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Review of High Altitude Aviation Preoxygenation / Denitrogenization Procedures and Draft Pressure Schedule for Open-Cockpit Balloon Flight to 65,000 Feet

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Review of High Altitude Aviation Preoxygenation / Denitrogenization Procedures and Draft Pressure Schedule for Open-Cockpit Balloon Flight to 65,000 Feet

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Abstract

Aviation Decompression Sickness (DCS) is a well-known and well-documented phenomenon in which a spectrum of physiological and cognitive symptoms result from aircrew exposures to altitudes greater than roughly 10,000 feet, where atmospheric pressures and the partial pressure of oxygen are significantly lower than the mean pressures in which the human body has evolved. The main factors involved in the likelihood of DCS are (a) exposure altitude, (b) exposure time at altitude, (c) preoxygenation / denitrogenization duration and procedure and (d) exercise at the exposure altitude. Mitigation of DCS is largely achieved by (a) preoxygenation / denitrogenization before flight, (b) use of 100% Aviator's Breathing Oxygen during flight, (c) limiting time at exposure altitude, (d) limiting exercise at altitude, (e) use of pressurized cabin and/or garment to offset low ambient pressure and (f) postflight transition-to-lower-altitude procedures. I review experimental and review literature on DCS factors and mitigations and present a draft pressure schedule for the Pacific Spaceflight / Copenhagen Suborbitals balloon flight planned to reach 65,000 feet MSL (19,812m) in 2015. The pressure schedule is maintainable with current peformance of the Pacific Spaceflight Mark I Pressure Garment (model *Gagarin*) in terms of pressure maintenance, but a Mark II garment must be built for use with 100% Aviator's Breathing Oxygen and to increase mobility while pressurized, which will decrease exercise at exposure altitude, the most important factor involved in DCS onset after prebreathing protocol. The draft pressure schedule requires the balloon pilot to alter suit pressure 13 times during flight, with important implications for placement and operation of the suit pressure controller, the suit pressure display, and backup suit pressure controllers.

1. Altitude Decompression Sickness

Altitude Decompression Sickness (DCS) is “a condition characterized by a variety of symptoms resulting from exposure to low barometric pressures that cause inert gases (mainly nitrogen), normally dissolved in body fluids and tissues, to come out of physical solution and form bubbles” [1]. Strictly speaking, bubble formation is highly positively correlated with DCS, but “...this does not imply causation...” [2:751] and the actual mechanisms, despite half a century of research, remain poorly understood; additionally, prediction of DCS is a matter with attending statistical error, and “...there is great individual DCS variation to altitude exposure” [2:758].

Nevertheless, DCS onset and symptoms are well-enough understood that computer models [see reference 2] have been produced to assist flight planning and careful DCS mitigation protocols have been effective in preventing DCS in high-altitude aviation: in the US there have been no DCS aircrew fatalities in over five decades, despite thousands of hours of high-altitude flights, largely in U2 aircraft [3:64]. Having said this, the recent reduction in U2 aircrew numbers and the increase in missions flown has led to an increase in reported DCS symptoms, with unclassified reports suggesting on the order of 16 severe cases between 2002 and 2009 [3a].

2. Altitude Decompression Sickness Factors

Four main factors account for most onset of DCS symptoms.

Exposure Altitude refers to the altitude to which the aircrew is exposed; specifically it references the atmospheric pressure and breathing gas composition at such an altitude. Without prebreathing / denitrogenization procedures before exposure, experiments on 542 male and female test subjects exposed to nine altitudes between 11,500 feet MSL (3,505m) and 25,000 feet MSL (7,620m) almost never resulted in DCS below 17,000 feet MSL (5,181m) [5] (though cognitive and physiological functions can be impaired by lowered partial pressure of oxygen above 10,000 feet MSL (3,048m), where the FAA requires use of supplemental oxygen (normally Aviators' Breathing Oxygen) for aircrews). In the noted experiments, by just over 23,000 feet MSL (7,010m), there was a 50% incidence in DCS symptoms, and by 25,000 feet MSL (7,620m) there was an 85% incidence of DCS symptoms [5:5-1-5-2]. Lacking preoxygenation / denitrogenization procedures, then, exposure to altitudes over 24,000 feet MSL (7,315m) can be expected to cause DCS symptoms in well over half of aircrews (DCS symptoms are described below).

Exposure Time at Altitude refers to the duration of the aircrew's exposure to a given altitude. Most DCS symptoms are expressed during flight, whereas most diving decompression sickness is encountered after surfacing. Experiments referenced above have shown that a 90-minute preoxygenation / denitrogenization procedure before exposure to an altitude of 35,000 feet MSL (10,668m), while breathing 100% oxygen and doing 'mild exercise' results in roughly half of expressed DCS symptoms; by 120 minutes of exposure to this altitude, over 80% of DCS sickness has been expressed. We may say that even after a 90-minute preoxygenation / denitrogenization procedure and breathing 100% oxygen, exposure to a pressure altitude of 35,000 feet MSL (10,668m) (where ambient pressure is 3.45psi or 0.234 atm or 0.237 bar) for more than 90 minutes exposes the aviator who experiences DCS to 50% risk of DCS symptoms if doing 'mild exercise', equivalent to walking. Such exercise is discussed below.

