CANADA’S AVIATION MEDICINE PIONEERS

by Lydia Dotto

The RCAF Institute of Aviation Medicine

Aerial view of the RCAF Institute of Aviation Medicine site.

It was a job that gave new meaning to the phrase “knock yourself out.”

Not long after World War II, bioscience officer Roy Stubbs and his colleagues at the Royal Canadian Air Force Institute of Aviation Medicine were trying to improve the design of pilots’ crash helmets and one thing they wanted to know was how much G-force it took to render someone unconscious.

“Nobody knew,” said Stubbs, who commanded the IAM’s Flying Personnel Medical Establishment from 1958 to 1963. “So we had accelerometers attached to our heads and bashed them against steel plates.” The rationale for this seeming madness was that they wanted to design helmets to provide the maximum protection with the minimum weight. They needed to know exactly how strong to make them and knocking their heads against a wall was “the only way we could find out,” Stubbs said.

He believes they got up to about 10 Gs (ten times the force exerted by earth’s gravity). “We had a doctor present—not that he could do anything after you’d done it. We got pretty dizzy at times, but a couple of beers later helped.”

His commanding officer wasn’t quite so sanguine, however. He happened by one day, witnessed their performance and, as Stubbs recalls the encounter, inquired: “What the hell are you doing?” And then added: “I don’t want you to do that anymore.”

Stubbs is one of a special breed of researchers who pioneered aviation medicine in Canada and, indeed, worldwide. Driven by the demands of World War II and the advent of new aircraft that could fly higher and faster than ever before, they broke new ground in studying the effects of high altitudes, low pressures and high acceleration on the human body.

These early researchers often served as their own guinea pigs, sometimes suffering serious injuries as a result. Stubbs, for example, broke his neck while testing ejection seats. “There were no human experimentation rules then—we did what we liked,” he said. “This is a time when we were trying to learn how to do things.” A former RCAF pilot himself, he said his greatest reward “was when the boys who had ejected [from their aircraft] came up to us and said thanks.”

“It was a wonderful career,” agreed Douglas Soper, a former RCAF navigator who was also a bioscience officer at IAM. “Not many people have that kind of excitement. It was, to us, a very useful thing to be doing. You felt a strong affinity for the aircrew. That’s what your job was for—to protect the aircrew. They felt you were part of the team.”

In a very real sense, these men are also part of the team that today includes astronauts and cosmonauts. The work they did on anti-gravity suits, pressure suits, helmets and oxygen masks, ejection seats, decompression sickness and motion sickness are all relevant to flying in space and their research laid a solid foundation on which today's operational space medicine program is based.

World War II Jump-Starts Aviation Medicine in Canada

Nobel Prize winner Sir Frederick Ba

In Canada, it all started with one man—an iconic figure whose name is instantly familiar to many Canadians, though usually not in the context of aviation medicine. Nobel Prize winner Sir Frederick Banting, the co-discoverer of insulin, was head of the University of Toronto's Banting and Best Institute for Medical Research as war loomed in Europe. Following the Munich conference in 1938, Banting did not share the misguided hope of many that there would be "peace in our time."

He was "more farsighted," noted an article in the November 1946, edition of the Journal of the Canadian Medical Services (JCMS). "He realized the inevitability of war. Without delay, he…called upon his staff of brilliant research scientists to familiarize themselves with some problems in the field of war aviation medicine. Thus, in the event of hostilities, Canadian scientists would not be caught napping but would be prepared to come immediately to the aid of their country."

According to Peter Allen, a former commercial airline pilot who wrote a paper on the early years of Canadian aviation medicine for the Canadian Aviation Historical Society Journal (CAHS), much of the credit for getting Banting involved belongs to Major A. A. James of the Royal Canadian Army Medical Corps, who had spent a year studying the state of aviation medicine in other countries. "Realizing that all countries except Germany were appallingly unprepared to support their aircrews in the coming war, James was determined to see that situation changed in Canada." He persuaded the very busy Banting that a research program was needed because the aircraft of the time had exceeded the physical capabilities of the crews that would fly them.

Banting realized immediately that the ability to fly at high altitudes would give Allied crews a tactical advantage in war. As a result, he started a fund-raising program and brought his research team together with James to focus on the most urgent medical problems. The result, said Allen, is that Canada initiated "the most powerful research program in the world designed solely to protect the pilots and aircrew who were about to wage the tremendous aerial battles in the skies over Europe."

Initially Banting's team worked out of the university, but it rapidly became apparent that a more private facility was needed to do classified research. A federal government grant enabled them to purchase the Eglinton Hunt Club near downtown Toronto in 1939. Known first as the No. 1 Clinical Investigation Unit and later as the RCAF Institute of Aviation Medicine, it was a top-secret facility disguised as an aircrew evaluation unit.

One of Banting's colleagues at the U of T, Wilbur Franks, was doing cancer research before the war and it was not immediately apparent what he could contribute to aviation medicine—until he heard James explaining that that fighter pilots were blacking out during high-speed maneuvers, such as pulling up hard out of a dive or making tight, fast turns in aerial dogfights.

These moves created strong centrifugal forces that caused blood to pool in the lower part of their bodies and made it difficult for their hearts to pump blood to the brain. Deprived of oxygen (a condition called hypoxia or anoxia), pilots often experienced first a loss of vision and then unconsciousness. The military considered this one of the most pressing problems affecting the performance of their pilots; James told the IAM scientists that it would provide an enormous tactical advantage if the G tolerance of the Allied pilots could be increased.

The blackouts were a consequence of increased G-forces created by changes in speed and/or direction. One G is the force exerted by earth's gravity, which is measured as weight. Thus, objects subjected to three Gs weigh three times their normal weight. At seven Gs, blood weighs as much as iron. It's not surprising, therefore, that the heart has trouble pumping it out of the body's extremities and up to the brain. In tight turns, the fighter aircraft used during the war, such as Spitfires and Messerschmitt 109s, could subject their occupants to more than seven Gs.

(The opposite situation occurs in negative-G conditions, or weightlessness, when body fluids tend to pool in the head rather than the legs, causing bloating and congestion. Astronauts refer to this condition as "puffy face and bird's legs." However, in the 1940s, that was an issue for the future; the JCMS article commented that "no tactical problem for protection against negative G presented itself during the war.")

What piqued Franks' interest was the fact that the pilots' problems stemmed from being subjected to centrifugal forces. He knew all about centrifuges and the damage they could do; he'd used them to spin test tubes for his cancer research and, after having too many tubes smashed by the G-forces created by spinning, he'd devised a workaround—floating the tubes in water to provide a counterbalancing pressure that cancelled out the centrifugal forces. The question immediately came to mind: could this work for humans as well?

The idea was that the water—which, like blood, gets heavier when subjected to G forces—would exert sufficient pressure against tissues in the lower part of the body to prevent blood from pooling in the veins of the calves, thighs and abdomen, thus allowing the blood to return to the heart in a more nearly normal way. The pressure also supports the arteries that carry blood from the heart. Both effects enhance the heart's ability to pump blood up to the eyes and brain even under considerably increased G loads.

Franks tried it first with mice, fashioning tiny water-filled G-suits for them out of condoms. It worked like a charm—amazingly, the mice tolerated up to 240 Gs without coming to harm. The next step was to develop a suit that could be worn by humans.

Enthusiastic about the potential of this concept to help fighter pilots, Banting sought funds to develop Franks' brain child at a time when many in government were less convinced than he that war was coming. In fact, much of their initial bankroll—the grand sum of $5000—was donated by a private citizen, Harry McLean, a wealthy, eccentric businessman known for his philanthropy.

The Anti-Gravity Suit and the Human Centrifuge

Harry McLean's money enabled Wilbur Franks to buy the materials and hire a tailor to make the first anti-G suit, which was secretly sewn together on an old sewing machine in Franks's office. In May, 1940, he donned this first rough version of his Franks Flying Suit and climbed into a Fleet Finch aircraft at Camp Borden. This was the first time he had ever flown in an aircraft—and he was initiating himself with high-speed aerobatics. He and the pilot were hit with about seven Gs while pulling out of a steep dive; the pilot experienced a temporary blackout but Franks did not.

