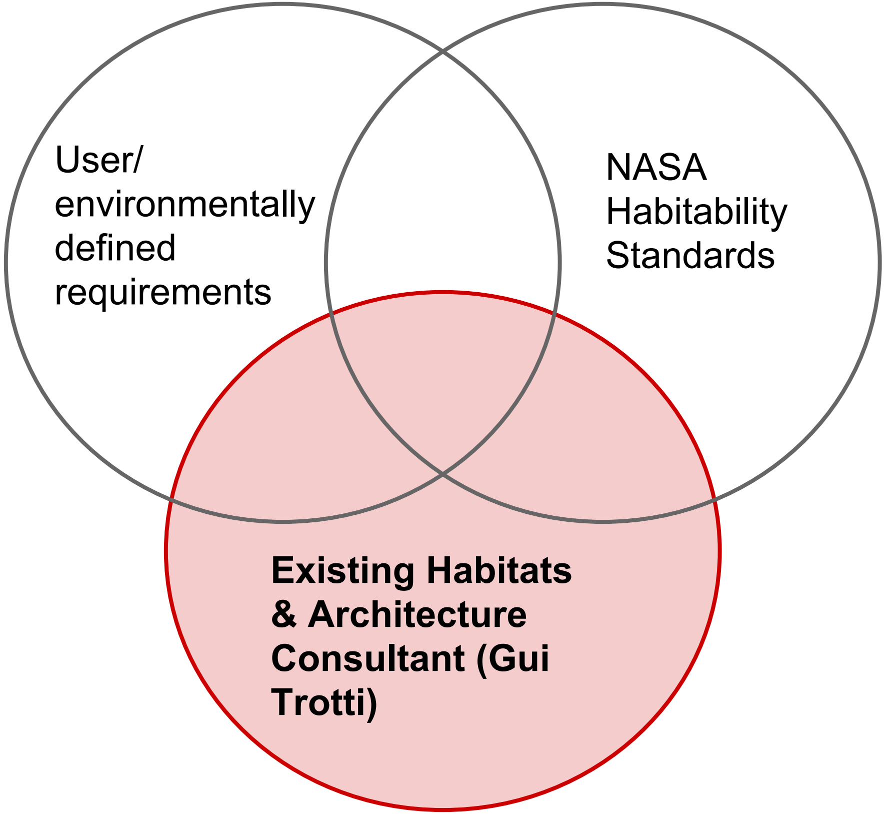
Concept of Operations
- Transporting habitat, “EVA” time, sleep time

Human consumption and production
- Food, Water, Air, Waste

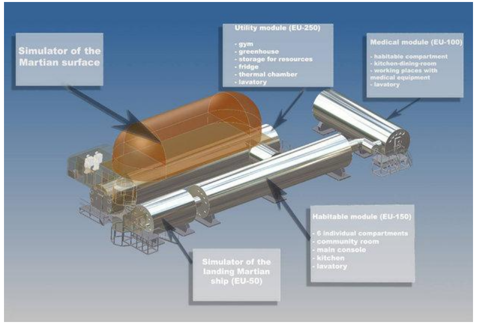
\+ **Safety Limits**
- CO2, O2, Temp, ...

Derived ECLSS requirements
- O2 (consumption, to fill hab), CO2 scrubbing, H2O vapor scrubbing, H2O consumed, Food Energy, Heat Production, ...