Preoxygenation / Denitrogenization Duration and Procedure refer to the preflight procedure of denitrogenizing the bodily tissues by breathing 100% oxygen (often referred to as 'prebreathe'). Preoxygenation / denitrogenization durations of up to four hours have been proposed and used in various Earth-based (as opposed to orbital) DCS-exposure programs (flights) (longer prebreathes are used by some spacecraft crews). However, “Beyond one hour of prebreathe [for Earth-based flights], only about 12% additional protection from DCS at 25,000 feet MSL (7,620m) is acquired with each additional hour of prebreathe.” [5:5-3], so shorter prebreathe periods are normally used. A standard protocol before high-altitude U-2 flights in the US is to breathe 100% oxygen for 60 minutes [6:77].

Recent attempts to improve prebreathe protocols have been successful: a study based on over 2,000 experiments indicates that a 10-minute period in which the aircrew (breathing 100% oxygen) reaches 75% of VO2 max for several minutes of exercise followed by a 50-minute rest period provides the same significant mitigation of DCS symptoms as the more logistically-complicating four-hour non-exercise prebreathe [6:77]. Specifically, this protocol reduces DCS symptoms by about 35% over nonexercise prebreathes when exposure altitude is above 35,000 feet MSL (10,668m) [7].

Preflight breathing of 100% oxygen, then, in some capacity, significantly reduces DCS risk.

Exercise at the Exposure Altitude refers to aircrew exertion at the exposure altitude. Experiments with 92 test subjects exposed to 35,000 feet MSL (m) pressure altitudes, while carrying out mild exercise and breathing 100% oxygen, has resulted in 94% DCS, and strenuous exercise 97% DCS; resting (seated) test subjects, however, experienced significantly less (c.50%-63%) DCS [8:510, 9].

We may say that either mild or strenuous exercise significantly increases the risk of DCS while decompressed.

3. Altitude Decompression Sickness Symptoms

DCS symptoms occur in a wide spectrum from minor irritation to debilitating. They include [7,10]:

- joint pain
- 'tingling' of the skin or inner tissues
- dyspnea (shortness of breath)
- skin mottling
- numbness
- ataxia (loss of muscle coordination)
- dizziness
- fatigue
- nausea
- headache
- substernal stress (chest pain)
- hot/cold sensation
- muscle pain
- memory loss
- 'foggy' thinking
- disorientation
- palpitation
- tremor
- blurred vision
- photophobia (sensitivity to light)
- rash
- timmitus
- vertigo

Severe central nervous system DCS symptoms in a recent case resulted in a pilot experiencing, over several hours following minor joint pain in the knees and ankles, “...worsening concentration, confusion, fatigue and headache...” [3:64] follwed over four hours later by “...color vision loss, hemianopsia (loss of half the visual field), hearing loss, and repeated emesis (vomiting)...” [3:65] and ultimately “The pilot was unaware of his surroundings...descending in a stall before recovering spontaneously...[making] multiple attempts to land [and] coming within 5 feet (1.5m) of a likely fatal ground impact...” [3:65]. Note that such severe symptoms are highly unusual and that most aviation DCS symptoms are rarely debilitating and normally resolve ('disappear') with recompression (aircraft descent into higher-pressure environments and/or increase in pressure garment pressure, whether automatic or pilot-actuated) [3].

We may say that while most DCS is an irritant and resolves on descent, it can be debilitating and lead directly or indirectly to loss of life.

4. Altitude Decompression Sickness Mitigation

Six main methods of DCS mitigation are currently used in modern aciation. Here I focus on those used in high-altitude aviation rather than for extravehicular activity (EVA) in orbit ('spacewalks'), which are also prepared for by such mitigation. This is because pressures, breathing gas compositions and gravity conditions obtaining in orbit are rather different from those on Earth, leading to different DCS mitigation in that environment, in part due to orbital conditions that affect bubble formation in unique ways [4:Section 11.4]. I also focus on methods specifically useful to maintaining pilot health in the proposed 2015 to 65,000 feet MSL (19,812m), as every high altitude flight and its DCS factors differ somewhat.

1. Preoxygenation / Denitrogenization: Prebreathing 100% oxygen to denitrogenize the tissues is mandatory for aviators exposed to altitudes greater than about 17,000 feet. Hour-long prebreathe periods are common today; longer (e.g. 4-hour) prebreathes have been deemed too logistically unwieldy to justify their small increase in DCS prevention.