Wilbur Franks in a plane during a G-force test.

He was jubilant that his concept worked, although it had not been a pleasant experience. The suit was cut to fit him standing up but he was sitting down in the plane. “When the pressure hit, I thought it was going to cut me in two,” he said later.

As a result of the tests, Franks realized that it was not necessary to cover the entire body, but only the essential areas of the lower body. He quickly modified the suit and a month later, it was worn by a Royal Air Force pilot, D’Arcy Greig, who flew a Spitfire in from England for the tests at Malton airport in Toronto. He became the first pilot ever to wear a true G-suit in flight.

Greig’s secret report noted that in his first 30-minute test, he pulled almost seven Gs without blacking out. He added that the suit was “somewhat uncomfortable” to wear, but did not impede his handling of the plane. In another 45-minute test two days later, he reported that the Spitfire “was subjected to almost continuous and violent maneuvers at high speed.” He estimated the maximum G forces exceeded eight Gs. (One dive produced accelerations beyond the limits of the aircraft’s accelerometer.) Again, he did not experience blackouts, but reported a “considerable feeling of fatigue in the legs and feet” at the end of the flight. A third test flight of 55 minutes was done the following day, during which he once experienced very momentary symptoms of blackout.

Grieg concluded that the concept was sound but the suit itself was “not a practical proposition. However, the results obtained were of such a convincing nature that further development is strongly recommended…”

Peter Allen’s CAHS paper noted that one of Greig’s tests “strained the composure of Franks to its limits.” Franks knew the suit reduced a pilot’s ‘seat of the pants’ feel for the plane and it was possible to push the aircraft to the point of breaking up. During one test, Greig disappeared from the view of those watching on the ground and didn’t come back for over half an hour, by which time Franks was on the verge of calling out the crash trucks. When Franks questioned Greig about where he had gone, the British pilot “stated quite matter-of-factly that a friend of his was attending a garden party on the lakeshore near Oshawa and he had put on an airshow for them with the Spitfire.”

An early photo of the Spitfire.

Franks and Banting quickly decided that continued testing of the suit in real aircraft was not the way to go. Not only were flight tests potentially dangerous and subject to the whims of unpredictable weather, they did not provide the precisely controlled environment that Franks required to understand and improve his creation. Since the development of the G-suit was still a top-secret project, they also represented a security risk; it was difficult to shield test flights from unclassified eyes.

This decision led directly to the development of a human centrifuge, the first device of its kind to be built by any of the Allied countries. The Germans had built a smaller, less sophisticated version before the war but Franks' device was the first that could mimic the effects of aircraft acceleration on the human body.

With a $25,000 grant from the National Research Council, a centrifuge was constructed in the Clinical Investigation Unit (CIU) and went into operation in mid-1941. It was a top-secret project, but there were telltale clues of its existence outside the CIU's walls. Powered by a 200 horsepower streetcar motor, it shared the city's electrical lines and every time it was fired up, streetcars on a nearby street would grind to a halt.

The centrifuge consisted of a spherical gondola suspended from a horizontal arm attached to a vertical shaft. The motor rotated the central shaft, causing the gondola to swing out on moveable joints to an almost horizontal position. The test subject sat inside the gondola in a seat resembling those in fighter aircraft. This seat was suspended independently of the gondola, allowing the subject to be positioned at different angles inside the gondola, including in an upside down position to produce negative Gs—a unique feature.

Subjects were monitored by an observer who transmitted signals into the gondola by turning on lights and sounding a buzzer. The subject responded by turning the signals off. A failure to turn off the lights indicated he had blacked out and could not see; however, he was still conscious and could respond to the buzzer. A failure to turn off the buzzer indicated the subject was unconscious.

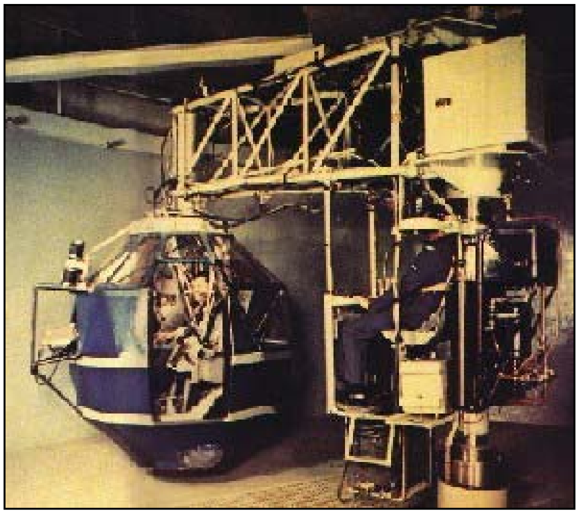
Subjects were also monitored with electrocardiographs, electroencephalographs and by a photoelectric device attached to the earlobe that measured blood flow to the head. The latter confirmed that the volume of blood going to the head was greatly reduced when the subject experienced high G forces.

The tests led to the following conclusions:

- During the standard five second run in the centrifuge, the average man will "greyout" at 4 Gs, blackout at 5 Gs and become unconscious at 6 Gs.
- Tolerance to G forces did not increase even if subjects did repeated runs in the centrifuge every day.

- The threshold at which subjects blacked out did not significantly correlate with age, weight, or body measurements or with resting blood pressure and pulse rates.

The centrifuge was, in fact, used to evaluate humans as well as G-suits. The JCMS article noted that "many aircrew trainees suspected by the instructors of having a very low G tolerance were referred during the war to this Unit for testing purposes. In this way, those with abnormally low G tolerances…were detected and transferred from pilot training before they got into difficulties."



An early centrifuge in use.

His work with the centrifuge enabled Franks to develop the first operationally practical G-suit. It consisted of a rubber bladder covered by a non-stretchable material that forced all the pressure produced by the bladder inward against the body. "As the blood got heavier under G, so too would the water in the suit get heavier and press in against the tissues with a force sufficient to prevent the pooling of blood and to support the arteries," the JCMS article noted.

Although the bladder could be filled with air rather than water, the water-filled suit had one advantage—once it was filled, it worked automatically as soon as G forces occurred. An air-filled suit, on the other hand, required connections to the plane and a source of compressed air to pump into the bladder in flight. In the early days of the war, planes didn't have the power to spare, said Peter Allen. "The planes needed all their power to get to altitude; it's not like they had surplus power to run a generator." He said the brilliance of Franks' design was that it was completely self-contained—precisely what was needed at the time he started working on the problem.

The Franks Flying Suit Mark III was used in combat for the first time in November 1942, by the Royal Navy Fleet Air Arm, which provided air cover for Eisenhower's invasion of North Africa at Oran, Morocco. Several of the pilots who wore the suit reported that it greatly enhanced their ability to maneuver in the air and outfly enemy aircraft without experiencing blackouts.

One noted that under attack by an enemy aircraft, 'I immediately went into a steep turn and pulled round very sharply, causing the enemy to spin. It recovered about 50 feet from the ground and ... attempted to land, probably very shaken." Another commented: "I had hit an enemy fighter. I watched him dive and expected him to crash. He pulled out though and started flying low down ... so I dived on him vertically and got a burst on him. After that I had to pull up sharply to avoid hitting the ground myself, but did not blackout and had complete confidence in the suit."

Allen added that the Royal Navy pilots particularly appreciated having a week's supply of fresh water on board "in case they were forced down in the desert or at sea."

The RAF recommended adoption of the suit for operational use, saying it would provide British pilots with a significant advantage over enemy aircraft. The pilots themselves were enthusiastic about the suit and wanted to wear it during air operations, but the RAF decided to limit its use, despite having stockpiled more than 8000 units, to preserve the secrecy of the device until it could be used to greatest advantage in the invasion of Europe, codenamed OVERLORD. There was concern that if it fell into enemy hands too soon, this advantage would be lost.

Moreover, by the time the suit was being mass-produced, the nature of the war had changed. Rather than engaging in short, furious dogfights, fighter pilots were more likely to find themselves escorting bombers over long distances—a situation that did not endear the heavy and uncomfortable water-filled suits to those who had to wear them.