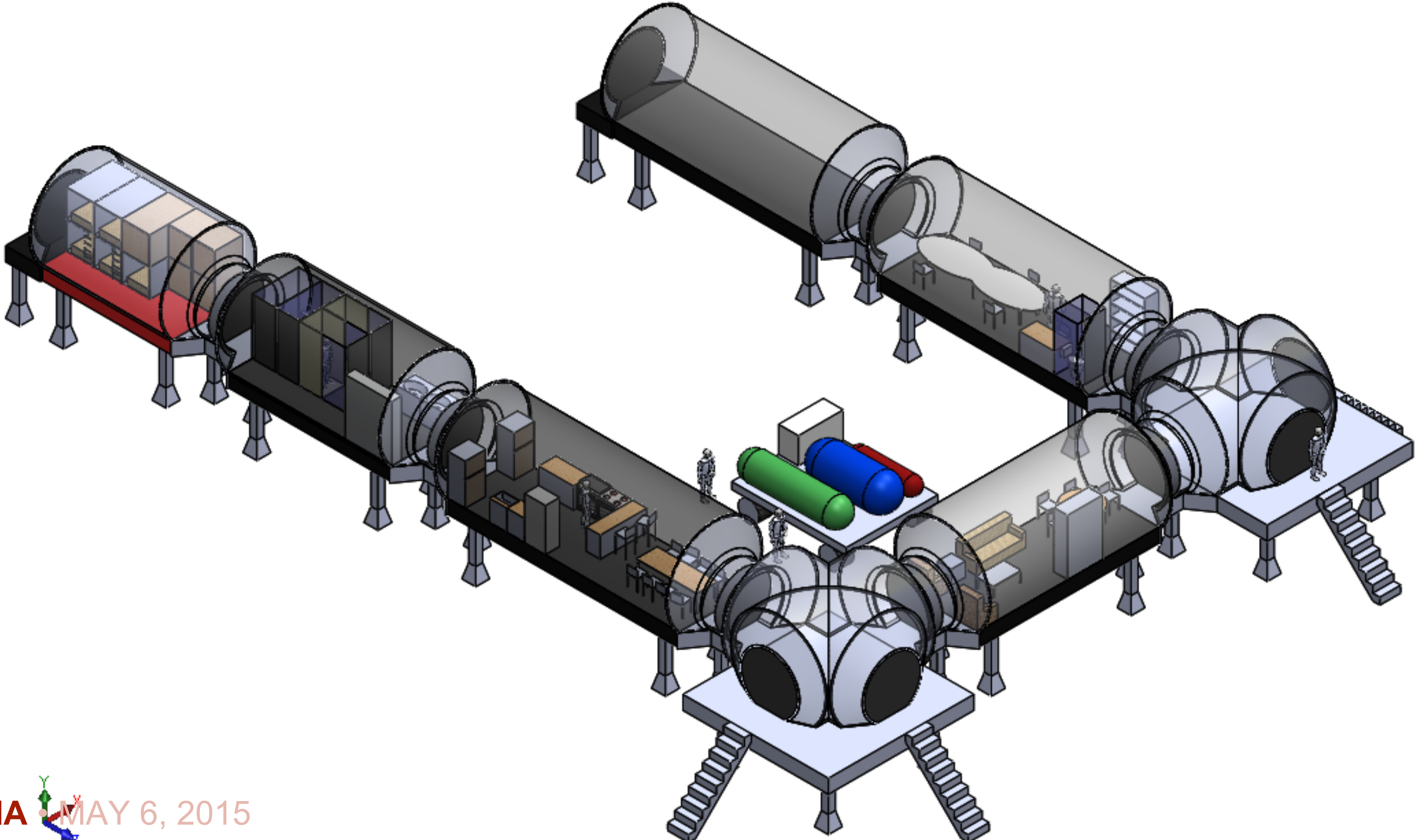
HABITAT DESIGN



- Literature Review of existing habitats
  - HI-SEAS
  - Mars 500
- Comparison of types of pressurized habitats
  - Inflatables, Hard Shells, Ribbed
  - Material selection
  - Modularity

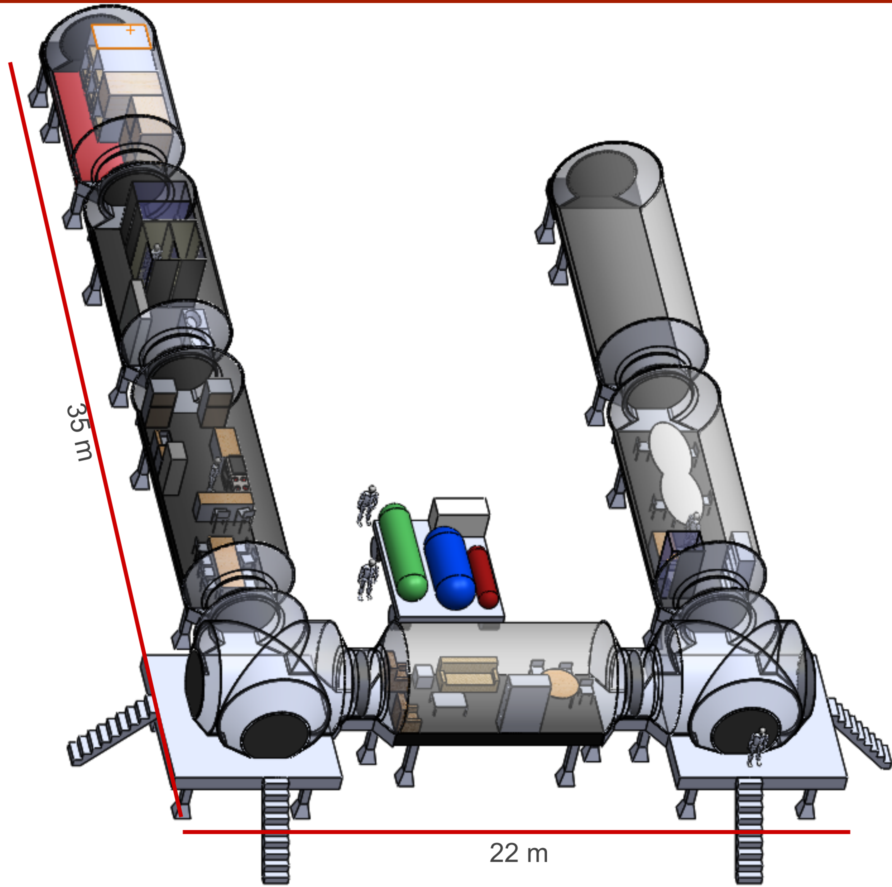


(Image Sources: mars500.imbp.ru, wikipedia.org)



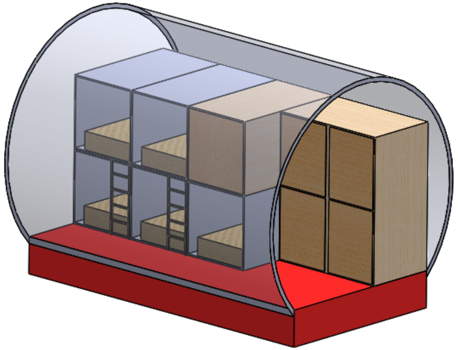
INFLATABLE HABITAT OVERVIEW

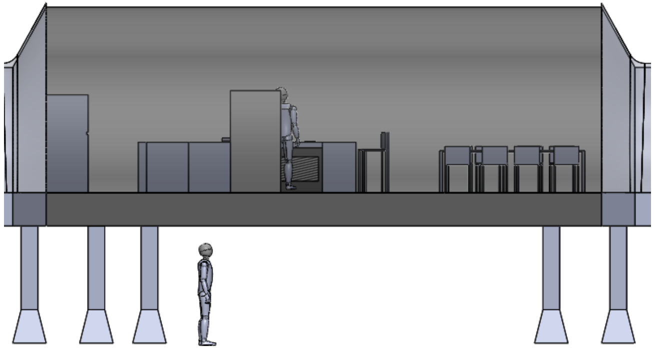
- Sizing
  - 922 m^3 total habitat volume
  - 3.048 m (12ft) wide floors (4.064 m at max)
  - < 13.5 (44 ft) length for transport
- Modules independently operated
  - Expandability
  - Machine shop, workout, etc.
- “Connection” platforms connect modules
  - Isolate emergencies
- Centralized ECLSS
  - Maintenance
  - Replaceability
- Raised platform
  - Weather (snow)
  - Removable habitat
- Habitation
  - Storage, Consumables for crew of 5, 6 days

