2-13-2015

Pressure Test Results Regarding Convolute Elbow Segments and Biomedical Monitoring

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Citation Details
Smith, C. (2015). Pressure Test Results Regarding Convolute Elbow Segments and Biomedical Monitoring. Pacific Spaceflight Research Brief #2015-1

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13 Feb 2015

Abstract

Pacific Spaceflight's Mark II / III pressure garment (model *Gagarin* with one newly-built elbow segment on the left arm) was pressurized to evaluate the mobility allowed by the newly-installed convolute arm compared to the right arm's older convolute elbow segment. Additionally a new helmet hold-down cable system was tested, as well as the C02 scrubbing system and heart rate, Sp02, suit's exhausted gas C02 levels and a new communication system. At pressures of 2.3psi – 2.5psi the helmet hold-down cable came free of the new hardware (a sailboat's one-way cleat system), raising the helmet ring explosively. This resulted from the hold-down cable coming free of the cleat cams due to changing geometry of the suit during inflation. All other tested elements worked well.

1. Introduction

On 07 Feb 2015 Pacific Spaceflight members CM Smith and A Knapton, accompanied by visitor Sarah Kay, put CM Smith into the Mark II/III pressure garment to test a variety of subsystems.

Breathing Gas was normal air (c.80% N, 20% 02) delivered from a 30 cubic foot (.84 m^3) SCUBA tank pressurized to c.2,800PSI at a flow rate of 60 cubic feet per hour (28 liters per minute) throughout the test. Suit pressure was manually controlled by the suited subject activating either the trainer cockpit's Suit Pressure Valve or the pressure garment's Emergency Manual Overpressure Dump Valve, mounted on the right thigh. The test lasted just over 17 minutes, during which suit biomedical data, communications, C02 data and general overview (via webcam) were monitored by A Knapton, operating the Control cabinet. During the test, suit pressure was raised to 2.3-2.5psi two times, and the suited person (CM Smith) operated only a few switches and levers, resulting in low physiological and cognitive demands in this test. Performance of the various subsystems are reported below.

2.1 Convolute Elbow Performance

At pressures above 1.8 psi the suited person evaluated ease of mobility of the elbow and wrist joints in both arms, the left being the newly-built convolute and the right being the convolute built in 2014 (**Figure 1**). Both allowed useful movement of the joints at this and higher pressures than in the Mark I garment, however the new (left) arm convolute was significantly less bulky and easier to flex and twist than the old (right) arm convolute. These are subjective evaluations that should be verified with a load-meter to quantify resistance to bending, but the overall impression is that the new convolute arm sections are radically less bulky and significantly more mobile at higher suit pressures than the older convolutes.

2.2 Helmet Hold-Down Cable Performance

At the first pressurization to >2psi pressures, the helmet hold-down cable assembly – using a sailing spring-operated one-way sheet cleat (similar to a mountaineering 'jumar' cam device) – released suddenly, allowing the helmet neck ring to 'pop' violently up (see video frames in **Figure 2** and video at https://www.youtube.com/watch?v=DZiKEGL_4uI with cable blowouts at just after 7:45 and 12:15). This was due to the changing geometry of the pressure garment cable in relation to the cleat when the suit was pressurized, which change allowed the hold-down cable to slip up (anterior to the torso) and out of the cleat cams. In sailing, this is the normal manner of releasing a sheet from the cleat. Unless this can be prevented by reconfiguring the geometry of the cable in relation to the cleat during pressuization and movement in the suit, this device should be excluded from consideration for this function. This device was tested as a lighter-weight alternative to a spring-activated buckle, but that device is unable to fail in the same way, e.g. having the cable disengage from the cable-stopping device.

2.3 Biomedical Monitor Performance

A CONTEC CMS60D pulse oxymeter monitored and recorded the suit operator's blood oxygenation (Sp02 %) and heart rate (Beats Per Minute) via an ear-clip reporting via a cable routed from inside the helmet through a gastight helmet port to the monitor unit and a PC screen installed in the Control Cabinet. The earclip was effective, but it was easily dislodged by movement of the head and should be secured to the ear with medical tape in the future. The audio and visual representations of these measures were effective monitors for AK to ensure normal physiology of the suited person. Recorded figures are seen in **Figure 3**.