2. Pressure Garment Breathing Gas: High altitude aviation normally supplies the aircrew with Aviator's Breathing Oxygen (normally 99.7%-99.8% O2). This must be supplied as the breathing gas for the 2015 flight pilot.

3. Limitation of Pressure Exposure Time: With an expected ascent and descent rate on the order of 1,000 feet per minute (304.8m per minute), the 2015 flight is expected to expose the pilot to pressures below those found at 30,000 feet (9,144m) for about 70 minutes. At such exposure, (with combined cabin and suit pressure of c.4.3psi or .292atm) aviators having prebreathed 100% oxygen for an hour, and breathing 100% oxygen, have a DCS incidence of roughly 50%-75% [7,11]. However, only about 25% of DCS symptoms occur before about 50 minutes of exposure [5:5-2]. Exposure can be reduced by increasing ascent and/or descent rates during flight and/or with somewhat uncomfortably high pressure garment pressures (over about 3.7psi) for a short period at the lowest ambient pressures of the flight, as described below. The 2015 flight's planned exposure duration profile is reasonable considering the low incidence of severe or debilitating DCS symptoms in such limited-duration exposures (see above).

4. Limitation of Exercise at Dangerous Exposure Altitudes: DCS symptom onset is strongly correlated with even mild physical exertion but can be signigicantly limited by avoiding physical work at altitude. For the 2015 flight the pilot will be seated comfortably and will not be called upon to move even the hands or arms much (except in the case of emergency) while at altitudes above 30,000 feet MSL (9,144m). Still, DCS risk will be lowered by use of constant-volume joints in the elbows and knees of the pressure garment.

5. Use of Pressure Garment Pressurization: Pressure garment pressure settings must be scheduled and altered during different phases of flight to reduce DCS risk. Lacking a pressurized cabin in the 2015 flight, a pressure garment and schedule will be mandatory. The garment will be the Mark II suit currently being designed rather than the current Mark I (Gagarin) suit, which is not rated for flight but is a proof-of-concept garment. A provisional pressure schedule is discussed below.

6. Transition to Increased Pressure and Posflight DCS Mitigation: While most DCS symptoms occur during flight and are resolved by recompressen even before landing, some persist postflight [3,3a,7]. Modern postflight mitigation includes medical checkout on landing followed by any combination of (a) immediate adminstration of 100% oxygen, (b) transport to a recompression chamber while travelling below 1,000 feet MSL (305m), (c) recompression therapy in a hyperbaric chamber (d) administration of a saline drip and (e) limiting exposure to lowered pressure (as in commercial flights) by grounding the aircrew for 24-48 hours [12].

5. DCS Mitigation Specific to the Pacific Spaceflight / Copenhagen Suborbitals 2015 Armstrong Line Expedition

The general DCS mittigation strategies reviewed above are below discussed with respect to details of the proposed 2015 flight.

1. Preoxygenation / Denitrogenization: A review of current methods indicates that a prebreathe period with exercise should significantly reduce DCS risk in the planned 2015 flight, which has an exposure profile similar to a short U2-flight. Specificially, a 60-minute 100%-oxygen prebreathe protocol employing a 2-minute warmup at 30%-40% VO2 max, three minutes at 75% VO2 max, a 5-minute cooldown period (using a fan) and a 50-minute rest period (all while breathing 100% oxygen; see [7]) will be sufficient to reasonably mitigate DCS in the planned 2015 flight. Figure 1 displays a reasonable prebreathe exercise regime.

2. Pressure Garment Breathing Gas: At a resting consumption rate of 28 liters per minute (c.1 cubic foot per minute) the 2015 pilot may be expected to consume 28 liters * 200 minutes of flight time = 5,600 gaseous liters of oxygen, or 200 cubic feet. Standard gaseous oxygen tanks with service pressures of roughly 3,000psi (204.1atm or 206.8bar) can easily contain 280 liters or 100 cubic feet each, such that two such tanks should be sufficient for the 2015 flight duration. Use of such gaseous supplies is significantly simpler than handling cryogenic oxygen, and molecular sieves require high airspeeds to extract oxygen from the atmosphere. The 2015 pilot will breathe 100% oxygen from non-ship supplies during the exercise, suitup and prebreathing periods, switching to ship supplies when installed into the capsule. The pilot will be able to regulate the flow of breathing gas manually by simple purge valve should there be a fault with the flowmeter that would normally and automatically deliver breathing gas.