“On longer range bombing missions, they were in the air for six to eight hours,” said Allen. “The crews resisted the suit. There were temperature issues—how do you keep it warm? It was heavy because it was filled with water. And it was uncomfortable because it was always filled. So you had a warmth problem, a weight problem and a comfort problem.”

Photos of the Mark VI (left) and Mark VII g-suit, two of the later models.

At this time, jet aircraft were starting to make an appearance and they did have sufficient power to pump air into the pilots’ G-suits. Later versions of Franks’ suit did, in fact, use air-filled bladders. They were lighter and more comfortable than the water suits but they were also more complex, requiring connections to the aircraft and valves to regulate airflow. These valves were designed with a spring-mounted weight that allowed air into the suit only when the G forces exceeded 2 Gs, so pilots only flew with inflated suits when it was necessary.

Even though Franks’ original suit was not used to the extent he’d hoped, his concept was the progenitor of the G-suits that were later worn not only by pilots but also by astronauts. Allen said the Canadians shared their findings with researchers who were also working on the problem in the United States, Britain and Australia. “The whole issue of acceleration had been around, but the problem just hadn’t been solved. There was a lot of research into ways to deal with acceleration but none of them worked. Franks’ suit was the first that worked. After Franks’ discovery was provided to them, everybody got in the game but it was because of Franks’ original discovery that they were even in the game.”

Allen added that Franks can also be credited with pioneering the use of the human centrifuge in acceleration research. He interviewed one of the German scientists who came to the United States to work in the space program after the war. “His view was that Franks made two significant contributions—the concept of the suit and creating the first suit that worked, and also the creation of the centrifuge to do acceleration research. There was no question in his mind about the breakthroughs Franks made.” This scientist told him that the German centrifuge developed before the war was “not a true human centrifuge” that could be used for research on the effects of acceleration.

Charles Bryan was a doctor who worked with Franks on the centrifuge studies in the 1950s and 1960s. His research focused on the effects of acceleration on the lung. He found that the alveoli—the tiny sacs at the bottom of the lung where oxygen actually transfers from the lung to the blood, became greatly compressed. This caused the subject to experience a lack of oxygen because “the bottom of the lung was essentially collapsed and almost airless.”

Bryan said the legacy of the G-suit is as important today as it was 60 years ago. “With the latest generation of fighters, G forces have come back as a really serious problem. G-forces with modern fighters are potentially very high indeed. They’re dodging rockets, doing terrain flying up and down, turning all the time, so G forces have come back with a vengeance and are as important as they were during the last war.”

As for Frederick Banting, he didn’t live to see the success of the invention he had championed. He was killed in February 1941, when the plane he was flying in crashed in a snowstorm near a frozen lake in Newfoundland. Two of the four people on board were killed and Banting and the pilot, Joseph Mackey, suffered serious injuries. Mackey was able to leave the plane to search for help, but the severely injured Banting died before the pilot returned.

Banting had been on his way to England to enlist the support of the British military for continued development of the Franks Flying Suit. He was reportedly carrying a copy of the suit on the plane with him. “It may be mythology, but that was the word of mouth that got carried down,” said Bryan. “The timing was absolutely right. Franks had just produced the suit so it was logical to take it to the Brits at that time.”

The purpose of Banting’s trip was not for public consumption, however. The newspaper article mentioned that Banting was on a “secret” medical mission and quoted an official of the National Research Council saying that “when the time comes and his contribution can be adequately assessed, it will be clear that no one has done more for our cause.”

In his paper, Allen noted that “thousands of Allied fliers would likely never realize how great a part he played in increasing their chances of survival in the skies over Europe and Asia. It is incredibly ironic that his last great field of research would involve the instrument of his untimely death.”

Allen said the early Canadian effort in aviation medicine was unequalled, comparing it to the U.S. Apollo program: “Never before had so many scientists been readily diverted to a single research project of such magnitude. Never before had so much been accomplished in so little time. Many years later, as Project Apollo unfolded from the U.S. Manned Space Program, the scale of Sir Frederick Banting's research efforts in aerospace medicine would finally be matched by another country.”

Pressure Suits

The G-suit dealt with only one of the physiological challenges faced by pilots flying high-performance aircraft. As planes flew higher and higher, crews also had to be protected against the drop in atmospheric pressure with altitude. Early military aircraft were not pressurized at all and were limited in how high they could fly without endangering the crew. Aircraft that were pressurized to maintain a safe level of internal pressure could fly much higher—but crews were still at risk if there was a sudden loss of pressure (known as explosive decompression) or when bailing out at high altitudes.

There are two kinds of pressure suits: partial pressure suits and full pressure suits. The former do not cover the entire body and contain inflatable tubes that apply pressure to the chest area, as well as the arms and legs. Above about 50,000 feet, pilots require a completely sealed full-body pressure suit equipped with an oxygen breathing system. These suits protect against several physiological risks associated with high-altitude flying, including:

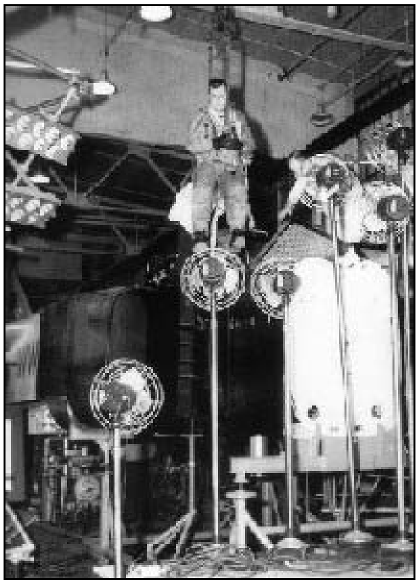
- Hypoxia: a decrease of oxygen in the blood caused by reduced atmospheric pressure. Hypoxia can affect vision, cause dizziness and reduce muscle coordination. Without an oxygen supply, pilots can lose consciousness in less than a minute after exposure to low pressures at high altitudes.
- Decompression sickness, also known as “the bends”: joint pain caused by nitrogen bubbling out the blood and tissues as a result of a rapid decrease in atmospheric pressure. Severe cases can result in death.
- Armstrong’s line: the altitude (roughly 60,000 feet) at which water goes from a liquid to a gas (i.e. boils) at body temperature. Exposure above this altitude can cause unconsciousness and death in seconds.

In the 1950s, after graduating from the University of Western Ontario with a degree in math and physics, Roy Stubbs worked on developing pressure suits for pilots who would be flying new Canadian fighter aircraft such as the Avro CF-100 Canuck and the soon-to-be-infamous Avro Arrow, which were then in development. These aircraft did not require the use of full pressure suits because they were used for fairly short-duration missions, unlike bombers that flew missions lasting many hours. What was required, said Stubbs, were “get-you-down suits” that could protect the pilot in the event of an explosive decompression while he brought the plane to a lower altitude. “Fighter or interceptor aircraft usually operated near base, unlike the bombers, so the suits got you down from altitude safely to return home if cabin pressure was lost,” Stubbs said. (Bombers, which ranged much further afield, couldn’t simply descend a safer altitude because this would increase fuel consumption, making it more difficult to get home.)

A photo of some of the early models of the pressure su

In the fighters, it was sufficient to wear a pressure vest and anti-G suit that could be inflated differentially if the aircraft lost pressure or created G forces. To accomplish this, Stubbs developed a pressure-gravity valve that was fitted to the pressure vest and went down to the G-suit. If the pilot experienced G forces, only the G-suit inflated. If cabin pressure was lost, both the G-suit and the pressure vest were inflated and a pressure oxygen mask was activated.

Stubbs said the development of the partial pressure suit was one important reason why the design of the Franks G-suit was switched from water to air. Both would be needed for the Arrow, which was being developed at the time. The scientists at the Institute of Aviation Medicine (IAM) and its successor organizations "were very much involved in developing equipment for it. We fitted out the test pilots with these suit systems so when they flew the Arrow, they had protection."



Soper during one of his pressure s experiments.