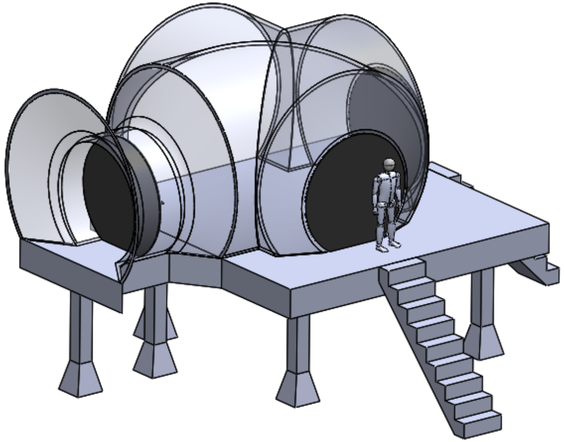


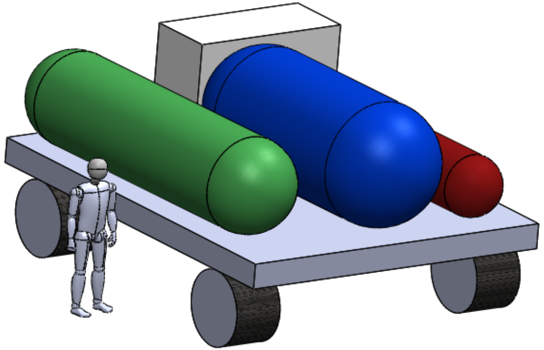
ARCHITECTURAL FEATURES

- Airlocks
  - Dual entry separates work modules from habitation modules
  - Minimal loss in total pressure
- ECLSS trailer
  - Air, Water, Waste tanks
- Japanese “Bedrooms”
  - Private, individual, ECLSS controlled sleeping quarters
- Raised platforms with embedded emergency system
- Reconfigurable layout









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"EVA" Design

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EVA REQUIREMENTS

“Extra Vehicular Activity” = work being done outside of the habitat

Goal: Eliminate any intermittent hypoxia effects

Solution: Maintain the same partial pressure of oxygen between the habitat and “EVA” work

Options:

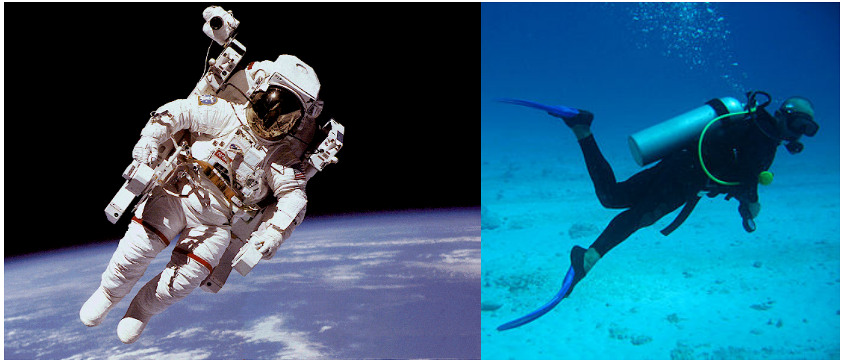
1. Add pressure on the body (spacesuit)
2. Adjust concentration of oxygen (SCUBA)

Considerations:

- Garment must not interfere with work
- Comfortable, easy to don/doff
- Integrate with sensors to monitor vitals

Risks:

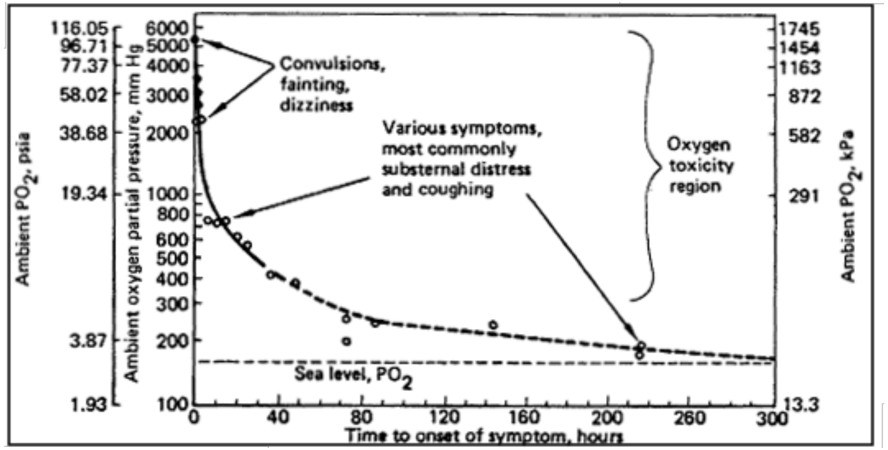
- Decompression Sickness
- Oxygen Toxicity



(Image Sources: er.jsc.nasa.gov/seh/suitnasa.html, wikipedia.org)

EVA REQUIREMENTS

		Breathing Air				Breathing pure oxygen		
	Barometric Pressure (mm Hg)	PO_2 in Air (mm Hg)	PCO_2 in Alveoli (mmHg)	PO_2 in Alveoli (mm Hg)	Arterial Oxygen Saturation (%)	PCO_2 in Alveoli (mm Hg)	PO_2 in Alveoli (mm Hg)	Arterial Oxygen Saturation (%)
0	760	159	40 (40)	104 (104)	97 (97)	40	673	100
10,000	523	110	36 (23)	67 (77)	90 (92)	40	436	100
20,000	349	73	24 (10)	40 (53)	73 (85)	40	262	100
30,000	226	47	24 (7)	18 (30)	24 (38)	40	139	99
40,000	141	29				36	58	84
50,000	87	18				24	16	15



PARTIAL PRESSURE OXYGEN CALCULATION

Alveolar Gas Equation

$$p_AO_2 = F_IO_2(P_{ATM} - pH_2O) - \frac{p_aCO_2(1 - F_IO_2[1 - RER])}{RER}$$

Quantity	Description	Sample value
p_AO_2	The alveolar partial pressure of oxygen (pO_2)	107 mmHg (14.2 kPa)
F_IO_2	The fraction of inspired gas that is oxygen (expressed as a decimal).	0.21
P_{ATM}	The prevailing atmospheric pressure	760 mmHg (101 kPa)
pH_2O	The saturated vapour pressure of water at body temperature and the prevailing atmospheric pressure	47 mmHg (6.25 kPa)
p_aCO_2	The arterial partial pressure of carbon dioxide (pCO_2)	40 mmHg (4.79 kPa)
RER	The respiratory exchange ratio	0.8

Sample Values given for air at sea level at 37°C.

