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Twenty Years of Canadian Altitude Research at DCIEM

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ABSTRACT

Following a tradition of pioneering research in protection of aircrew from the effects of high-altitude exposure, in 1975, DCIEM once again became involved in a project that would push the then state-of-the-art in altitude protection. In support of Canada's New Fighter Aircraft Program, DCIEM developed a "get-me-down" protective ensemble that would allow aircraft operations to as high as 80,000 ft. without the requirement for a full pressure suit. Although this technology was never used by Canada, its development led directly to DCIEM being invited to participate in the USAF program, called the Tactical Life Support System (TLSS). Continued research has pushed our understanding of the physiology of positive pressure breathing (PPB), and utilizing our latest designs of full coverage anti-G-suits, DCIEM subjects can routinely undergo exposures of 20 minutes at PPB levels of up to 80 mm Hg. As a result of this work, DCIEM is now considered to be the leading authority in high-altitude protection and the physiology of PPB.

RÉSUMÉ

Dans la longue tradition des précurseurs en matière de recherche sur les effets de l'exposition à haute altitude, en 1975 l'IMCME a une fois de plus participé à un projet qui aurait pour effet de repousser davantage les frontières de la protection en haute altitude. Afin d'appuyer le Programme du nouveau chasseur canadien, l'IMCME a mis au point un ensemble protecteur de saut ("get-me-down") qui permettrait de voler à environ 80 000 pi. sans qu'il ne soit nécessaire d'enfiler une combinaison pressurisée complète. Bien que le Canada n'ait jamais utilisé cette technologie, sa mise au point a donné lieu à une invitation lancée à l'IMCME pour participer au programme "Technical Life Support System (TLSS) (Système de survie technique) de la USAF. Des recherches subséquentes nous ont permis de mieux comprendre la physiologie de la respiration sous pression positive (PPB). Par ailleurs, l'utilisation de notre plus récente combinaison complète anti-g a permis aux sujets de l'IMCME de s'exposer régulièrement pendant 20 minutes à des niveaux PPB de 80mm de Hg. Ces travaux ont ainsi permis à l'IMCME de devenir le chef de file en matière de protection en haute altitude et en physiologie PPB.

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INTRODUCTION

During and after the Second World War, the Royal Canadian Air Force (RCAF) Institute of Aviation Medicine (IAM) had an illustrious record of ground-breaking research in the area of aircrew protection for high-altitude flight. Some of the earliest work on the effects of positive pressure breathing (PPB), both at altitude and under high acceleration, was carried out in the Toronto laboratory. Unfortunately, most of the results of this research was lost during the 1950–60 timeframe when a management perception arose that anything not discovered during the previous 10 years was not worth retaining. As a result, all the reports and records of this world-leading research were destroyed.

In 1966, I was sent by the Defence Research Board of Canada on a post-doctoral fellowship in aviation medicine at the Royal Air Force (RAF) Institute of Aviation Medicine (IAM) in Farnborough, UK. While at Farnborough, I was involved in studying the effects of positive pressure breathing and explosive decompressions at altitudes to 56,000 ft. On my return to the Defence Research Medical Laboratories, a predecessor of Defence and Civil Institute of Environmental Medicine (DCIEM), I became involved in diving research.

This all changed in 1975 with the release of the Statement of Requirements (SOR) for the New Fighter Aircraft (NFA). This SOR stated that the NFA would be required to cruise at 60,000 ft and pop-up for weapons delivery to 80,000 ft. Most fighters of the day had operational ceilings of 50,000 ft. The challenge was to meet the operational requirements without resorting to a full pressure suit, not considered compatible with fighter operations. As a result, some quick re-education in altitude protection was required. This subsequent work become known as Project Phoenix.

Although the RCAF IAM had done much of the early work on PPB at high altitude, reports were almost non-existent. We then visited United States Air Force (USAF) laboratories at Brooks and Wright Patterson Air Force Bases and the Naval Air Development Center (NADC) Warminster to discuss the USAF and United States Navy (USN) full and partial pressure suit experience. These visits were followed by a visit to RAF IAM, where we were brought up to date on the PPB jerkin and G-suit. I found that nothing very much had changed over the past 10 years as our allies did not then have an operational requirement for such high altitudes.

At this time we also became aware of the new PPB ensemble developed by the Royal Swedish Air Force (RSAF), comprising a mini-abdominal bladder and a 3.2 PPB/G-suit ratio (Larsson and Stromblad, 1967). The RSAF claimed in its paper that its much-reduced abdominal bladder and increase in G-suit pressure provided similar protection to the RAF jerkin (complete bladder coverage of the torso) and G-suit ensemble with equal pressure in the jerkin and G-suit. At DCIEM, we reasoned that if the Swedish suit, with its much reduced jerkin, could equal the protection of the RAF ensemble, then perhaps the RAF ensemble would provide greater protection if it was used with an increased PPB/G-suit pressure ratio.