Pulse averaged in the 70's to 80's (slightly higher than normal for the suited person), climbed rather steadily as the suited person increased suit pressure, anticipating the usual loss of mobility at these pressures, and then spiked (to just over 100 BPM) at both times that the helmet hold-down cable released unexpectedly (stars indicated in Figure 3). As suit pressure was relieved and the problem was understood, pulse returned to normal. Note that there is a slight data dropout of pulse less than 2 minutes before the end of the test.

Blood oxygenation was a normal figure for the suited person (98-99%) throughout the test, with perhaps momentary drops immediately after helmet hold-down cable release events, though it is not clear if these are causally correlated.

2.4 C02 Monitor Performance

An RAD-0301 Miniature C02 and Temperature Monitor was used to monitor suit gas exhausted from the suit through its manual pressure setting valve installed inside the Kazbek trainer. Data recorded are seen in **Figure 3** and discussed below.

Although the C02 scrubbing system pumps were run during the test (to monitor their power consumption rates and to test the gastight properties of their various chambers and hoses), the scrubbing chamber contained no C02 absorption medium. Thus, high C02 levels were noted throughout the test, averaging just over 2800 parts per million, a figure that if breathed causes Average to Dysfunctional cognitive performance in a variety of tasks [Satish et al. 2014; see also **Figure 4**]. The suit occupant did not notice any signs of C02 poisoning, however; nor did the test technicians notice impairment of his speech or performance [NOTE: *a C02 Poisoning Symptoms diagram will be posted on the Control Cabinet for all future tests*]. This is likely because the gas being drawn from the suit to flow past the C02 sensor is drawn from the lower-left abdomen through-port, whereas breathing gas is continuously flowed into the helmet via a tube mounted just anterior of the lips. C02-rich gas exhaled from the lungs, then, appears to migrate out of the helmet region, which is continually replenished with a continuous flow of breathing gas (in this case, normal air) that should contain <500PPM C02. Future tests will monitor C02 levels in the helmet and other regions of the suit, simultaneously, to verify this impression. In any case, the 2800PPM C02 level is too high, and reducing it by some combination of improving gas flow routing and C02 scrubbing (in a semi-closed system) is being actively pursued.

2.5 Communication System Performance

Motorola model MR350-R consumer walkie-talkies were used for helmet-to-exterior communications. One radio is mounted on the side of the Kazbek trainer frame, with its leads routed to the helmet (which contains the microphone and speaker) through a gastight helmet throughport. The A push-to-talk transmit button fashioned from a normally-circuit-open momentary switch was mounted in a large grip on the trainer frame (**Figure 5**). This allowed the suited person to transmit by pressing the button only, saving the power and complications of VOX-activated or other modes of transmission, many of which have been attempted, with varying success, in several years of testing these systems. The large grip was installed so that the transmit button could be found easily with somewhat bulky, pressurized gloves, even without visually locating it; once the grip is found, simply by feel if the suited person is engaged in some other activity, finding the small transmit button was easy. It is possible to splice in other such momentary buttons, such that one could transmit by a foot pedal, for example if both hands are engaged; these options will be explored. This system worked well, with loud and clear communications throughout the test.

3. Comments

This test indicated superior flexibility and reduced bulk of the newly-built convolute arm section compared to the 2014-built convolute arm section. The sailing vessel's spring-and-cam helmet hold-down cable stop device was found to be potentially unsuitable for this application. The biomedical and other monitors, and communication systems, were found to function adequately. Real-time and post-test reports from the biomedical and C02 monitors were found to be tolerably accurate and useful during and after tests, ensuring that tests may now be quantified and and analyses improved.

4. References

[1] Satish, U. et al. 2014. Is CO2 an Indoor Pollutant? Direct Effects of Low to Moderate CO2 Concentrations on Human Decision?Making Performance. *Environmental Health Perspectives.* Online at doi:10.1289/ehp.1104789.