PARTIAL PRESSURE OXYGEN CALCULATION

Our Results - Calculating Fraction of Inspired O_2 to match Habitat and EVA

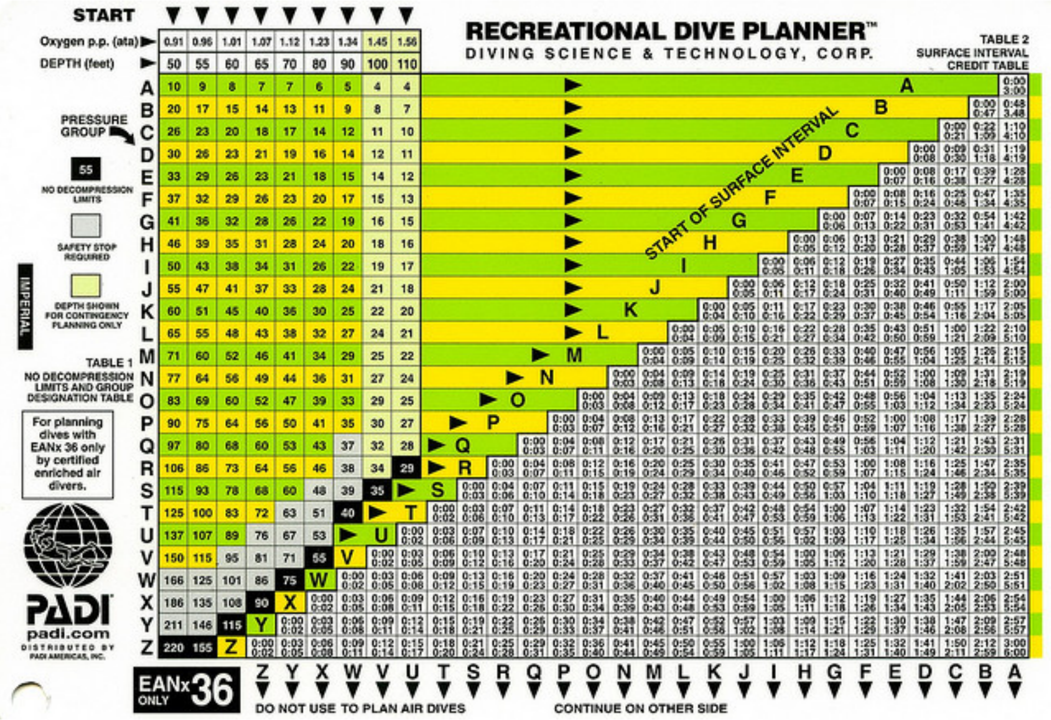
	Fixed	Variables			Constants		
	P_AO_2	F_IO_2	P_{atm}	Extra Pressure on Skin	PH_2O	P_aCO_2	RER
Habitat	101.5	21%	850	0	62.66	53.33	0.8
EVA (No Suit)	101.5	37.3%	500	0	62.66	53.33	0.8
EVA (Suit)	101.5	32%	500	74.8	62.66	53.33	0.8

(Pressures in millibars)

"Suit" would need to apply 74.8 mbars (56.1 mmHg) of pressure.

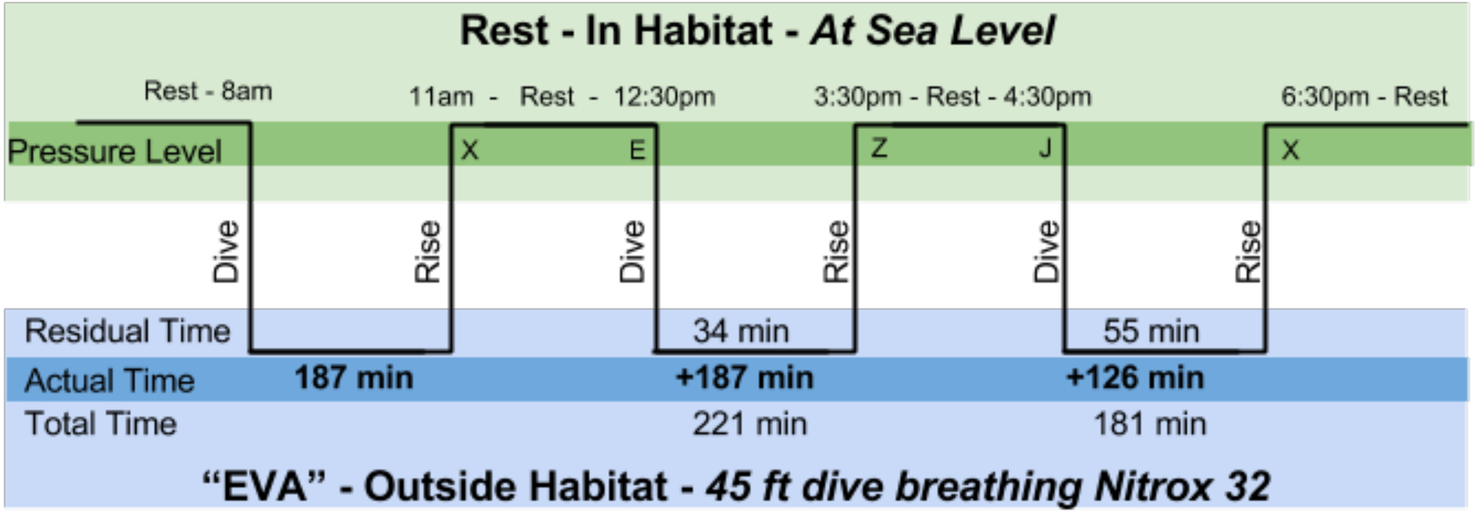
- Balancing risk of decompression sickness (DCS) and oxygen toxicity
- Maintaining alveolar partial pressure oxygen = reduces DCS risk
- Higher concentration of oxygen = increases oxygen toxicity risk
    - below 100% oxygen use = less of a risk