3. Limitation of Pressure Exposure Time: As mentioned, the 2015 balloon flight is expected to have ascent and descent rates of roughly 1,000 feet per minute (304.8m per minute); these are averages as different rates are expected at launch, in the highest altitudes, and on final descent before landing. These rates are currently being modeled, but it they are reasonably comparable to those experienced in other such balloon flights [13,14,15]. As currently planned, the 2015 flight is expected to expose the pilot (breathing 100% oxygen) to pressures below those found at 30,000 feet (9,144m) for 75 minutes minutes, from minutes 95-170 of flight (see Table 1). By regulating the pressure garment pressure according to the figures presented in Table 1 (between about 1.6psi-2.8psi or .108atm-.190atm), the body's perceived pressure will not drop below that expected at 34,500 feet (10,515mm), a reasonable pressure altitude (if breathing 100% oxygen) at which about 75% of aviators report mild DCS symptoms including tingling skin and mild joint pain. Such symptoms are not to be taken lightly, but are routinely resolved by the pilot's manuually increasing suit pressure for some time. Currently the Mark I suit is difficult—but not impossibly so—to wear and move in freely at pressures above 2.8psi. Addition of constant-volume joints, a priority for the Mark II pressure garment, should mitigate the lack of dexterity that is the tradeoff for higher suit pressures. Note that the Mark I garment has borne pressures of up to 3.5psi without unacceptable leak rates for periods of up to an hour.

It was noted above that only about 25% of DCS symptoms occur before about 50 minutes of exposure to pressures and breathing conditions comparable to those of the proposed 2015 flight [5:5-2]. Adjustment of suit pressure to higher levels for longer periods of exposure to altitudes over 30,000 feet (9,144m) is another possibility to mitigate DCS risk on this flight.

Depending on the design of the balloon and its control system, ascent and descent rates might be higher than those currently modeled, also reducing DCS risk exposure.

Finally, in emergency circumstances, recompression of the pilot could be accomplished by one of three methods. First, the suit could be brought to a very high pressure (e.g. 5 psi or a perceived altitude of 27,000 feet MSL (8,229m) , which was safe for *Apollo* astronauts for multiple days) while ground-control effects a remote venting of the balloon's lift gas (at 5psi the suit would likely be too stiff to do more than sit). Note this would require closing the suit's overpressure valve, which is currently manual and cannot be done remotely. Second, the pilot could bail out to reach higher pressures at high speed: at terminal velocity for a human body being roughly 140mph or 225kph, from 65,000 feet MSL (19,812m) it would take about 3.5 minutes to reach 25,000 feet (7,620m), below which the incidence of DCS is significantly reduced, especially with exposure times measured in minutes rather than hours, and the parachute could be deployed. Finally, if the pilot is debilitated, ground control could remotely vent the ballon's lift gas or separate the gondola from the balloon, allowing it to freefall to higher pressures before parachutes would be deployed. Obviously the automation required for this latter option makes it the least desireable, but the point is that there are options to the problem of the pressure garment not holding appropriate pressure. These scenarios envision a slow leak with chronically low suit pressure: a catastrophic suit loss-of-pressure resulting in venting of all breathing gas to the atmosphere would likely render the pilot unconscious in less than a minute (Time of Useful Consciousness at certain altitudes is being researched at present) and lethal in less than a few minutes.

4. Limitation of Exercise at Dangerous Exposure Altitudes: It is clear that DCS incidence is signigicantly limited by avoiding physical work at altitude. For the 2015 flight the pilot will be seated comfortably and will not be called upon to move even the hands or arms much (except in the case of emergency) while at altitudes above 30,000 feet MSL (9,144m). Still, DCS risk will be lowered by use of constant-volume joints in the elbows and knees of the pressure garment.

5. Use of Pressure Garment Pressurization: Pressure garment pressure settings must be scheduled and altered during different phases of flight to reduce DCS risk. Lacking a pressurized cabin in the 2015 flight, a pressure garment and schedule will be mandatory. The garment will be the Mark II suit currently being designed rather than the current Mark I (Gagarin) suit, which is not rated for flight but is a proof-of-concept garment. A provisional pressure schedule was discussed above.

6. Transition to Increased Pressure and Posflight DCS Mitigation: Preventing postflight DCS in the 2015 flight will be relatively straightforward. A ground medical team can adminster 100% oxygen while the pilot is transport to a recompression chamber; if this is done by aircraft the flight level should be kept below 1,000 feet MSL (305m). At the recompression chamber (which should be prepared to receive the pilot, and its personnel briefed) recompression therapy can be carried out if needed, and according to the decision of a flight physician. Recompression should be accompanied by a saline drip and the pilot grounded from ascending to above 1,000 feet MSL (305m) for 24-48 hours.