FIGURE 1. Pacific Spaceflight Model II/III Pressure Garment (Left) with lightweight, slim convolute elbow section installed on suit's L arm and older section on suit's R arm. Right photo shows suited person installed in Kazbek trainer.

FIGURE 2. Sailing vessel spring-activated cam-action cleat used as helmet hold-down locking mechanism in test reported here.

FIGURE 3. Biomedical data visualizations for 17-minute test reported here. See text for discussion.

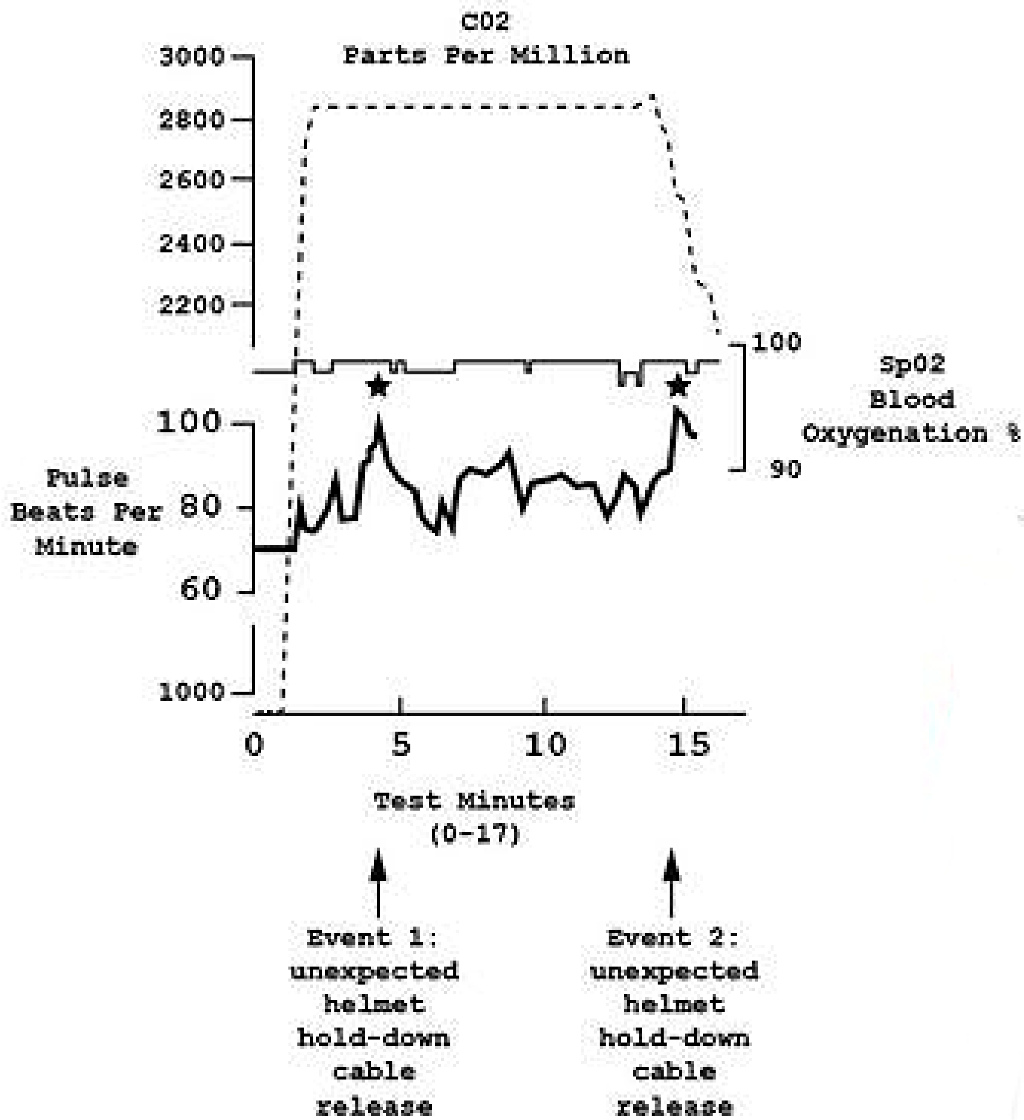

FIGURE 4. Carbon dioxide levels and impairment effects, 600PPM-2,500PPM (modified after Satish et al. 2014). Note that effects differ not only by C02 level but also by variety of cognitive action; nevertheless, levels below 600PPM may be considered generally unacceptable and levels above 1,000PPM may be considered generally unacceptable.