- Use PADI Dive Tables to create a schedule of work and rest
    - Lower risk of DCS
- Model operations as repetitive dives breathing Nitrox 32 or 36 to lowest depths (45-50 ft)
    - Our scenario is a 8.28 ft dive
- Keeps track of residual Nitrogen in the body



Oxygen p.p. (ata)	0.91	0.96	1.01	1.07	1.12	1.23	1.34	1.45	1.56
DEPTH (feet)	50	55	60	65	70	80	90	100	110
A	10	9	8	7	7	6	5	4	4
B	20	17	15	14	13	11	9	8	7
C	26	23	20	18	17	14	12	11	10
D	30	26	23	21	19	16	14	12	11
E	33	29	26	23	21	18	15	14	12
F	37	32	29	26	23	20	17	15	13
G	41	36	32	28	26	22	19	16	15
H	46	39	35	31	28	24	20	18	16
I	50	43	38	34	31	26	22	19	17
J	55	47	41	37	33	28	24	21	18
K	60	51	45	40	36	30	25	22	20
L	65	55	48	43	38	32	27	24	21
M	71	60	52	46	41	34	29	25	22
N	77	64	56	49	44	36	31	27	24
O	83	69	60	52	47	39	33	29	25
P	90	75	64	56	50	41	35	30	27
Q	97	80	68	60	53	43	37	32	28
R	106	86	73	64	56	46	38	34	29
S	115	93	78	68	60	48	39	35	
T	125	100	83	72	63	51	40		
U	137	107	89	76	67	53			
V	150	115	95	81	71	55			
W	166	125	101	86	75				
X	186	135	108	90					
Y	211	146	115						
Z	220	155							

