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MARS ENVIRONMENT SIMULATOR, ENVIRONMENTAL AND AEROSPACE PHYSIOLOGY LABORATORY SIMON FRASER UNIVERSITY.

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ABSTRACT

Established in September of 1997, the Aerospace Physiology Laboratory in the School of Kinesiology at Simon Fraser University (Burnaby, British Columbia, CANADA) is equipped for a wide range of human physiological testing. It contains equipment for measurement of non-invasive blood pressure, electrocardiograms, breath-by-breath respiratory gas exchange, blood gases, and Doppler ultrasound blood flow. The laboratory is also equipped with a respiratory feedback control system, computer-controlled tilt table and cycle ergometer. The Aerospace Physiology Laboratory is integrated via computer (audio, video, and data) with the existing Environmental Physiology Unit (EPU) at Simon Fraser University. The main features of the EPU are: a dive/altitude chamber complex with an altitude capability of 33.5 km (110, 000 ft, equivalent to Mars atmospheric pressure). The dive/altitude chamber has living quarters for four with life support and communications systems for eight. The integration of the Aerospace Physiology Laboratory and the EPU provides a unique facility for Mars related research. Mars hardware, extra-vehicular activity (EVA) and life support systems as well as human physiology and performance can be studied in a controlled simulated Mars environment.

We have embarked on an ambitious program to build a state-of-the-art aerospace physiology laboratory and to reshape the Environmental Physiology Unit to meet the demands of the next century. This combined Environmental and Aerospace Physiology Laboratory is the only university research facility in Canada with the capability to research physiological issues associated with diving, aviation, and space environments. The facility extends Canadian science capabilities into research related to astronaut health and life support, decompression sickness, and EVA life support technology development. In addition to physiological research and testing, the Environmental and Aerospace Physiology Laboratory provides a world-class scientific and technical training facility for both academic and industrial partners.

INTRODUCTION

The Environmental Physiology Unit (EPU) was installed in the School of Kinesiology at Simon Fraser University in 1981. The main features of the EPU (Figure 1), are a dive/altitude chamber complex (a life support and environmental control system with an original operating range of 305 metres sea water dive depth to 12,000 metres altitude. We have upgraded the

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altitude capabilities to 33,530 metres.), a climatic chamber capable of simulating temperatures of -30∞C to 50∞C, and hot and cold immersion tanks ranging from 5∞C to 50∞C. Now in its fifteenth year of operation, the EPU is undergoing a technological overhaul to upgrade the facility to allow it to meet the demands of innovative research in the new millennium.

The author's Aerospace Physiology Laboratory contains equipment for measurement of non-invasive blood pressure (BP), electrocardiograms (ECG), breath-by-breath respiratory gas exchange, blood gases, and Doppler ultrasound blood flow. The laboratory also contains a respiratory feedback control system, computer-controlled tilt table and cycle ergometer.

These devices are fully integrated to function within the climate and dive/altitude chambers in the EPU. The Environmental and Aerospace Physiology Laboratory allows for innovative research related to human physiological responses and adaptations to both terrestrial (including aquatic) and space environments

This "Environmental and Aerospace Physiology Laboratory" at SFU provides a unique research and teaching facility for the study of human physiology and performance (such as the effects of diving, altitude, temperature, humidity and environmental gases) in extreme environments. I will focus on the altitude capabilities and research possibilities of this facility.

THE FACILITY

The Environmental Physiology Unit (EPU) at Simon Fraser University's School of Kinesiology was installed in 1981. The main features of the EPU (Figure 1) are a dive/altitude chamber complex, a climatic chamber, and hot and cold immersion tanks.

Figure 2: Installation of dive/altitude chamber.

Dive/Altitude Chamber

The central feature of the EPU is the combined hyper/hypobaric system. The chamber complex constructed to PVHO-1 (Pressure Vessel for Human Occupancy-1) standards was designed, fabricated and installed (Figure 2) by Perry Ocean Engineering of Florida. The main features are outlined in Table 1. It consists of three interconnected chambers: entry lock, wet chamber and living chamber. The wet chamber is situated below the entrance lock and connected by a 0.75 metre diameter trunk. The design incorporates both internal and external doors. This accommodates separate pressurisation of each chamber, and evacuation of either the living chamber or the complete complex.