As mentioned above, Figure 2 indicates a draft pressure schedule; note that on descent it allows for opening the pilot's (complete suit depressurization) at 10,000 feet (3,048m) on descent. A more conservative pressure schedule in seen in Figure 3, which includes CAPCOM messages to the pilot at various flight minutes and keeps the pilot pressurized throughout landing. This schedule highlights that there are 13 times during flight that the pilot will be required to set the pressure suit setting, which has several implications. First, the pressure suit pressure controller must be easily accessed and actuated by the pilot. Second, suit pressure must be visible on a control panel display, which is much easier to read than a wrist-mounted display for verification of suit pressure. Third, such a panel display of suit pressure must accurately display suit pressure. Fourth, a method of remotely setting suit pressure would be desireable in the event that the pilot is disabled. Fifth, a completely automatic suit pressure setting device should be developed such that if the pilot is debilitated and remote activation of suit pressure from ground control fails, the suit will maintain an acceptable pressure.

6. Comments

From the perspective of DCS risk management, planning the 2015 flight is a matter of identifying the pilot's exposure, identifying appropriate mitigations, and putting them in place. In addition to properly-functioning hardware, the flight must be planned to reduce DCS risk, so hardware, consumables (such as breathing gas and drinking water) and flight plan must be integrated. Because of the vulnerability of balloon aviation to weather, it is inevitable that plans and hardware configurations will change before the flight and it is likely that plans will have to be adjusted during the flight due to variations in, for instance, ascent or descent rates from the modeled flight. Planners on all levels must keep this flexibility in mind.

It is equally important to note that the pilot of the planned 2015 flight will have a significant (but not necessarily 100%) chance of incurring DCS symptoms. However it must be remembered that these occur in a wide spectrum, are rarely more than an irritant, are most often resolved by the pilot making a manual increase in suit pressure, are mostly resolved by landing, rarely persist after landing, and have not caused an aviation fatality in US operations for over half a century. Certainly we will be as cautious as possible, but if a good DCS mitigation protocol is constructed and approved by flight physicians, we should have confidence in our preparations.

7. References

1.http://www.faa.gov/pilots/safety/pilotsafetybrochures/media/dcs.pdf

2. Pilmanis, A.A., L.J. Petropoulos, N. Kannan and J.T. Webb. 2004. Decompression Sickness Risk Model:

Development and Validation by 150 Prospective Hypobaric Exposures. *Aviation, Space and Environmental Medicine* 75(9):749-759.

3. Jersey, S.L., R.T. Baril, R.D. Mcarty and C.M. Millhouse. 2010. Severe Neurological Decompression Sickness in a U-2 Pilot. *Aviation, Space and Environmental Medicine* 81(1):64-68.

3a. http://www.airspacemag.com/military-aviation/Killer-at-70000-Feet.html?c=y&page=2

4. Brady, T.K. And J.D. Polk. 2011. In-Suit Light Exercise (ISLE) Prebreathe Protocol Peer Review Assessment. *NASA/TM-20110217062/Volume I*. National Aeronautics and Space Administration, Langley Research Center, VA.

5. Webb, J.T. And A.A. Pilmanis. 2000. Altitude DCS Susceptibility Factors. Paper presented at the RTO HFM Symposium “Operational Medical Issues in Hypo- and Hyperbaric Conditions”, Toronto, Canada, 16-19 Oct. 2000. Available at http://ftp.rta.nato.int/public/PubFullText/RTO/MP/RTO-MP-062/MP-062-05.pdf.

6. Webb, J.T. And A.A. Pilmanis. 1999. Preoxygenation Time Versus Decompression Sickness Incidence. *SAFE Journal* 29(2):75-78.

7. Pilmanis, A.A. 2010. Recent Severe CNS Altitude Decompression Sickness (DCS) in U-2 Pilots. Paper presented at USRA Seminar, March 10, 2010. Available at http://www.dsls.usra.edu/20100310.pdf .

8. Webb, J.T., Krause, K.M., A.A. Pilmanis, M.D. Fischer and N. Kannan. 2001. The Effect of Exposure to 35,000 ft on Incidence of Altitude Decompression Sickness. *Aviation, Space and Environmental Medicine* 72(6):509-512.

9. Webb, J.T. And A.A. Pilmanis. 1999. Preoxygenation Time Versus Decompression Sickness Incidence. *SAFE Journal* 29(2):75-78.

10. Webb, J.T., Krause, K.M., A.A. Pilmanis, M.D. Fischer and N. Kannan. 2001. The Effect of Exposure to 35,000 ft on Incidence of Altitude Decompression Sickness. *Aviation, Space and Environmental Medicine* 72(6):509-512.

11. Webb, J.T., Pilmanis, A.A. And M.D. Fischer. 2002. Moderate Exercise after Altitude Exposure Fails to Induce Decompression Sickness. *Aviation, Space and Environmental Medicine* 73(9):872-875.

12. Allan, G.M. And D. Kenny. 2003. High-Altitude Decompression Illness: Case Report and Discussion. *Canadian Medical Association Journal* 169(8):803-807.

13. Ryan, C. 1995. The Pre-Astronauts: Manned Ballooning on the Threshold of Space. Annapolis, Maryland, Naval Institute Press.