OPERATIONAL SCHEDULE - 32% O_2

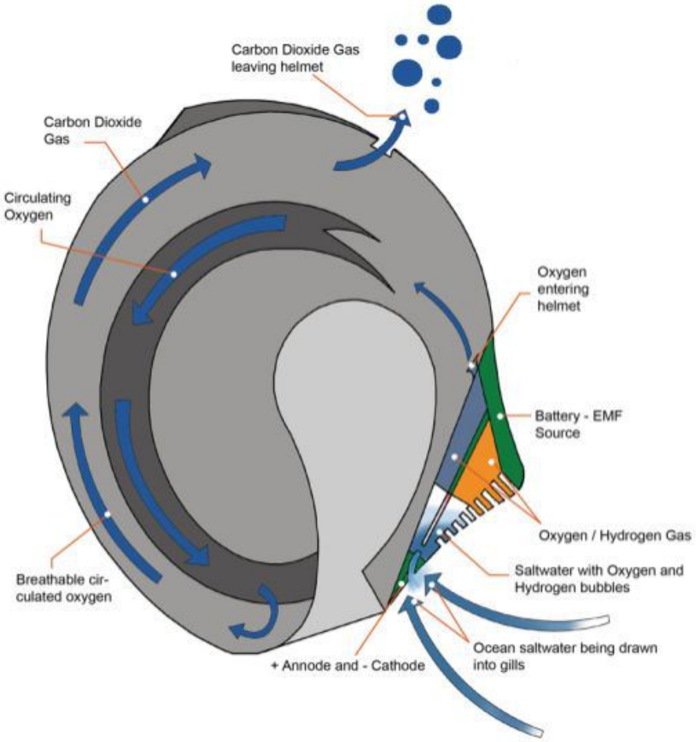


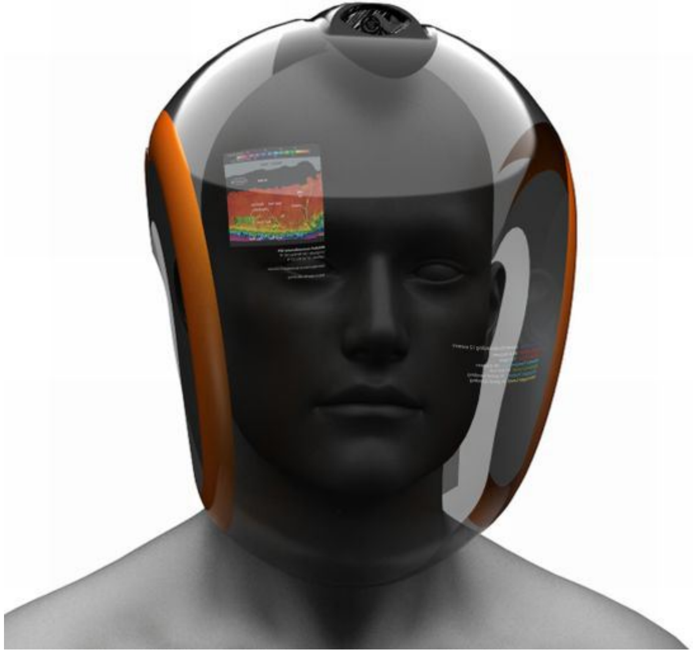
Based on PADI Dive Tables

OPERATIONAL SCHEDULE - 36% O_2

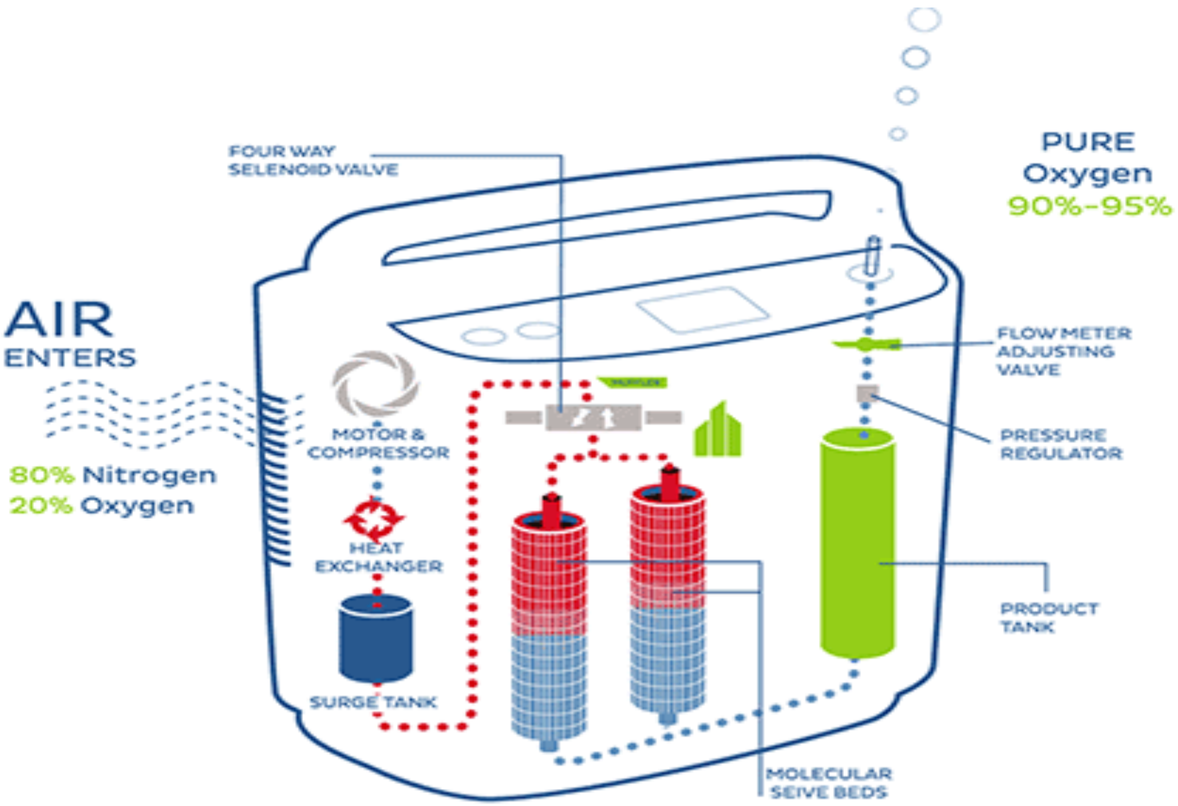
Based on PADI Dive Tables


IMMERSED
SENSES
Immersed Senses is the future of underwater diving and exploration. Immersed Senses changes the way the diver sees, hears, and breathes underwater allowing them to become a part of their surrounding environment.
Adam Wendel 2010

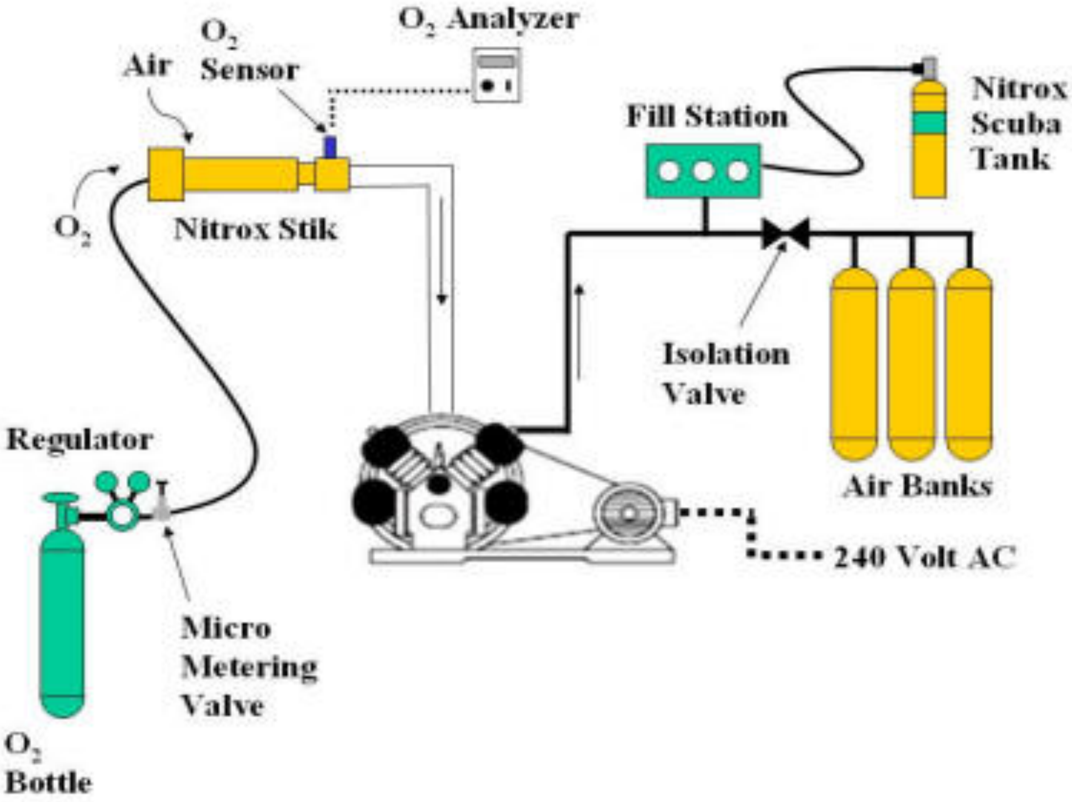

Carbon Dioxide Gas
leaving helmet
Carbon Dioxide
Gas
Circulating
Oxygen
Oxygen
entering
helmet
Battery - EMF
Source
Oxygen / Hydrogen Gas
Saltwater with Oxygen and
Hydrogen bubbles
Breathable cir-
culated oxygen
Ocean saltwater being drawn
into gills
+ Annode and - Cathode



- Concentrates oxygen from ambient air to supply an oxygen enriched gas mixture
- 90-95% pure oxygen is released



CONTINUOUS GAS BLENDING WITH NITROX STIK

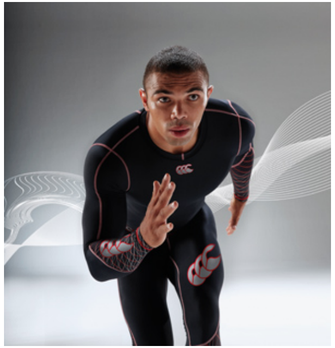


- Uses pure oxygen and patent pending “Stik” to homogeneously mix air and oxygen at the inlet of a high-pressure air compressor
- While compressor is running, throttles oxygen supply until desired oxygen concentration is achieved
- Oxygen analyzer monitoring the outlet of compressor will indicate desired oxygen concentration
- Safely make Nitrox up to 40%