Since both the G-suit and the pressure vest were made of rubber, aircrew wearing the suits ran the risk of suffering heat stress in flight. "The body loses a lot of heat by evaporative cooling. If you put on an impermeable suit, you can't lose heat by the evaporation of moisture," said Douglas Soper, who worked on the design and testing of a ventilation system for the suit.

The overheating resulted not only from the pilot's metabolism and exertions but also from aerodynamic heating of the skin of the aircraft, which was radiated into the cabin. (Astronauts inside the space shuttle face a similar phenomenon during re-entry into the earth's atmosphere, which is why the shuttle is coated underneath with heat-resistant tiles.)

One of the options for ventilating the suits was to create a garment threaded with small tubes filled with cooling water, a design that is employed today in the suits used by astronauts for spacewalks. However, in Soper's day, they decided this was too complicated and instead developed a system that drew air from the aircraft's air conditioning system. This resulted in a tug-of-war with the engineers responsible for the Arrow's cooling system.

The Arrow "was a very demanding aircraft in many ways," said Soper. "We hadn't got to the sophisticated electronics we have today; we had the old-fashioned radio tubes. They not only used a lot of electricity, they produced a lot of heat. Every time I thought I had enough AC [for ventilating the suit], the electronic engineers would have to have some more cooling for the electronics bay and they would take it away from the cockpit and its occupants. It became quite a back-and-forth struggle."

After testing the ventilated suit in a wooden mockup of the aircraft using heat lamps to simulate high-heat conditions, Soper was ready to try it in the Arrow itself. The test never happened. "I was supposed to fly in the Arrow the day it was cancelled," he said.

Like everyone else associated with the project, he was shocked and disappointed by the news. However, he didn't have much time to brood about it because he was scheduled to go to the Royal Air Force Institute of Aviation Medicine in Farnborough, England, to continue work on air-cooled garments. "The British were very interested in what we had been doing with the Arrow and they picked my brain. They were building the TRS-2, a big fighter aircraft that had a lot of similar features. They were particularly interested in the design of our cockpit AC outlets because if large quantities of air are blown out of an orifice, a very noisy whistling condition results which they were having trouble solving."

In 1959, Soper went to Farnborough, where he spent more than two years engaged in several research projects. His interest in how the body loses heat led him into some interesting adventures. For example, he studied professional fish filleters who worked on the docks cutting up cod fish off the fishing ships. The fish were kept in ice to preserve them and the filleters were continually plunging their hands into icy seawater. “They were very skilled men. They were filleting the fish with razor sharp knives—it was like skilled surgery with ice-cold hands. They were so cold that if they missed with the knife and cut their hands, they wouldn’t even know it until they saw them bleeding. I wondered, how could they do this?”

Many people tried the job because it paid well, but most gave it up in short order because they couldn’t stand the cold. “Some could only stand it once, some for a week. But some of them could do it all the time,” said Soper. “They were a unique set of people that had unique blood flow through the hands.”

At the other end of the temperature scale, Soper subjected himself to sweltering conditions to gain insight into the mechanisms of body heat loss and the conditions that induce heat stress. “We were trying to understand what goes on in a cockpit when people get overheated,” he said. “Heat stress can be fatal very quickly.” He recalled an incident in which two U.S. pilots were flying long distances over tropical waters wearing rubber suits to protect them if they went down at sea. “One guy got into real trouble from heat stress. He was flying so erratically at the end that it was obvious he was going to crash. You could hear the two pilots on the intercom, hollering, pull up, pull up. Too late, too late.”

In extreme heat conditions, Soper said, “you reach a point where you can’t lose heat, you can only gain heat. You can’t lose heat from conduction or convection if the air around you is hotter; you can’t lose heat by evaporative cooling if the air is saturated.”

That’s exactly the state he found himself in during tests at Farnborough. He lay on a bed on top of a large balance arm inside a compartment that he described as “a big tin can.” The temperature and humidity were maintained at a level that made it impossible for his body to lose heat. The subject had to remain motionless during the heat exposure so that the beam balance could measure the amount of sweat that dripped off his body. The exposures were about one hour long.

This system allowed his body temperature to continue climbing into an artificial fever situation. “You would get very hot,” he said. In fact, he sometimes went into convulsions due to hyperventilation. The people who were monitoring the experiment couldn’t see him inside the tin can, but they were alerted to the convulsions when the balance arm on which the bed was resting started to shake. “They'd put my head in a paper bag so that I could re-breathe my own respiratory carbon dioxide and in a couple of minutes the convulsions from the hyperventilation would stop.”

For relief, he would sometimes slip outside the building into the cool morning air. “I was stark naked and I would go out and lean against the wall—it was the quickest way to cool off. One day, I was leaning against the wall with my eyes closed when I heard a female voice saying, ‘Good morning, Flight Lieutenant.’ I don’t think I was even interested in replying, I was so hot.”

Between 1954 and 1956, Roy Stubbs also worked at Farnborough on the development of full-body pressure suits. These suits were not being developed in Canada at the time because Canada was not flying long-range bombers on which they would be needed. Some of the bombers could fly above 50,000 feet and the flights could last for many hours, so the crews needed protection from getting the bends in the event of cabin depressurization. “The bomber crews were normally far from base, so they had to stay at altitude to have enough range to continue on the mission, or to get home if cabin pressure failed,” Stubbs said.

The British were flying bombers, so Stubbs was seconded to Farnborough to help develop a full pressure suit there. As its name suggests, and unlike the partial pressure suit, the full pressure suit covers the entire body, including the hands and feet, and also requires the use of a pressure helmet. The entire unit must be completely sealed.

One of the things Stubbs examined was the suit's comfort factor. "We had done testing in altitude chambers, so we knew the suit would protect us. What we had to find out was whether it was a practical thing to wear. Could you fly in it? Was it too cumbersome?"

Like Soper, he was also interested in heat stress. Wearing the suit was like wearing a rubber glove all over the body and it could be "pretty miserable," he said. It had to be ventilated even while the aircrew was walking to board the plane.

Particularly concerned about the use of the suit in tropical climates, Stubbs and his colleagues tested it in a bomber flying out of Khartoum, Sudan. It was so hot that the plane couldn't take off during the day because its jet engines needed cooler air; in fact, it could barely taxi. Stubbs noted that these tests demonstrated that ventilation suits were needed even on the ground, as temperatures could reach nearly 60˚C. He added that the plane was always welcomed by ground crews at the bases it visited because, after flying at 52,000 feet, it was nicely chilled. "They wanted to climb inside a cold airplane, so we got great treatment."

Another result of the tests, he said, was the realization that "more development work was necessary to improve our full pressure helmets."

Helmets and Oxygen Masks

An early model of an oxygen mask to be used with a pressure suit.

Pressure suits were of little use without proper helmets and oxygen masks and the Institute of Aviation Medicine (IAM) scientists invested a lot of effort in improving both. As head of the Flying Personnel Medical Establishment, Roy Stubbs felt there was an urgent need for a new helmet design that would protect aircrew during ejections from high-speed aircraft. One of the major goals was to design a helmet and mask that would stay on the pilot's head during an ejection or a crash. "The crash hats we were using would not stay on your head when you crashed—they were always coming off," said Soper, who headed the team that tested the new design from 1961 to 1967 after returning from Farnborough.

The helmets were also vulnerable to being whipped off by the plane's slipstream when a crewmember ejected. When that happened, he also lost his oxygen mask and communications system. Stubbs developed on a new helmet design that would ensure the pilot would keep the oxygen mask during the ejection process. "We had to design it as a two-piece unit and that had never been done before. You put it on as a one-piece unit, but if the wind force was too high, the outer shell would just break off. It disconnected, but left the mask on." He took the idea to Gentex, a company that was the top helmet maker in the United States at the time, and they built a model that was put through extensive trials at IAM.

Stubbs devised a way to test the helmet designs for slipstream tolerance in the decompression chamber—although not with human subjects this time. ("There were limits," said

Douglas Soper.) The window of the chamber was removed and replaced with a stovepipe that acted as an air funnel. Then a dummy's head wearing the helmet being tested was placed in front of the stovepipe. With just a thin piece of kraft paper covering the stovepipe hole, the pressure in the chamber was reduced to the desired altitude. "When you cut the paper, the air would rush in with an instantaneous pulse," said Soper.