14. Ryan, C. 2003. Magnificent Failure: Free Fall from the Edge of Space. Washington, D.C., Smithsonian Institution Press.

15. Winzen Research, Inc. 1959. Manhigh I. Holloman Air Force Base, New Mexico. Available at http://gsfcir.gsfc.nasa.gov/dl/balloontech/2588/PDF/MANHIGH_I.pdf.

FIGURE 1. Ten-Minute Prebreathing Exercise Period to Be Followed by 50 minutes of Rest Preflight. Aviator's breathing oxygen is to be breathed for both the exercise and rest periods. Based on reference 7.

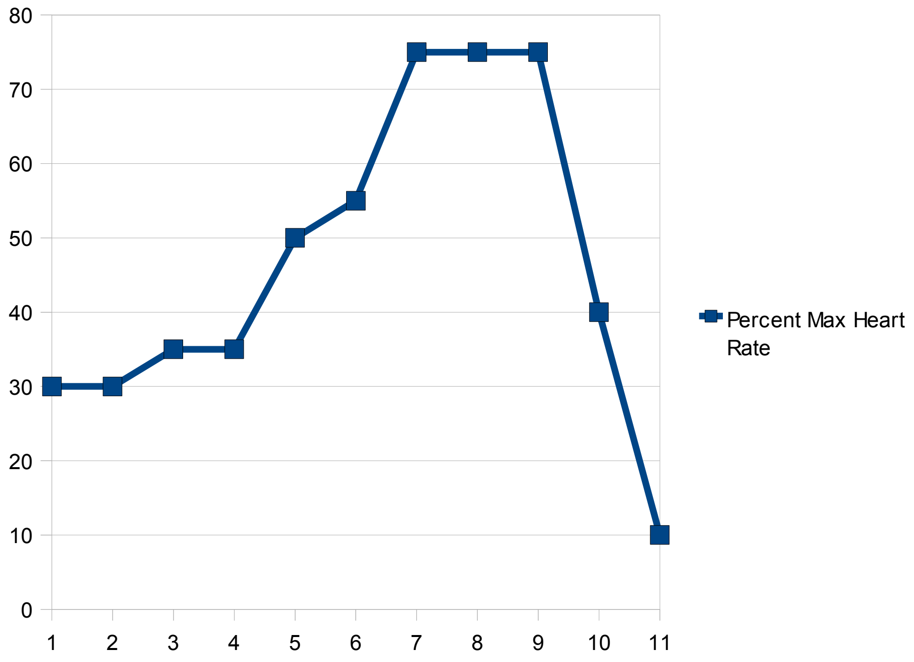
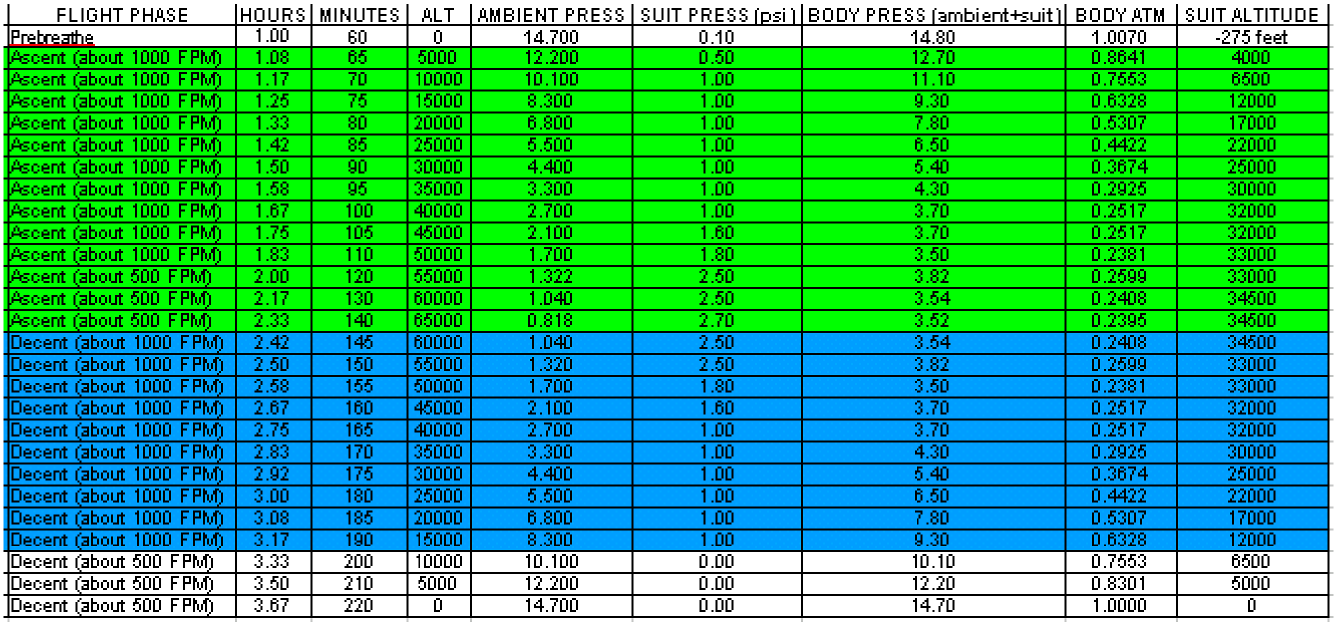
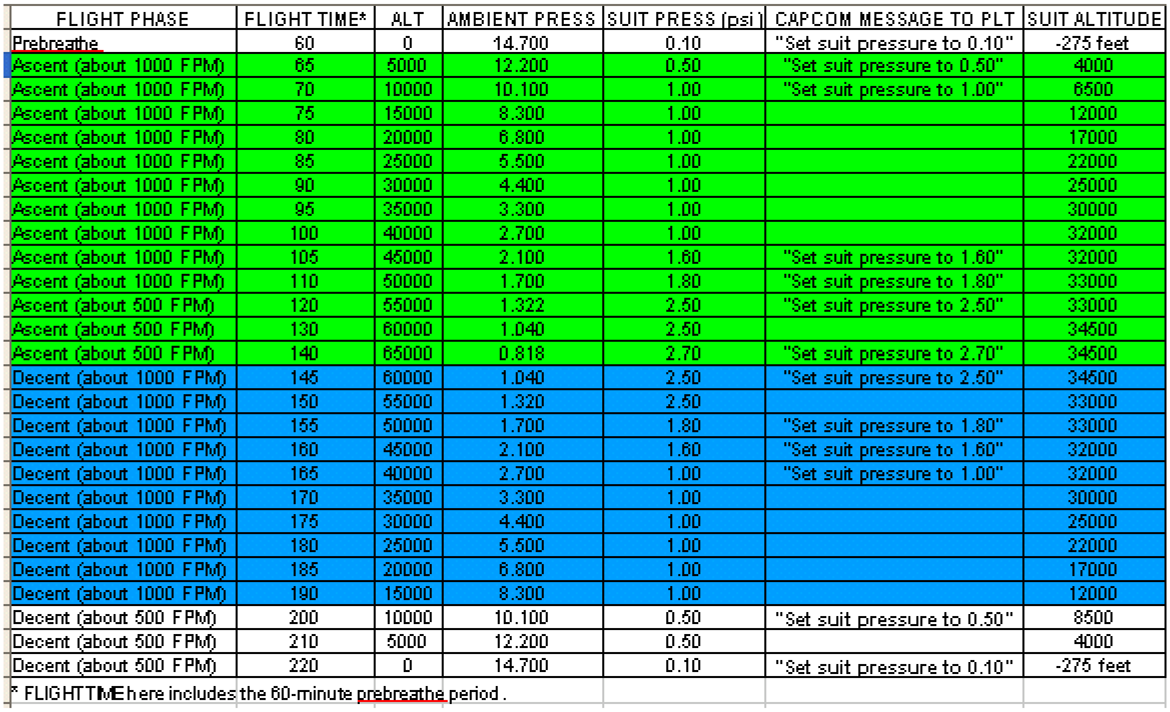