SUIT OVERVIEW

- Suit option will depend on desired enriched oxygen mixture used
- Options:
  - Use 32% oxygen with suit, shorter or no prebreathe in airlock
  - Use 37% oxygen with no suit, possibly a longer prebreathe in airlock
- Looking for anything that can provide 50-65 mmHg to compensate for 37 to 32 percent oxygen composition
- Options:
  - Compression garment like Jobst medical systems
  - CEP compression sleeves
  - Other athletic compression garments

https://bridgerridgerun.files.com/cep.jpg



http://www.innovationintextiles.com/lycra-sport-fabric-in-mercury-compression-line/

http://www.jobst-usa.com/

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Sensor Suite

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DESIRED MEASUREMENTS

Most important measurements based on basic physiological, environmental specific, and hypoxia-specific parameters of interest

- Body core temperature
- Heart rate & heart rate variability
- Blood pressure
- Oxygen saturation
- Carbon dioxide saturation
- Activity intensity

Cosinuss C-SP01

Measures:

- Heart rate
- Heart rate variability
- Core body temperature

Worn like headphones - can easily wear inside helmet

Bluetooth transmission; 2.4 GHz radio frequency

Link: http://www.cosinuss.com/en/sports

ActiCal

Measures:

- Omni-directional acceleration
- Step counts
- Correlates with activity level/energy

Worn on wrist or clipped onto belt

On board memory; 32 Hz sampling rate

Link: ActiCal

Samsung Simband

Measures:

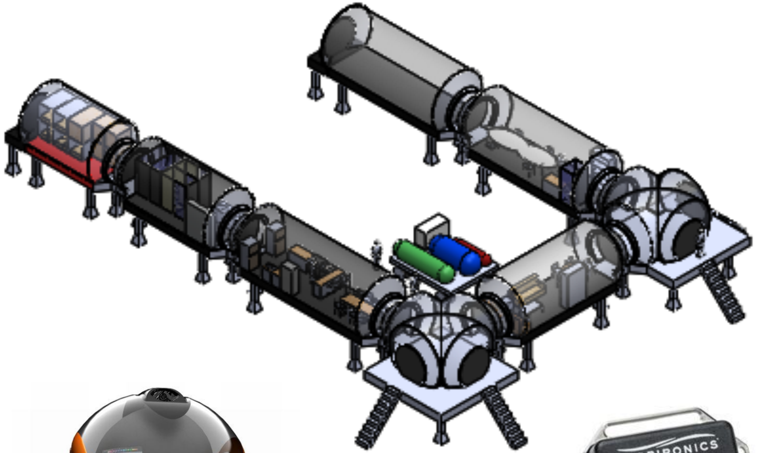
- Heart rate
- Blood pressure
- Blood O2 and CO2 levels
- ECG (heart beat rate & regularity)
- Bioimpedance => body fat
- Galvanic skin response => amount of sweat
- Skin & core temperatures

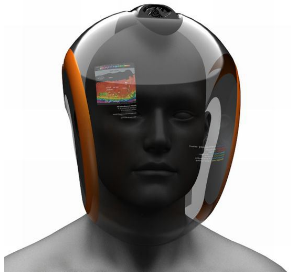
Worn on wrist like watch

Bluetooth & Wi-Fi; real-time display

Link:Samsung Simband

We have created a conceptual design of a countermeasure including a pressurized habitat, exploration capability, and monitoring techniques for further understanding of this physiologic issue





Potential for collaboration on future work….coming soon!

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Outreach Session

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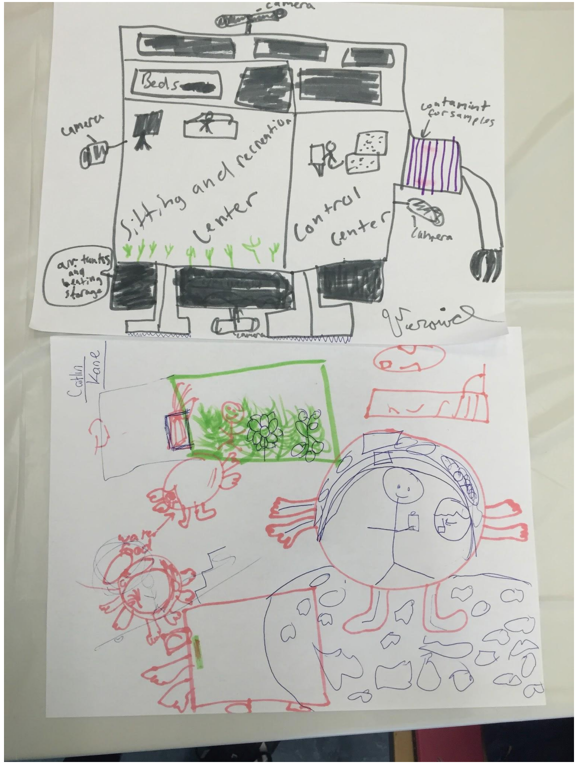
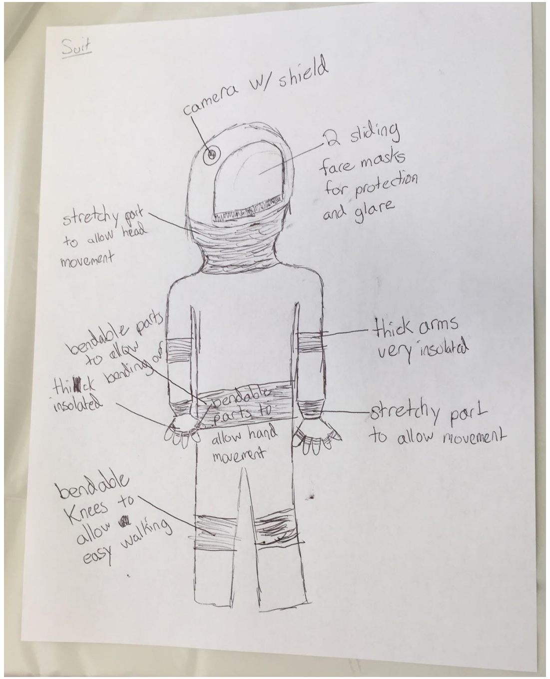
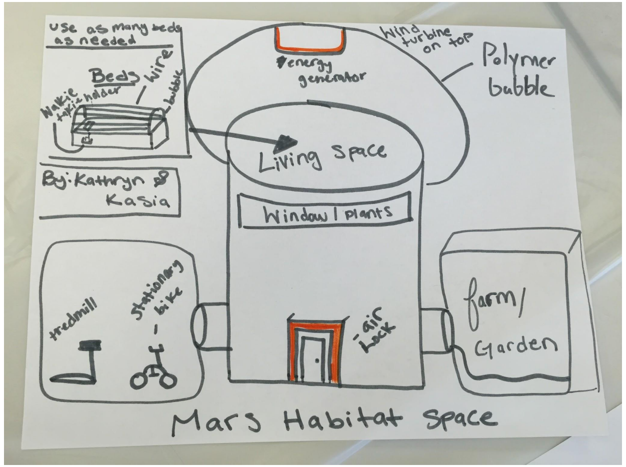
OUTREACH WITH SWE KEYS