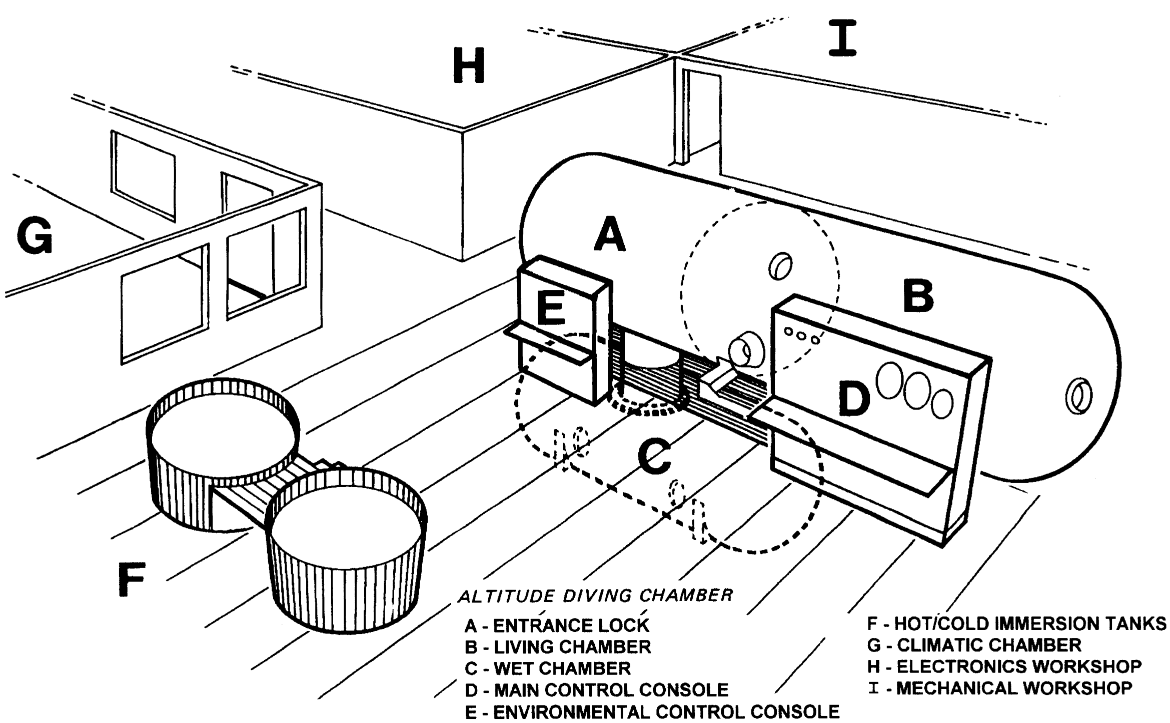

Figure 1: Diagram of Environmental Physiology Unit

We have expanded the altitude capabilities of the chamber so that we can achieve an atmospheric pressure equivalent to that on Mars (~5 mm Hg: 33,530 metres or ~110,000 ft Earth altitude).

TABLE 1: HYPO-HYPERBARIC CHAMBER

DETAILS	ENTRY LOCK	MAIN CHAMBER	WET CHAMBER
Dimensions			
dia x length: m	2.0 X 2.4	2.0 x 4.8	2.0 x 3.6
Pressure			
(m sea water)	305	305	305
Altitude			
(m elevation)	33,530	33,530	33,530
Access: 0.76 m			
to all chambers	3	1	1
pressure doors	external: 3	1	1
altitude doors	internal: 2	1	1
Medical lock	!	1	!
dia x length		30 x 35 cm	
View ports	2	4	1
breathing masks			
mixed gas	8	8	!
O_2 masks	!	8	!
Lights	1	2	1
Fold-up bunks	!	4	!
Data ports	4	5	!
Gas sample port	1	1	!
Internal power	12V DC	12V DC	!