This work resulted in the development of "the first helmet that would stay on your head in an accident," he said. It was used by the Canadian Air Force for many years.

Of course, the oxygen systems associated with the helmets were also critically important. In his CAHS paper, Peter Allen notes that "in 1939, the oxygen masks used by the British, American and Canadian air services were sadly inadequate. They were extremely wasteful of oxygen and many a mission had to be completed after the supply had been used up." He said that Canadian-developed pressure vests and oxygen masks allowed Allied pilots to fly 2000 to 5000 feet higher than enemy pilots. "This was a closely guarded secret which the enemy did not know about until after the war." An "ingenious" valve in the oxygen mask that assisted pilots in breathing out against the mask's pressure allowed "our reconnaissance aircraft to operate above the ceiling of enemy fighters, enabling them to perform essential tactical photography while escaping unscathed." Researchers at the Clinical Investigation Unit (CIU) were also the first to develop an oxygen mask that did not freeze up at high altitudes. The freezing problem, which often blocked the oxygen supply, resulted from the freezing of moisture in the pilot's exhaled air. These masks were used by Royal Canadian Air Force pilots during the war and its innovations were later used in masks developed for British and American pilots.

While at Farnborough, Soper helped to evaluate a new, more sophisticated pressure-breathing helmet being designed by a British company. Positive pressure breathing masks deliver oxygen to the pilot's respiratory system at higher than ambient pressure—they literally force air into the lungs. They're needed to maintain consciousness in the event of a cabin depressurization at altitudes above about 35,000 feet.

Positive pressure systems are not comfortable; they blow out the chest and lungs and make breathing quite difficult because the user has to breathe out forcefully. "Above 45,000 feet, the face is puffed up like a frog because of the pressure of the oxygen mask," said Charles Bryan. The pressure can also cause blood to pool in the lower body, requiring counterpressure from a pressure suit.

The standard oxygen mask used at the time, known as the Pate suspension mask, was not adequate to deliver oxygen under pressure, said Soper. It had straps strung through rollers that were used to pull the mask tight to the face but they did not provide a strong enough seal for positive pressure breathing. "Even when you turned up the tension to counter the oxygen pressure, you got a lot of leaking." The new British helmet, on the other hand, "had a visor built into it and you could get a lot of pressure built up with this thing."

The reason Canada was interested in this helmet was—again—the Arrow, which could fly up to about 60,000 feet. "When the Arrow was cancelled and we didn't have an aircraft that would go that high, we went back to the Pate," said Soper. "We didn't need the other one."

Around this time, however, the issue of oxygen supply at high altitudes was beginning to extend beyond the military. "Big passenger jets were being built and they would fly at 40,000 feet so they had to be pressurized," said Bryan, who was assigned to investigate how long it took for passengers and the flight crew to get oxygen masks on. "That meant trying to figure out how long they would stay conscious."

Bryan and another officer, Wilson (Bill) Leach, devised a series of tests in a decompression chamber that involved taking test subjects from the pressure at 8000 feet to the much lower pressure at 40,000 feet in a matter of seconds. This is known as explosive decompression—the kind of thing that can happen if a plane's hatches or windows blow open or if the sealed cabin is breached in some other way. The tests were risky. "When decompression occurred, there was a terrific rush of gas from the lungs," said Bryan. "If you happened to have your throat closed, if you were swallowing at that point, your lungs could burst. We always made a point of making sure the mouth was open at the time we pulled the plug."

Typically, Bryan and Leach were their own guinea pigs. "If you're going to do experimental work, you should do it first on yourself," Bryan said. "My work was to sit in the chamber at 8000 feet and get blasted to 40,000 feet." He added wryly: "I had to persuade several of my friends to do the same thing—that's why I have so few friends."

Soper served as a test subject for some of these experiments and he had an unexpected and rather frightening experience as a result. Subjects undergoing explosive decompression experienced hypoxia "which we thought cleared up as soon as you received oxygen and returned to a lower altitude," Soper said. "On one occasion, I found that after the initial effects, there could be a lingering, more lasting effect of which we were not aware."

The experiment was conducted in a decompression chamber at a lab in Downsview and afterwards, Soper got into his car to drive back to his office at the original IAM site on Avenue Road near downtown Toronto. "I have absolutely no recollection of leaving Downsview or of the drive itself until I found myself in central Toronto near College and Bay Streets, having overshot my destination by several miles. When I realized where I was, I pulled into a parking space to try and sort things out. It was very frightening. Not only could I not figure out why I was there but I realized that I had no memories of what had happened. So, puzzled about the events, I drove back to the Avenue Road site. It was noon when I got there and my colleagues were in the bar. I told them what had happened and there was a lot of laughter and teasing about my forgetfulness. Nobody took my amnesia seriously until [Bryan] had a related experience a short time later.

"When Dr. Franks heard about these events, he was horrified and said that these hypoxic experiences were costing us grey cells. As a result, guidelines and restrictions were imposed on what sort of experimental work we could carry out in the future. It still frightens me when I think about that drive through Toronto traffic, of which I have no memories at all. How lucky not to have been involved in an accident!"

The tests in the decompression chamber revealed that passengers who experienced a sudden loss of cabin pressure had about 15 seconds to get their masks in place. The situation is made more urgent by the fact that passenger jets, unlike military aircraft, can't dive rapidly to a lower altitude where it would be possible to breathe without a mask. They must descend more slowly and at a much shallower angle or risk serious structural damage. "We've had airliners go into a sharp descent because of malfunctions," said Bryan. "In one case, the pullout was so drastic, the engine fell off."

When they did tests to see if passengers could survive without oxygen during a typical slow descent in a commercial airliner, "we had to abort every time," Bryan said. "With the shallow descent, it took a long time to get to a breathable atmosphere. At the rate of descent that the plane could stand, we'd get serious brain damage—even young, fit people couldn't get enough oxygen."

He noted, however, that modern airliners are designed with a scoop in front that forces air into the aircraft as it descends, providing some pressurization. Therefore, an explosive decompression may not drop the cabin pressure as low as that at 40,000 feet. A pressure level closer to about 25,000 feet would be more typical and "that gives you a minute or so" to get on an oxygen mask, he said. “Although there have been rapid decompressions [in commercial airliners], there have been very few of a catastrophic nature.”

A film of the decompression chamber tests was distributed to the Canadian airlines and their pilots, providing graphic evidence of what could happen in an explosive decompression. The IAM scientists also trained airline pilots and their research led directly to the development of the drop-down oxygen masks that are now used in commercial planes. Unlike the more sophisticated pilot’s masks, the passenger masks are round so that people who have never seen one before and are trying to put it on under stressful conditions “don’t have to figure out what was up and what was down,” said Bryan.

In 1960, Leach (who later became Surgeon General of the Canadian Forces) received the coveted McKee Trophy, which was awarded each year for “meritorious services in advancement of Canadian aviation.” The report of this award particularly emphasized Leach’s specialized work on the effects of anoxia and explosive decompression and its applicability to the new generation of military and civilian jet aircraft. “The results of this research have received national and international acclaim and have provided a base for further research in many countries. His work has also resulted in improved airline and military crew training techniques and the design of new oxygen equipment.

“During his research work, Leach continually exposed himself to explosive decompression and periods of anoxia at high atmospheric altitudes despite the fact that no observations had ever been made which recorded the effects of such exposure. The personal courage he displayed in the pursuit of his research was beyond the call of duty and has resulted in greater safety for people the world over who fly in high altitude aircraft.”

Ejection Seats

A photo of an early ejection seat.

One of the most dangerous jobs at the Institute of Aviation Medicine was testing ejection seats. The seats were dangerous for pilots, too; even though they were intended as a life-saving device, many pilots were getting killed or injured while ejecting.

Roy Stubbs studied one particular issue with the ejection seat that was commonly used at the time, called the Martin Baker seat. “The problem with the early Martin Baker seats was that they put the parachute behind the head, so the head was forced forward in the head rest. When you ejected, you could break your neck.”