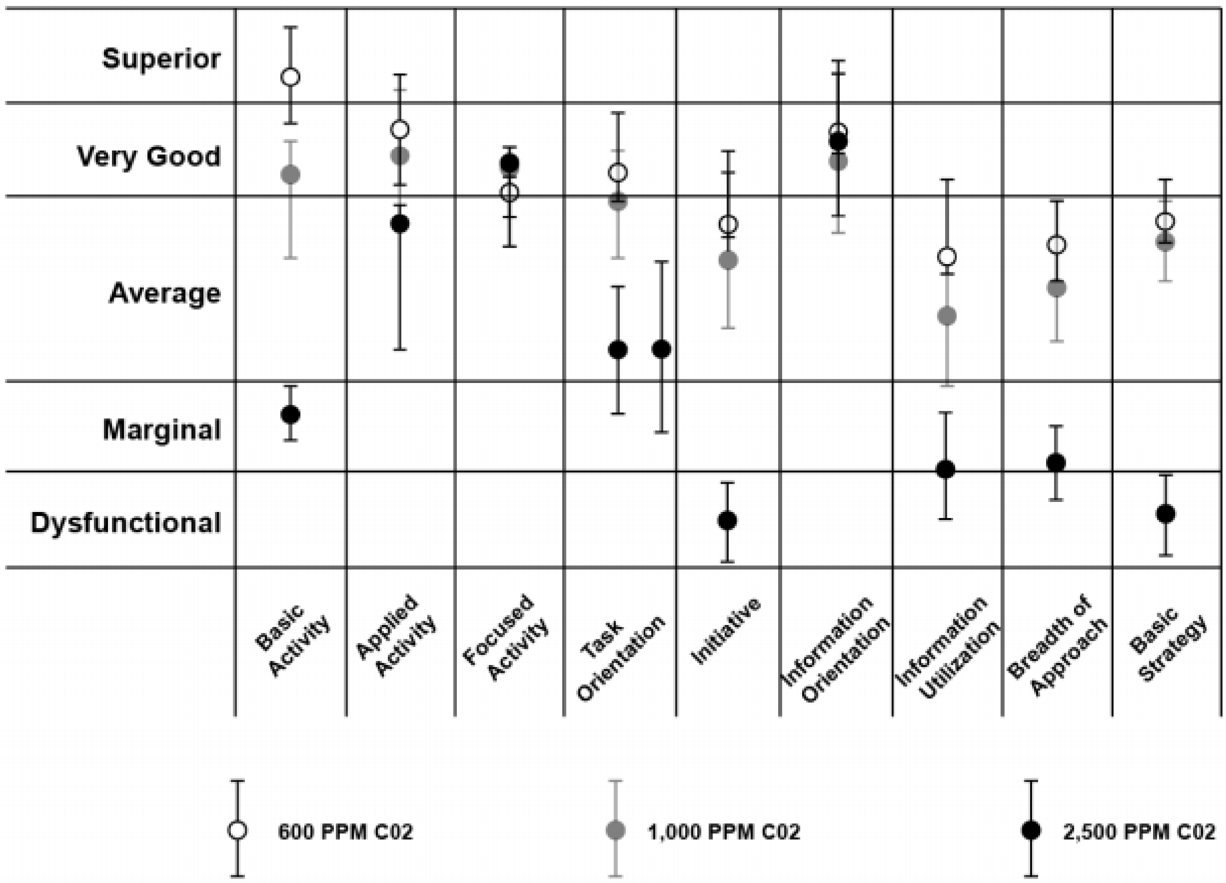

FIGURE 5. Manual push-to-talk momentary button used in reported test to transmit from the Kazbek trainer via mounted Motorola radio (L) and microphone & speaker mounted inside helmet.