Certification: PVHO-1; ASME Sect 8 Div 1; CSA draft standard

The main living chamber is outfitted to support a maximum of eight persons. It includes a 30 cm diameter medical lock, communications, fire detection and suppression system, four fold-up bunks, a table, and demand line-breathing masks. Two independent breathing lines (BIBS) provide emergency and treatment gases: one line to supply special mixtures and one dedicated to oxygen. The oxygen is exhausted from the masks to an external dump. High-pressure air is supplied to the system by means of two 17 cfm Bauer compressors. Air storage is provided by four 143 m3 (5,060 cubic feet) cylinders at 26,700 kPa (3,000 psi). This allows air pressurisation of the chamber system to a maximum of 305 metres for wet or dry equipment testing. During human occupancy one storage cylinder is dedicated to driving the fire suppression system. Sprinklers are controlled by a tracking pressure regulator and cover the entrance lock and main chambers with a deluge of 6.8 L s!1 from a high-pressure reservoir.

Control of all three chambers is provided from a central console with voice and television monitoring. The console provides independent system control to each chamber. In case of a line malfunction, the chamber controls have cross-connections to allow isolation of any component. All through-hull penetrations have internal and external shut-off valves. Atmospheric monitoring of each chamber is provided at the control console. An Environmental Control System developed by the Nova Scotia Research Foundation controls the ambient conditions within the chambers. The system consists of two loops, serving the wet and dry chambers respectively. These control ambient air purity and temperature in all units of the chamber complex and also provide temperature control and filtration of water in the wet chamber.

A custom computer controlled hydraulic breathing machine is also available. This device is capable of simulating human ventilatory function over a wide range of pressures[11]. A range of tidal volumes, respiratory frequencies and gases can be programmed into the device to test a wide variety of commercial and experimental breathing apparatus.

For hardware testing, the bunks and other non-essential items can be remove from the chamber to provide a larger volume for the test hardware. Single components must be less than 0.76 m (30”) in diameter and assembled systems must be less than 2.0 m (78”) in diameter (See Table 1 for specs). Through the treatment gas console various gas mixtures can be introduced into the chamber and continuously monitored, allowing for the simulation of both Mars pressure and atmospheric gas conditions.

Aerospace Physiology Laboratory

The author’s Aerospace Physiology Laboratory is situated across the hall on the same level as the EPU, in the School of Kinesiology. The researchers in the laboratory are experts in the field of G-physiology including the effects of space flight on cardiovascular control and the development of orthostatic intolerance in astronauts. This facility is equipped to allow for a wide range of human physiological monitoring and testing. The following are available:

Transcranial Doppler (TCD) Ultrasound: TCD provides mean flow velocity (MFV) of the red blood cells. This technique has been used extensively in studies of astronauts, bed rest subjects, and healthy or patient populations to measure MFV in the middle cerebral artery. The MultiFlow Doppler unit (DWL Elektronische Systeme GmbH, Germany) has the ability to collect two ultrasound signals simultaneously with analogue data input and output ports for multisignal data collection (A similar device was used on Neurolab, STS-90).

Non-invasive Arterial Blood Pressure: The NIBP 7000™ (Colin Medical, San Antonio, TX) using the oscillometric method (Semiconductor pressure sensor over the radial artery) can be used to collect continuous non-invasive blood pressure and provide beat-to-beat estimates of arterial blood pressure. If required, gravitational correction can be applied for estimates of heart or brain level arterial pressure. As well, the modular construction of this device makes it ideal for blood pressure monitoring in the hyper/hypobaric chamber (see integration below).

Heart-rate monitor: The ECG waveform can be recorded from the analogue output of a LifePak-8 Cardiac Monitor (Physio-Control, Redmond WA). This can be used to determine heart rates and RR-intervals (commonly used in cardiovascular research).