To prevent this happening, the seat assembly had a D-ring device attached to the back of the seat above the pilot’s head. In order to eject, he was supposed to pull this ring down over his helmet to restrain his head and keep it from snapping forward when the ejection seat fired. The D-ring also had a “face blind” that would protect his head from windblast.

“In an emergency situation, they might not get the D-ring all the way on, so there were a lot of broken necks,” said Stubbs. In fact, his was one of them. During one experiment at a test facility in England, he didn’t get the ring on properly and “my head went down until I was biting my navel. I had to wear a collar for six months or a year. Surgery wasn't good enough to do anything; it had to heal itself. For 20 years, I had a neck with very little movement; all the disks in the neck region were totally fused. It wasn't much fun but we learned a lot." He received the standard compensation for an injury on the job—two dollars.

In the end, it proved impossible to overcome the problem with the Martin Baker seats. The advent of rocket-propelled seats provided a better alternative, however. "The parachute was placed down on the back of the body to keep the spine lined up, so the head wasn't being pushed forward," Stubbs said.

The rocket seats also helped with another problem: the high G-forces that pilots endured during ejection and the danger of spinal damage this created. "We wanted to determine what kind of G we could have without breaking spines," said Stubbs.

One concern related to the survival pack the pilot sat on, which contained a radio, a water supply and other things they would need after ejecting. It was compressed by the force of ejection and there was concern that it would rebound from this compression within the first few tenths of a second and apply added force to the spine just as the ejecting pilot was experiencing maximum G-forces. There was also a need for a small depression to be created in the middle of pack to allow room for the pilot's tailbone, which might otherwise snap off when the body was pressed down during ejection.

Stubbs said the early seats were fired using a cartridge like that in a shotgun. "You had 30 inches to accelerate the seat out of the plane and clear the tail. You had to take a man from 0 to 60 miles per hour in one tenth of a second." It was quite a jolt, delivering up to 20 Gs.

Tests done in collaboration with the US Air Force on the ejection seat tower at Wright-Patterson Air Force base in Ohio showed that if seat packs were made from new fibreglass-resin material, "the rebound was delayed and did not produce the added force in the vital early time frame of the ejection sequence. So the risk of spinal injury was reduced in most ejections," Stubbs said.

When the rocket-propelled seats came in during the 1960s, they made things a little easier because they did not deliver their power in one initial burst, but continued to burn for a time while the seat cleared the plane. "With the rocket giving thrust all the way up for 10 to 12 feet, you don't exceed four to five Gs," said Stubbs.

Douglas Soper investigated another aspect of the Martin Baker ejection seats used in the CF-100 aircraft, namely an alternative release mechanism to the standard over-the-head D-ring. There was concern that under high G-loads, the aircrew might not be able to raise their arms up to reach the D- ring.

He focussed particularly on the ejection problems faced by the navigator, who sat behind the pilot. "They were being killed because they were not ejecting from the aircraft—they were just not getting out. Quite a large number of back seat occupants of the CF- 100—perhaps 10 or 12—were killed without anyone successfully ejecting. Jan Zurakowski, the chief test pilot for Avro, lost his observer in an accident near Oshawa. We didn't know why."

Soper examined one mechanism that consisted of a rod extended over the navigator's left shoulder. "You grabbed this rod and sort of pulled it forward and you would be ejected." He tested the mechanism in flight, although he didn't actually eject from the aircraft. "The explosive charge had been removed since the purpose of the experiment was to prove that you could actually pull the handle on this particular design."

It was nevertheless quite an adventure. The aircraft ascended to around 10,000 feet with its canopy off, as would be the case if the aircrew were going to eject. "It was not only turbulent, but extremely noisy," said Soper. "At the right time, I reached up and pulled the handle. The slipstream grabbed my arm and pulled it back along the fuselage. Later, I joked that I was probably the only person who flew in the CF-100 who touched the tail with my hand."

Another of the early ejection seats with a variety of helmets used in testing.

At the time, however, it wasn't a laughing matter. Soper dislocated his shoulder and lost his crash helmet, even though it was strapped on. "The slipstream cleaned it right off my head. Air could get underneath it and just lifted it right off. I never even felt it go." He had real difficulty at this point because he couldn't communicate with the pilot to let him know what was happening. The plane was too noisy for them to talk to each other—and, in any event, his communications system had flown away with his helmet—but Soper had rigged a system that would turn on a red light in the pilot's cockpit. "I had a toggle switch where I could wipe my hand down and tell him I was in trouble."

Unfortunately, with his left arm pinned back, he couldn't easily reach the switch. "It was in front of my left arm, which was trapped outside the aircraft. And I couldn't see anything because of the buffeting." However, he managed to move his right arm over enough to where he thought the switch should be and, luckily, was able to communicate his distress to the pilot, who immediately brought the plane down.

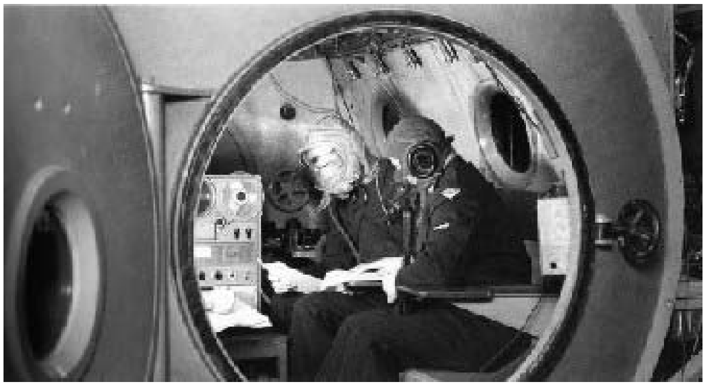
Despite his injury, he felt the test was a success because it solved the mystery that had puzzled him. "We now knew why the people in the rear seat couldn't get out of the plane. With the canopy off, as in a real ejection, the airflow over the rear cockpit became very turbulent. When the rear seat occupant reached up to use the standard over-the-head D-ring, the slipstream pinned his arms so that he couldn't pull the mechanism or do anything at all. This was verified later by a navigator who lived to tell the tale. He had been ordered to eject and when he didn't, his pilot managed to land the aircraft back at base. The navigator had his hands pinned in the extremely cold slipstream and lost portions of his fingers, which were frozen."

The solution was to install a transparent windscreen in front of the rear seat to deflect the slipstream. "That seemed to solve the problem," said Soper. "However, at night, navigators couldn't see out because of interfering reflections from the windscreen. Some navigators wanted the windscreen removed. So you can solve one problem and unwittingly create another."

Decompression Sickness

Among the many risks faced by pilots flying at high altitudes is the danger of decompression sickness, also known as "the bends." Since air is about 79% nitrogen and 21% oxygen, body tissues such as fat, organs, muscles, skin and blood are normally saturated with nitrogen. When someone moves rapidly from a higher pressure to a lower pressure environment, this nitrogen can bubble out rapidly, causing symptoms ranging from joint and chest pains, shortness of breath and blurred vision to headaches, dizziness and nausea. Left untreated, severe cases can result in a coma and death.

Decompression sickness is a risk for divers who ascend too rapidly from deep waters, because they are moving from a higher pressure at the depths to a lower pressure at the surface. Similarly, as pilots ascend from the surface to high altitudes, the reduced pressure puts them at risk of decompression sickness. Astronauts also face this problem during spacewalks because their suits are pressurized at a lower level than the space shuttle or the space station.



A photo of an early decompression chamber.

The first decompression chamber in Canada was built in a lab at the Banting Institute. According to Peter Allen, Frederick Banting, who was "a great believer in the use of 'scientist rabbits' " was the first person to expose himself to an equivalent altitude of 40,000 feet. At the Institute of Aviation Medicine (IAM), the decompression chamber was used from its earliest days to study the causes of and treatments for decompression sickness, both for aviators and divers. This work continues today at its successor organization, the Defence and Civil Institute of Environmental Medicine (DCIEM -- recently renamed Defense and Research Development Canada (DRDC)-Toronto), which is also doing decompression research related to spacewalks.