GROUND-LEVEL EXPERIMENTS

To explore this theory, we planned a very ambitious experiment to compare three suits covering a total of 10 PPB conditions and 10 subjects. This resulted in a 10 x 10 Latin square design — 100 individual experiments which we completed in about six weeks. We selected PPB levels of 50 and 70 mm Hg and investigated jerkins from the RCAF, RAF, and RSAF. The G-suits were very similar. We used PPB/G-suit pressure ratios of 1 and 3.2, except for the Swedish suit, which we used only with a ratio of 3.2. The PPB ratio of 3.2 had been used by the RSAF (Larsson and Stromblad, 1967).

The results of these experiments were reported (Ackles *et al.*, 1978) and led to an elimination of the early RCAF jerkin from further consideration as it was proven inadequate at the higher PPB pressures. We confirmed the Swedish claim that the RSAF suit offered equal protection to the RAF ensemble with a ratio of one. As we had speculated, the RAF ensemble with a ratio of 3.2 gave the greatest protection against physiological effects of PPB. In this experiment, we began a long study on the cardiovascular effects of PPB using impedance cardiography. Although we were mildly criticized for using a technique that did not have a direct calibration, we were convinced that we were at least accurately measuring relative changes in stroke volume and cardiac output. I believe that subsequent publications have validated our initial convictions.

The next series of experiments looked at PPB G-suit ratios of 1, 2, and 3.2 (using the RAF ensemble). It was confirmed that of these ratios, 3.2 gave the best protection. We always defined the best protection as that ensemble or ratio that resulted in the least change in cardiovascular parameters from control during the period of PPB. Next, we examined a ratio of 4, which proved to be better than 3.2. Ratios higher than 4 were not evaluated due to reported discomfort during the ground-level PPB. Also, the G-suit pressure at 280 mm Hg was higher than the arterial pressure.

HIGH-ALTITUDE EXPERIMENTS

The next series of experiments looked at PPB at altitude. We felt that we had established an optimal protection package with the RAF jerkin and G-suit and a PPB to G-suit ratio of 4. Since DCIEM had not conducted high-altitude experiments for many years, we started by following a training program based on an RAF IAM report. Starting with explosive (< 0.3 seconds) decompressions to 56,000 ft for three minutes with PPB pressure of 70 mm Hg, we soon progressed to 60,000 ft with the same PPB pressure. As expected, the RAF jerkin and G-suit gave excellent protection with a ration of 4. At this time, we realized the limitation of high levels of PPB using a mask without a pressure or partial-pressure helmet. Some preliminary tests also showed that the RAF P/Q masks would not seal reliably beyond 80 mm Hg. With the maximum level of PPB established at 80 mm Hg, the question of attaining 80,000 ft became relevant.

The Air Standardization Coordinating Committee (ASCC) WP 61 Air Standard on High Altitude stated that the inspired pO_2 must be at least 120 mm Hg. Hence, PPB pressure of 70 mm Hg additional to the 56 mm Hg that exists at 60,000 ft would meet the standard. It was decided to progress carefully with complete studies at 60,000, 72,000, and, if possible, 80,000 ft. The aim of this series of experiments was to determine what degree of hypoxia would still be compatible with full consciousness.

The first series at 60,000 ft for three minutes with 60 mm Hg PPB (PI_{O2} = 114 mm Hg) was uneventful. The next series at 72,000 ft for two minutes with 80 mm Hg (PI_{O2} = 110 mm Hg) was again uneventful, although we were concerned about the effects of exposure to less than 47 mm Hg because of tales of body fluids boiling away. This was 1977, and our understanding was not as advanced as it is today. The series was completed with no problems.

We then repeated the 72,000 ft exposures but with a PPB of 70 mm Hg (PI_{O2} = 100 mm Hg), and again the series was successful. We were especially interested in the arterial oxygen saturation during these exposures. We had developed a rule of thumb that we would not allow the saturation to drop below 65% at any time. Following this success, and having equalled the PI_{O2} at 80,000 ft (100 mm Hg), we cautiously did the rapid decompression series to 80,000 for one minute with a PPB level of 80 mm Hg (PI_{O2} = 100 mm Hg). Our main concern was gas ebullism and not hypoxia. Again, the series was completed successfully without incident. I believe that I reported the only interesting phenomenon due to the extremely low atmospheric pressure (20 mm Hg). With the 80 mm Hg of PPB, there was considerable tearing in the eyes, so much so that it was at times difficult to complete an assigned task. My eyes became quite cold (not uncomfortably so) due to the boiling away of the tears in the low atmospheric pressure.