FIGURE 2. Provisional Pressure Schedule for Armstrong Line Expedition to FL650. Ascent and descent rates are estimated in Column 1.



FLIGHT PHASE	HOURS	MINUTES	ALT	AMBIENT PRESS	SUIT PRESS (psi)	BODY PRESS (ambient+suit)	BODY ATM	SUIT ALTITUDE
Prebreathe	1.00	60	0	14.700	0.10	14.80	1.0070	-275 feet
Ascent (about 1000 FPM)	1.08	65	5000	12.200	0.50	12.70	0.8641	4000
Ascent (about 1000 FPM)	1.17	70	10000	10.100	1.00	11.10	0.7553	6500
Ascent (about 1000 FPM)	1.25	75	15000	8.300	1.00	9.30	0.6328	12000
Ascent (about 1000 FPM)	1.33	80	20000	6.800	1.00	7.80	0.5307	17000
Ascent (about 1000 FPM)	1.42	85	25000	5.500	1.00	6.50	0.4422	22000
Ascent (about 1000 FPM)	1.50	90	30000	4.400	1.00	5.40	0.3674	25000
Ascent (about 1000 FPM)	1.58	95	35000	3.300	1.00	4.30	0.2925	30000
Ascent (about 1000 FPM)	1.67	100	40000	2.700	1.00	3.70	0.2517	32000
Ascent (about 1000 FPM)	1.75	105	45000	2.100	1.60	3.70	0.2517	32000
Ascent (about 1000 FPM)	1.83	110	50000	1.700	1.80	3.50	0.2381	33000
Ascent (about 500 FPM)	2.00	120	55000	1.322	2.50	3.82	0.2599	33000
Ascent (about 500 FPM)	2.17	130	60000	1.040	2.50	3.54	0.2408	34500
Ascent (about 500 FPM)	2.33	140	65000	0.818	2.70	3.52	0.2395	34500
Decent (about 1000 FPM)	2.42	145	60000	1.040	2.50	3.54	0.2408	34500
Decent (about 1000 FPM)	2.50	150	55000	1.320	2.50	3.82	0.2599	33000
Decent (about 1000 FPM)	2.58	155	50000	1.700	1.80	3.50	0.2381	33000
Decent (about 1000 FPM)	2.67	160	45000	2.100	1.60	3.70	0.2517	32000
Decent (about 1000 FPM)	2.75	165	40000	2.700	1.00	3.70	0.2517	32000
Decent (about 1000 FPM)	2.83	170	35000	3.300	1.00	4.30	0.2925	30000
Decent (about 1000 FPM)	2.92	175	30000	4.400	1.00	5.40	0.3674	25000
Decent (about 1000 FPM)	3.00	180	25000	5.500	1.00	6.50	0.4422	22000
Decent (about 1000 FPM)	3.08	185	20000	6.800	1.00	7.80	0.5307	17000
Decent (about 1000 FPM)	3.17	190	15000	8.300	1.00	9.30	0.6328	12000
Decent (about 500 FPM)	3.33	200	10000	10.100	0.00	10.10	0.7553	6500
Decent (about 500 FPM)	3.50	210	5000	12.200	0.00	12.20	0.8301	5000
Decent (about 500 FPM)	3.67	220	0	14.700	0.00	14.70	1.0000	0

FIGURE 3. Revised Pressure Schedule Including Capcom Messages to Pilot. This schedule does not allow for opening the pilot's visor at 10,000 feet MSL on descent, but keeps from .50psi to .10psi in the pressure suit until landing.



FLIGHT PHASE	FLIGHT TIME*	ALT	AMBIENT PRESS	SUIT PRESS (psi)	CAPCOM MESSAGE TO PLT	SUIT ALTITUDE
Prebreathe	60	0	14.700	0.10	"Set suit pressure to 0.10"	-275 feet
Ascent (about 1000 FPM)	65	5000	12.200	0.50	"Set suit pressure to 0.50"	4000
Ascent (about 1000 FPM)	70	10000	10.100	1.00	"Set suit pressure to 1.00"	6500
Ascent (about 1000 FPM)	75	15000	8.300	1.00		12000
Ascent (about 1000 FPM)	80	20000	6.800	1.00		17000
Ascent (about 1000 FPM)	85	25000	5.500	1.00		22000
Ascent (about 1000 FPM)	90	30000	4.400	1.00		25000
Ascent (about 1000 FPM)	95	35000	3.300	1.00		30000
Ascent (about 1000 FPM)	100	40000	2.700	1.00		32000
Ascent (about 1000 FPM)	105	45000	2.100	1.60	"Set suit pressure to 1.60"	32000
Ascent (about 1000 FPM)	110	50000	1.700	1.80	"Set suit pressure to 1.80"	33000
Ascent (about 500 FPM)	120	55000	1.322	2.50	"Set suit pressure to 2.50"	33000
Ascent (about 500 FPM)	130	60000	1.040	2.50		34500
Ascent (about 500 FPM)	140	65000	0.818	2.70	"Set suit pressure to 2.70"	34500
Decent (about 1000 FPM)	145	60000	1.040	2.50	"Set suit pressure to 2.50"	34500
Decent (about 1000 FPM)	150	55000	1.320	2.50		33000
Decent (about 1000 FPM)	155	50000	1.700	1.80	"Set suit pressure to 1.80"	33000
Decent (about 1000 FPM)	160	45000	2.100	1.60	"Set suit pressure to 1.60"	32000
Decent (about 1000 FPM)	165	40000	2.700	1.00	"Set suit pressure to 1.00"	32000
Decent (about 1000 FPM)	170	35000	3.300	1.00		30000
Decent (about 1000 FPM)	175	30000	4.400	1.00		25000
Decent (about 1000 FPM)	180	25000	5.500	1.00		22000
Decent (about 1000 FPM)	185	20000	6.800	1.00		17000
Decent (about 1000 FPM)	190	15000	8.300	1.00		12000
Decent (about 500 FPM)	200	10000	10.100	0.50	"Set suit pressure to 0.50"	8500
Decent (about 500 FPM)	210	5000	12.200	0.50		4000
Decent (about 500 FPM)	220	0	14.700	0.10	"Set suit pressure to 0.10"	-275 feet

* FLIGHT TIME here includes the 60-minute prebreathe period .