In fact, IAM developed the first decompression computer for use by divers who made repeated deep dives. Depending on the depth to which they'd dived, how long they'd remained at depth and how often they dived, such divers had to ascend slowly and stop at prescribed points along the way to allow nitrogen to escape from their tissues slowly. The IAM team developed a pneumatic computer that computed decompression schedules in real time and an electronic computer that computed schedules faster than real time (milliseconds rather than seconds).

"We designed an electronic computer before computers as we know them today existed," said Roy Stubbs. "If a diver got in trouble in the ocean, they would phone in and tell us what his experience had been, what depth he'd been to and how long. We would plug this into the computer and generate the procedure for him to come to the surface. This was radioed out to the ship and he would do it."

Stubbs later became the chief scientist at DCIEM, where he developed a diving research facility that could reach greater depths than any other in the world at the time—6000 feet. It was named after him when he retired.

Aviators generally experienced less severe cases of decompression sickness than divers, according to Harold Warwick, who, as an RCAF medical officer during World War II, was involved in evaluating the susceptibility of military crews. This is because more nitrogen is dissolved in body tissues at the high pressures found underwater than at the surface. "The decompression sickness that occurs when you take people to altitude from ground level is not as severe as in a person who is at increased pressure, like a diver, and is then brought to the surface. We never saw severe neurological problems."

A photo of an early decompression computer.

When Warwick joined the RCAF Medical Branch in 1941, he was assigned to the No. 2 Clinical Investigation Unit in Regina, where he and his commanding officer, Chester Stewart, developed a program to evaluate the resistance of trainees to decompression sickness. "We had one pressure chamber there," he said. "We determined that a suitable method was to expose individuals for two hours at a simulated altitude of 35,000 feet, with a rate of ascent of half an hour. You didn't need to keep them there longer than that, because the symptoms would appear within that time."

Warwick was another researcher who did not ask others to do what he wasn't willing to do himself. "I've had decompression sickness in all its forms. We had to be in the chamber when trying to determine the best method for testing."

As a result of this work, in 1942, he and Stewart were assigned to the No. 1 Flying Personnel Medical Section of the Y Depot in Halifax, Nova Scotia, where 12 decompression chambers had been built to evaluate men headed for war. "That's where graduates of the joint air training plan assembled before they went overseas on the big ships," said Warwick. "It was not just pilots, but also navigators and gunners—what we called aircrew." Later this testing facility was transferred to Lachine, Quebec.

More than 6500 people were put through nearly 17,000 exposures. Warwick recalls that roughly a third exhibited a natural resistance to decompression sickness. The researchers found that the rate of ascent was an important factor in determining the extent to which subjects experienced decompression sickness. They also found correlations with time of day—the incidence was higher in the morning than in the afternoon—and with atmospheric pressure. And they discovered that people who tended to be big and heavy were more susceptible, possibly because their bodies had a higher percentage of fat that did not release nitrogen as quickly as other tissues.

In those days, aircraft were not pressurized and some would be flying at 30,000 feet or more— altitudes that would generally induce some degree of decompression sickness in many people. Warwick said there was particular concern about the susceptibility of crews on photo reconnaissance missions, which flew at quite high altitudes. "You wouldn't want a person to be doing photo reconnaissance or high-altitude bombing if they were going to be developing severe pain," Warwick said.

The men who were tested in Halifax had a note placed on their record whether they were susceptible or resistant to decompression sickness but Warwick says he doesn't know "what practical use came of that or what attention was paid to it. I can only assume they wouldn't pick a person for high altitude flights if they knew he was susceptible." He added that some crewmembers did regularly experience mild symptoms and "just carried on."

Warwick said the Royal Canadian Air Force's work in decompression sickness was a pioneering effort that attracted the interest of researchers elsewhere. "The Americans were quite interested—we had numerous visits from people in the U.S. to see what we were doing. We were ahead of them in that regard. In 1943, they were hardly into the war. Canada was a forerunner."

Motion Sickness

For millions of years, the human body evolved without ever encountering the conditions it experiences when strapped into a plane rolling around the sky and accelerating. It's not surprising, therefore, that the vestibular balancing system in the inner ear that controls our sense of position and motion has found the experience rather disconcerting.

The vestibular system is comprised of two elements: the semi-circular canals, which sense angular motions, and the otoliths, which sense changes in position relative to the force of gravity and tell us up from down. Both have evolved to cope with the range of conditions that humans normally experience on the earth's surface. The accelerations and maneuvers experienced in high-performance jets—as well as the lack of gravity in space—are beyond historical human experience. One consequence of this is motion sickness.

Motion sickness, with its attendant symptoms of nausea and vomiting, was recognized early as a threat to the safe operation of an aircraft or spacecraft. When Stubbs went to the Institute of Aviation Medicine (IAM) in 1950, "one of the first things I was asked to do was help study the physics of motion." The study involved cats as well as humans. "Cats are very susceptible to motion sickness," he said. "We studied what motions would make them sick, then did it ourselves. We wanted to define the math of the motions that were causing sickness."

Another researcher, Walter Johnson, a professor at the University of Western Ontario, was asked by Wilbur Franks to join IAM to study the problem. He examined the question of what kinds of motion would cause the worst motion sickness. "This research culminated in a new finding, an essential finding, as to how the inner ear is maximally stimulated to produce nausea," he said. "We showed that the inner ear acts like a gyroscope. If you spin it in one plane and tilt the gyro in another plane, forces are set up to produce a stronger stimulus that is very nauseating. Say you're in boat or plane that's pitching up and down and your turn your head sideways—that's the worse thing you could do. It's more effective in causing nausea than anything."

Stubbs noted that one of the things that led them in this direction were old Navy tales that "you should nail your head to a bulkhead. The three of us, Johnson and Franks and I, sat down and talked and all the old tales came up."

The researchers invented diabolical machines that "would produce these terrible effects on people," said Johnson, who created a device that produced vertigo by spinning test subjects around like a top. Later, another machine, called the Precision Angular Mover, was developed; it rotated test subjects around all three axes—pitch, yaw and roll.

As usual, the researchers subjected themselves to the tortures they were asking others to endure. Johnson admits it wasn't easy to find volunteers. "I had my problems. Not everyone wanted to do it because they knew what would likely happen. But I got enough volunteers to publish my results."

As a result of this work, in 1951 Johnson, Stubbs and Franks wrote a scientific paper that concluded that the best way to prevent the worst nauseating stimulus was to strictly control head movements relative to the rest of the body—no bobbing motions or rotating the head. They patented a headrest designed to minimize motion sickness in pilots and astronauts essentially by immobilizing their heads.

Johnson put these findings to practical use when he investigated a problem with parachutists at a training base in Alberta. "They were complaining of getting nauseated before they jumped in rough air. In order to offset that effect, I suggested they install head rests in the airplanes that were taking them up and that helped a lot."

As a result of his discovery of the most potent stimulus on the inner ear that caused nausea, Johnson received an award from the Aerospace Medical Association in 1956 for "outstanding services to aviation medicine."

The researchers also found that antihistamines, which were just then being developed, were useful in reducing the symptoms of motion sickness. However, since they had a sedating effect, the drugs couldn't be given to pilots or others with operational responsibilities.

The motion sickness rotator, a machine used to produce the symptoms of motion sickness.

Johnson was also invited to work with the early groups of astronauts chosen for the U.S. space program in the early 1960s. He participated in training flights in aircraft that can create brief periods of weightlessness by flying a roller coaster pattern. "I was instructing them on how to keep their heads still," he said. (Johnson had to follow his own advice—he found he too was susceptible to motion sickness if he moved his head too much.)

Many people in the space program were surprised to discover that motion sickness was a problem. After all, the early astronauts were all veteran test pilots, used to doing all kinds of tricky maneuvers in high-performance jets. However, it turned out that weightlessness was another thing altogether. "With the lack of gravity, they thought could do whatever they wanted about moving their bodies," said Johnson.