From these quite extensive physiological and the rather limited performance results, we postulated that emergency get-me-down escape was probably possible from altitudes as high as 80,000 ft. We had shown that a human could survive the hypoxia and high levels of PPB at altitudes as high as 80,000 ft with PPB as high as 80 mm Hg. The question remained whether a pilot could successfully recover a high performance aircraft under these conditions.

FLIGHT SIMULATOR EXPERIMENTS

To answer the question "Could the pilot fly the aircraft?" an interesting series of experiments was devised using a simple non-motion base T-33 flight simulator. We developed a flight profile starting with straight and level flight at an altitude of 40,000 ft with a heading of 360°. At the signal of a decompression, the test subject was to immediately throttle back to idle, deploy the speed brakes, and start a single spiral decent to the left or right to end up at 20,000 ft again with a heading of 360° while maintaining complete control of the aircraft. Each descent was scored on root mean square deviation from the ideal profile by recording outputs from the primary flight instruments. The subjects were trained fighter pilots and an equal number of technicians and scientists from DCIEM who were trained to fly the profiles, the reasoning being that pilots were highly trained so their responses might be considered to be almost reflexes, whereas the non-pilot subjects would perhaps be more sensitive to the experimental conditions.

Following extensive training, we investigated the effects of high levels of PPB on flying performance. No decrement in performance with PPB levels up to 80 m Hg for the two to three minutes was observed. The effects of hypoxia were then examined by providing hypoxic breathing mixtures that maintained the arterial saturation as close to 65% as possible. Again, no measurable effect was observed on flying performance.

The final series of experiments combined the effects of PPB with hypoxia. To do this, we had to provide extremely hypoxic mixtures to the subjects who were pressure breathing at 80 mm Hg. Under this, the most difficult condition, the non-pilots showed slightly more deviation from the ideal flight path than the pilots, but at no time did anyone lose control of the aircraft. All profiles were completed successfully. We interpreted the results of this series of experiments to be an indication that our aim of developing a protective system for emergency get-me-down from altitudes as high as 80,000 ft without the use of a full pressure suit was achievable.

Following these simulator experiments, we evaluated and tested a new jerkin design that had less coverage than the RAF jerkin, but had a more pleasing appearance. While not having quite the protection of the RAF jerkin, the new Canadian jerkin, as it was known, did provide adequate protection as long as the G-suit:PPB ratio was 4:1.

FLIGHT TRIALS

As a final check, we conducted a flight trial in which we decompressed the cockpit during flight. This took place in 1979 in a dual CF-104 equipped with a special PPB regulator. The pilot wore the new CF jerkin and standard G-suit with an RAF P/Q mask. The safety pilot was fitted with a USAF full pressure suit. We conducted four flights (flown by four different test pilots) to a maximum altitude of 64,000 ft. At altitude, cockpit pressurization was dumped and the pilot flew a controlled descent recovery profile. The PPB was set to 70 mm Hg. All flights went well, with the test pilots reporting that they hardly noticed the PPB.

At this time we declared that we had developed the requested system for the Canadian Forces (CF). However, by this time the plans for the NFA had matured into a commitment to the F-18. This aircraft did not have significant altitude capability, so the CF thanked us for our efforts and lost interest in our work.

USAF TACTICAL LIFE SUPPORT SYSTEM (TLSS)

The expertise developed at DCIEM was recognized, however, when the SOR for the Tactical Life Support System (TLSS) specifically directed that the TLSS altitude protection be developed at DCIEM. This led to a long association with the USAF through contractors Boeing and Gentex. DCIEM designed the TLSS G-suit and actually constructed the first integrated TLSS flight suit. DCIEM carried out all the altitude trials and tested the compete system prior to USAF final acceptance trials.

SINCE TLSS

Since the completion of the TLSS project, DCIEM has continued to expand the limits of its knowledge of the physiology of PPB in partnership with the USN at the Naval Air Warfare Center, Warminster.

DCEIM has demonstrated that G-suit coverage is very important for protection against the adverse physiological effects of PPB (Goodman *et al.*, 1992). The new full coverage G-suits offer far superior coverage compared to the standard G-suit. However, our understanding of the physiology of PPB is still incomplete, especially with respect to arterial oxygen saturation (Buick and Porlier, 1991). DCEIM has also demonstrated that it is possible for subjects to sustain PPB levels up to 88 mm Hg for at least 20 minutes with complete coverage G-suits. With the standard G-suit of Project Phoenix, five minutes of PPB at 70 mm Hg was an eternity.

As a result of these Canadian efforts in pushing the frontiers of knowledge in high-altitude physiology over the past 20 years, DCIEM is now recognized as a world leader in high-altitude research.

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