"Humans in Extreme Environments!"







Design a Habitat or Suit for Mars!

THANK YOU!

Conceptual Design of a Countermeasure for Intermittent Altitude-Induced Hypoxia

MAY 6, 2015

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Backup Slides

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HABITAT POWER

- Considerations - lighting, environmental control, appliances, electronic devices, water heater
- Est. Total Wattage = ~39 kW
  Est. Total kWh per day = ~229 kWh

Option #1: Generator

48 kW: ~$14,500
15.7 L/hour of propane
2630 L propane weekly
>$25,000 propane annually

Option #2: Solar Panels

100%: 120 panels (310 W)
244 square meters
$36,300

50%: 60 panels
122 sq. m
$18,150

Option #3: Combination

Emergency power to maintain vital functions = 22 kW in 1 hr

Generator + emergency solar:

12 solar panels (310 W)
24 square meters
$3500

Solar + emergency generator:

22 kW generator
$8,730
15.7 L/hour of propane
1 hr propane = $3

Top-Level Design Variables

Hab/airlock combined value	922.2150362	*m^3*
Number People	5	people
"Number Days"	6	days
Habitat Temperature	295.15	K

Concept of Operations

Concept of Operations (Day)	Time Start (hr)	Time End (hr)	Time Spent (hr)
Sleeping Habitat	0	8	8
EVA	8	8	0
Active habitat	8	24	16

Human consumption and production

Awake, EVA	Use/CM-d AVG (kg or MJ)	Consumption/ CM-h EVA (kg or MJ)	Molar Mass (kg)	Consumption/ CM-h (mol)
Oxygen		0.075	0.032	2.344
Carbon Dioxide		-0.093	0.044	-2.114
Water (respiration/perspiration)		-0.294	0.018	-16.343
Water (urine)	-1.7	-0.071	0.018	-3.935
Water (hydration)	2	0.365	0.018	20.278
Heat Load (sensible) (MJ)	6.31	-0.566		
Heat Load (latent) (MJ)	5.51	-0.494		
Food Energy (MJ)		1.062	0.0461189	

Safety Limits

Safety Values		Source
Max EVA CO2 partial pressure (kPa)	3	http://www.marsjournal.org/contents/2006/0005/files/Lange2003.pdf
Min EVA O2 partial pressure (kPa)	21	HIDH (min total pressure for 12 hrs)
Max habitat CO2 partial pressure (kPa)	1.03	Space Shuttle
Min habitat O2 partial pressure (kPa)	29.7	HIDH (min total pressure for 14 days)
Max ppH2O (kPa)	1.86	HIDH

Derived ECLSS requirements

	EVA (mol)	Empty (mol)	Active (mol)	Sleeping (mol)	Total (mol)	Total (kg)	Hab Only (kg)
O2 requirement (for consumption)	93.750	17.040	85.200	27.000	222.990	7.136	4.136
O2 requirement (to fill space)	0.000	11,161.841	11,161.841	0.000	22,323.682	714.358	714.358
O2 requirement (total)	93.750	11,178.881	11,247.041	27.000	22,546.672	721.494	718.494
CO2 produced (total)	-84.545	-15.709	-78.545	-24.818	-203.618	-8.959	-5.239
CO2 held in atmosphere	0.000	387.094	78.545	308.549	774.188	34.064	34.064
CO2 scrubbing requirement	-84.545	371.385	0.000	0.000	286.840	12.621	16.341
H2O produced (respiration/perspiratic	-653.704	-62.773	-313.867	-84.000	-1,114.344	-20.058	-8.292
H2O produced (urine)	-157.407	-62.963	-314.815	-157.407	-692.593	-12.467	-9.633
H2O consumed (hydration)	811.111	111.111	555.556	0.000	1,477.778	26.600	12.000
H2O consumed (Non-hydration)					28 (or 1.08) Li	1,160.300	
H2O vapour held in atmosphere	0.000	699.024	699.024	0.000	1,398.049	25.165	25.165
H2O vapour scrubbing requirement	-653.704	636.251	385.158	-84.000	283.705	5.107	16.873
	(MJ)	(MJ)	(MJ)	(MJ)	(MJ)		
Metabolic energy produced (sensible)	-22.635	-5.264	-26.320	-8.960	-63.179		
Metabolic energy produced (latent) (M	-19.765	-2.736	-13.680	-3.680	-39.861		
Food energy required (MJ)	42.480	14.393	71.965	0.000	128.838	5.595	
	EVA (Watts)	Empty (Watts)	Awake (Watts)	Sleep (Watts)		Total	
Heat production (sensible-rad/conv/cc	-785.933	-91.389	-456.944	-311.111		-408.333	
Heat production (latent-water)	-686.290	-47.500	-237.500	-127.778		-200.926	
Total	-1,472.222	-138.889	-694.444	-438.889		-609.259	