He was not surprised that they couldn't, having already concluded that a lack of gravity could very likely make astronauts sick. He was well aware that gravity affected the inner ear; he'd seen patients who were disoriented because of problems with their otoliths and they sometimes experienced nausea and vomiting.

Although Johnson heard from other people that the early crews were experiencing nausea, the astronauts themselves didn't admit this to him. "It was sort of hard on their morale. They were supermen, carefully chosen." (In fact, the first time the problem was openly acknowledged was on Apollo 9 in 1969, when astronaut Russell Schweikart vomited twice. However, there were indications that the problem may have occurred on earlier Gemini flights; one Gemini spacecraft came back to earth with a dark stain on the console that was later determined to be chocolate pudding. (See "Canada's Space Medicine Pioneers–Dwight Owen Coons.")

One issue that drove a lot of research into motion sickness in the space program was the search for a test that could predict who would get sick in space. The fact that seasoned test pilots were getting sick in space was the first indication that a failure to experience the malady on earth was no guarantee of what would happen on orbit. “There’s a reason for that,” said Johnson. “You can’t experience weightlessness on earth. There’s no way you can duplicate it on earth.” The brief seconds of weightlessness that can be created in aircraft flying roller-coaster arcs are not sufficient, he said. “I don’t think there’s any way you can predict other than actual exposure in space.”

Photo of the prime crew of the third manned Skylab mission signed by the astronauts: "To Dr. Walter Johnson, Our sincere best wishes."

Former Canadian astronaut, Ken Money, who worked with Johnson at DCIEM and devoted much of his career to studying motion sickness and vestibular disorientation, was one of those who searched for a predictive test. He commented that disorientation was, and still is, “a big killer of fighter pilots” and, in fact, the leading cause of all fatal fighter aircraft accidents. What was happening to pilots at that time was that a lot of them got motion sick at the beginning of flight training and a lot of them, after a considerable amount of expensive training, failed because of motion sickness. There was an interest in dealing with it efficiently—selecting those who weren’t going to make it and getting rid of them early, and helping those who could get over it. I wasn’t thinking of spaceflight at the time, although spaceflight was anticipated then.”

His involvement with the space program came through Johnson. “Walter Johnson was a world authority on motion sickness. He was invited by the Americans, anticipating motion sickness in spaceflight, to help them make plans for it. Since I was his student at the time, he invited me to go with him.”

Money started working part time on a project for NASA that involved altering the vestibular system of monkeys in an effort to understand whether it was the semi-circular canals or the otoliths that were primarily implicated in causing space motion sickness. The plan was to fly the monkeys in space, together with others whose vestibular systems had not been altered; however, the research project fell prey to funding cuts and the monkeys never flew.

It was not until more than a decade later that Money started working with American astronauts in an effort to find a predictive test. The astronauts weren't thrilled about the project because "nobody likes to get motion sickness, in a test or any other way," Money said. "But they had their assignment and they did it. "

Many were, in fact, quite astonished that they could even get sick. Their attitude was that "motion sickness was something that the guys who flunked out of pilot school had," said Money. "Several were surprised they got motion sickness at all, but of course we had fiendish devices that would get anybody sick. My major finding, after a lot of testing, was that there wasn't any ground-based test that would predict with any accuracy at all susceptibility to motion sickness in space, so we stopped doing that."

Like Johnson, he concluded that the space environment was unique. "The stimulus in space is quite different. You don't get prolonged weightlessness anywhere else. You can be quite immune to everything else and still get sick in space."

There was another reason for giving up the testing: it was not only unpopular with the astronauts, it was expensive because tests had to be done before, during and after flight. One of the most significant problems was getting accurate reports of episodes of motion sickness in space. The astronauts just didn't like admitting to being sick, Money said. "We were never absolutely sure that we were getting reliable reports." In fact, he learned more about what really went on during informal social gatherings than he did in the formal debriefings. "We'd be sitting around after work, going to the local pub, and they'd get chatting and you'd be amazed what came out. We'd find out that so and so said he wasn't motion sick at all when he was vomiting all over the place. I said, you can't do science like this. I figured it was no use, so basically we gave it up."

There probably weren't a lot of people who were fudging their reports, Money said, but it mattered because he had such a limited number of people to work with. "When you're using small numbers, it only takes one or two to throw an entire experiment out the window. We never did get a test that would predict motion sickness."

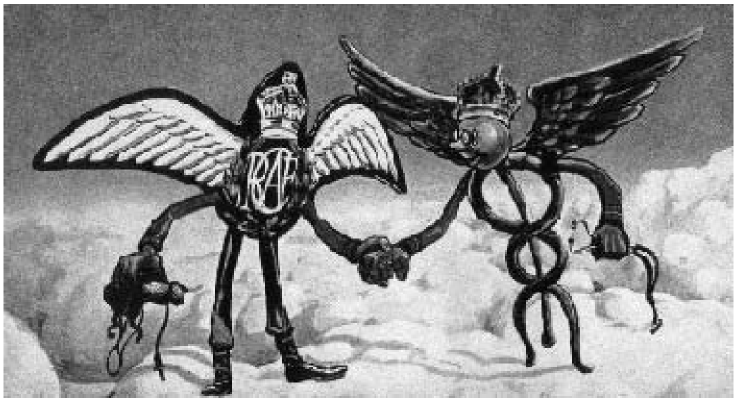
The only alternative was to provide astronauts with medication if they feel sick in flight. At one time, Money said, rookie astronauts and those who'd been sick on previous flights were given medication on the ground before launch. This turned out to be a useless strategy. "They were thinking that using the medications was preventing the sickness, but they were only postponing it. They were slowing the normal habituation process to weightlessness, so the astronauts were drugged for two days, then they'd come off the medication and get sick."

As a result, the procedures were changed and now astronauts can take the medication in flight if they feel they need it. "It's up to the individual whether he wants treatment," said Money. "If he figures he can get his job done, they won't impose it on him."

Space motion sickness remains a significant problem that can affect mission operations, especially during the first few days of a flight. This is one reason why many critical tasks, such as spacewalks, are not scheduled during the habituation period. Money estimates that about 90% of all astronauts experience some degree of motion sickness, with nearly a third being sick enough to vomit. "NASA reports that around 70% have some motion sickness, but I think that's low," he said.

A Legacy for the Space Program

Much of the research done at the Institute of Aviation Medicine (IAM) from the 1940s to the 1960s had direct relevance to the emerging space program, which had to deal with issues related to pressure and G-suits, oxygen masks, helmets, and even, in the early days, ejection seats.



Research done by doctors and pilots working together at the IAM formed the basis for today's space program.

“In the Gemini and Mercury programs, they had ejection seats,” said Roy Stubbs, who was invited to conferences to discuss the work he and his colleagues had been doing at IAM. He was even invited to join the team of NASA engineers designing equipment for the space program but he declined, preferring to stay in Canada and continue doing research for the military.

“It wasn’t as important as what we were trying to do under NATO,” he said. “It was far more interesting for me to do that. We were into our own programs, which were very good. I enjoyed being in Canada and I decided to stay. I never regretted that decision because I felt loyal to Canada and wanted to do what I could there.” In recognition of his efforts, he was elected, along with Wilbur Franks, by their peers worldwide to the newly formed International Academy of Astronautics. They were the first Canadians to be so honoured.

As for the risks the work entailed, that was just part of the deal, Stubbs said. “We knew there was risk involved, but we thought it would be manageable.” And there was a payoff: “It was an exciting time—every step you took was a step forward.”

References

- *The Journal of the Canadian Medical Services*, Vol. 4, No. 1, November 1946.
- *The Remotest of Mistresses: The Story of Canada’s Unsung Tactical Weapon: The Franks Flying Suit*, by Peter Allen. Canadian Aviation Historical Society Journal.
- *Franks’ Incredible Flying Suit: The Canadian Invention that Changed the Face of the War*, by Andrew Duffy. Ottawa Citizen, November 11, 2001.
- *Banting Tended Injured Pilot Before His Own Life Ebbed Away*, newspaper article, February 26, 1941. From the Sir Frederick Banting Archives, http://www.newtecumseth.library.on.ca/banting/database/000047.html