Ventilation and Gas Exchange: A breath-by-breath gas analysis system has been established by Dr. R.L. Hughson (University of Waterloo) for precise measurement of ventilation and gas exchange and has been the basis for development of software by Marquette Electronics Inc. (Milwaukee, WI) as part of the current GASMAP project for NASA. This software is being used in this research laboratory. The small, versatile RAMS M-100 Laboratory Gas Analyser is used because of its size and compatibility with existing hardware and software. This system is also used by NASA for MIR, the Space Shuttles, and will be used on the International Space Station. This allows for smooth transfer of experimental design from ground-based to space-based projects.

Respiratory feedback control system: Gas mixtures will be regulated and monitored using a computerised gas mixing system 14. Respiratory gases will be monitored from the RAMS unit and air of various concentrations of CO_2, O_2 and N_2 can be mechanically mixed to produce specified gas concentrations. In the situation where expiratory values are being regulated by inspiratory gas mixtures expired gas concentrations will be monitored and inspired gas mixtures modified using a computer algorithm 8.

Blood Gas and Haemoglobin analysis: Blood gas and hemoglobin analysers (AVL Scientific Corporation, Roswell, GA) with microsamplers are available. Research projects involving an integration of cerebral, cardiovascular and respiratory physiology often require the ability to obtain reliable blood gas and haemoglobin content values.

Computer-controlled cycle ergometer: The breath-by-breath system can also control the work rate on the cycle ergometer. Many research protocols for testing human exercise capacity and performance require computer control of work rate on a cycle ergometer. This is essential for any program involving human cardiorespiratory assessment.

Computer-controlled tilt table: A major component of the research by the author involves the investigation and assessment of orthostatic intolerance. Clinical tests of orthostatic intolerance involve the use of a tilt table. The research in this lab will involve investigations of transitions between head-down and head-up tilt (negative and positive "G", with the direction of gravity to or away from the head). The time spent in each position and the rate of transition may have important implications for orthostatic intolerance. A custom, computer-controlled, tilt table that can be used in the lab and in the altitude chamber has been designed to obtain the necessary range and rate of motion; -90° (head down tilt) to +90° (head up tilt) (±70° in the chamber) at 45° s!1 maximum rotation.

Lower body negative pressure (LBNP): LBNP is also used as a cardiovascular challenge and has been used extensively to determine the effects of cardiovascular deconditioning (seen with space flight). Tilt tests are not always conducive to many of the measurements that are needed to test research hypotheses. LBNP can be applied at low levels to primarily stimulate the cardiopulmonary baroreceptors or at higher levels to also include the arterial baroreceptors. As well LBNP can be applied in conjunction with tilt to increase orthostatic loading in the head-up tilt position.

Data collection apparatus: The analogue signals from these devices are recorded simultaneously on a PC using a MetrabyteTM compatible A/D board and a sixteen-channel computer strip chart recorder (RUN Technologies, Laguna Hills, CA). Beat-by-beat analysis of these data is performed off-line. All analogue signals are transmitted to the A/D board via standard BNC connector cables and may be connected to any device that is compatible.

Integration: Environmental & Aerospace Physiology

The Aerospace Physiology Laboratory is integrated with the Environmental Physiology Unit. This involves complete integration of the research devices in the EPU for on-line remote observation with network/internet access. All of the computers and the TCD are on an internal 100 base T network using a SUN UltraSPARC system as the network server. This is connected to the University network (currently at 10 base T). Large data files can be transferred from one device to another with great ease and speed. The SUN UltraSPARC also serves as a station for multisignal data analysis, with software for converting Doppler audio signals into velocity profiles used in beat-by-beat analysis. All of the equipment can be moved easily between the Aerospace Physiology Laboratory and EPU. Sufficient network ports exist to maintain network connections in either or both rooms.

At present, the majority of monitoring devices cannot withstand exposure to the temperatures and pressures that may exist in the EPU. Furthermore, for safety reasons, only low current, low voltage devices may be used in the dive/altitude chamber. Monitoring devices, and computer hardware necessary for conducting research in the EPU, have to be outside with their sensors (e.g. Doppler ultrasound probes, blood pressure sensors) located inside. The dive/altitude chamber has been fitted with specialised data access ports (Table 1) in both the entry lock and the main chamber to link outside data collection devices with their respective sensors inside the hyper/hypobaric chamber. Along with specialised connections for specific equipment residing in the facility, data ports contain wiring with internal and external BNC connectors for generic use. Some of these are being used to connect ECG and EEG electrodes to their respective monitoring devices.

A computer keyboard, flat screen monitor and pointing device (mouse) are being modified or protected to withstand the environments within the chamber; the remainder of the computer will remain outside the chamber. This will allow researchers inside the facility access to data display as well as full network access. These can also be used in studies involving human computer interactions.

At present we are working with Stephen Braham, also at Simon Fraser University (member M.A.R.S. experiment, Haughton Crater, Devon Island, Canada) to have the research devices in the facility accessible for on-line remote observation and interaction with network/internet access. The facility has video monitors and voice communication devices that will be integrated into the computer network system so that two-way communication with video, voice and data will be possible via the Internet, as well as the usual e-mail and text communication. In long duration studies (e.g. involving extended stays in the chamber6) the computer components will allow subjects greater access to and from the outside world.

The School of Kinesiology

The School of Kinesiology is a diverse department with research in environmental physiology (thermal, altitude, and diving) whole body exercise physiology, biomechanics, ergonomics, motor control behavioural neuroscience, and cellular/ biochemical mechanisms of disease (neural, heart and diabetes).

My interests cover the full range of environmental and aerospace physiology. I have interests in cardiovascular and cerebrovascular modelling 1,2,4,5 with specific interest in orthostatic intolerance 3 and space flight deconditioning 7. My lab is currently investigating orthostatic cerebrovascular dysautoregulation (OCD). This condition may cause syncope during orthostatic stress. Persons with this condition have decreases in cerebral blood flow with orthostatic stress without apparent decrease in systemic blood pressure. This condition is thought to be due to an inappropriate cerebral blood flow autoregulation response to orthostatic stress.

Several other faculty members work in areas related to this facility. These areas include: the interface of human and mechanical systems in areas such as underwater work and industrial ergonomics 12,13 (Dr. J Morrison); human motor control, grasping and remote manipulation in human-computer interaction (Dr. C MacKenzie); the effects of prolonged exposure to altitude on brainstem function using EEG (Dr. H Weinberg); the relationship and markers of genetic abnormalities in heart proteins and cardiovascular responses to tilting and environmental stress (Dr. E Accili); and, nitrogen gas kinetics during compression and decompression, specifically investigating nitrogen absorption, transport, saturation and elimination in real time9,10 (G Morariu, Adjunct Professor and Senior Research Engineer, Aerospace Physiology Laboratory; Dr. M Lepawsky, Adjunct Professor SFU, and Head, Hyperbaric Medicine, Vancouver General Hospital).

Figure 3: Altitude/dive chamber at SFU.

More information on the School of Kinesiology and its faculty can be found at “http://fas.sfu.ca/kin/”.

SUMMARY

This laboratory is the first Canadian University research facility that allows for a full range of aerospace physiology testing. Not only does the integration of the Aerospace Physiology Laboratory and the Environmental Physiology Unit at SFU provide a unique research and teaching facility for the study of human physiology and performance, but it also provides a state-of-the-art scientific and technical training facility for both academic and industrial partners.

The main component is the dive/altitude chamber (Figure 3). This chamber is unique in Canada and most probably one of a few chambers world wide with both diving and altitude capabilities. In the areas of space related research we are able to investigate the physiological effects related to astronaut EVA (30,000-ft altitude pressure, pure oxygen), including decompression sickness research, and human-machine interface. As well we can assess hardware under Mars conditions including Mars EVA equipment.

As a completely enclosed environmental system the hypo/hyperbaric chamber complex also provides a facility where real simulations of a Mars Habitat can be run. The participants are isolated and communicate via an audio, video and data link (over which realistic time delays and signal problems can be simulated). Through computer control of the onboard systems, various scenarios such as air pressure leaks and EVA's can be performed with continuous monitoring of hardware and astronaut physiology.

Current research projects include: the investigation of the effects of altitude and orthostatic cerebrovascular dysautoregulation on orthostatic intolerance (BCHRF); human eye tear film bubble nitrogen kinetics in hyperbaric environments (BCHRF); and effect of chronic elevations in environmental CO2 on cerebral autoregulation (NSERC/CSA). We also provide, on a service contract basis High Altitude Indoctrination (Physiologic Training) for private and professional pilots, and flight training schools.

These are only a few of the activities that are possible or presently underway in this facility. Any person, group, or company interested in using the facility is asked to contact the author.

Abbreviations: BCHRF – British Columbia Health Research Foundation
NSERC – Natural Science and Engineering Research Council (Canada)
CSA – Canadian Space Agency.

REFERENCES

1. Blaber AP, Bondar R, Stein F, Dunphy PT, Moradshahi P, Kassam M and Freeman R (1997) Complexity of middle cerebral artery blood flow velocity: effects of tilt and autonomic failure. Am.J.Physiol. 273:H2209-H2216.

2. Blaber AP, Bondar RL, Stein F, Dunphy PT, Moradshahi P, Kassam M and Freeman R (1997) Transfer function analysis of cerebral autoregulation dynamics in autonomic failure patients. Stroke 28(9): 1686-1692.

3. Blaber AP, Bondar RL, Moradshahi P, Dunphy PT, Serrador JM, and Hughson RL (1997) Inspiratory CO_2 increases time to presyncope during repeated 90 head-up tilt. Aviat. Space Environ. Med., 68:A266.

4. Blaber AP, Bondar RL, and Freeman R (1996) Coarse grained spectral analysis of HR and BP variability in patients with autonomic failure. Am.J.Physiol. 271:H1555-H1564.

5. Blaber AP and Hughson RL (1996) Cardiorespiratory interactions during fixed pace resistive breathing. J.Appl.Physiol. 80:1618-1626.

6. Goldberg SV, Schoene RB, Haynor D, Trimble B, Swenson ER, Morrison JB, Banister EJ. (1992) Brain tissue pH and ventilatory acclimatization to high altitude. J. Appl. Physiol. 72:58-63

7. Hughson RL, Yamamoto Y, Blaber AP, Maillet A, Fortrat JO, Pavy-LeTroan A, Marine JF, Güell A, and Gharib C (1994) Effect of 28 day continuous head down bedrest with

countermeasures on heart rate variability during LBNP. Aviat. Space Environ. Med., 65:293-300.

8. Modarreszadeh M, Kump KS, Chizeck JH, Hudgel DW, & Bruce EG: (1993) Adaptive buffering of breath-by-breath variations of end-tidal CO2 of humans. J.Appl. Physiol. 75:2003-2012.

9. Morariu GI, Strath RA, Lepawsky M, Dobrescu RF (1998) A quantitative study of post-decompression tear film bubble formation. Proceedings of the European Underwater Biological Society. August 1998, Stockholm Sweden, Proceedings XXIVth Ann. Meeting EUBS: 212-215.

10. Morariu GI, Strath RA, Lepawsky M, Longely CR. (1996) Exercise induced post - decompression ocular bubble development. Proceedings of the International Joint Meeting on Hyperbaric & Underwater Medicine. Milano, Italy. Pp 509 - 512. 4 - 8.

11. Morariu GI (1992) A volumetric-pump type respiratory simulator. Proceedings at the 5th International Conference on Environmental Ergonomics. Nov. 2-7, Maastricht, Netherlands. Pp. 196-197.

12. Morrison JB,. Taylor NAS and Voogt SL. (1992). The effect of hydrostatic imbalance on respiratory mechanics of the diver. In: Lung physiology and diver's breathing apparatus. Ed. V. Flook, A. Brubakk, Aberdeen University Press, Aberdeen, U.K. p 101-124.

13. Morrison JB, Taylor NAS. (1990). Measurement of static and dynamic pulmonary work during pressure breathing. Undersea Biomed. Res.: 17(5) 453-467.

14. Robbins PA, Micco AJ, Swanson GD, & Schubert WP. (1982) A fast gas mixing system for breath-to-breath respiratory control studies. J. Appl. Physiol. 52: 1358-1362.