The Anti-G Suit

The g or anti-g suit **is a tight-fitting suit for use in high-performance air flight that covers parts of the body below the heart and is designed to retard the flow of blood to the lower body in reaction to acceleration or deceleration; sometimes referred to as a *g*-suit. Bladders or other devices are used to inflate and increase body constriction as g-force increases.**

The circulatory effects of high acceleration first became apparent less than two decades after the Wright brothers' seminal powered flight. During Schneider Trophy Races in the 1920s, in which military and specialized aircraft made steep turns, pilots would occasionally experience "grayouts". An early documented case of *g*-induced loss of consciousness, or *g*-LOC, occurred in the pilot of a Sopwith Triplane as long ago as 1917. But the problem only became significant with the dawn of higher performance planes in World War II. In the quarter century between global conflicts, the maximum acceleration of aircraft had doubled from 4.5*g* to 9*g*.

Two medical researchers play key roles in the evolution of the anti-g during the 1930s and '40s. In 1931, physiologist Frank Cotton at the University of Sydney, Australia, devised a way of determining the center of gravity of a human body which made possible graphic recordings of the displacement of mass within the body under varying conditions of rest, respiration, posture and exercise. He later used his technique to pioneer suits that were inflated by air pressure and regulated by *g*-sensitive valves. At the University of Toronto, Wilbur R. Franks did similar work that eventually led to the Mark III Franks Flying Suit – the first anti-*g* suit ever used in combat. His invention gave Allied pilots a major tactical advantage that contributed to maintaining Allied air superiority throughout the war, and after 1942 the Mark III was used exclusively by American fighter pilots in the Pacific.

At the same time the anti-*g* suit was being perfected, it was realized that pilots who were able to tolerate the greatest g-forces could outmaneuver their opponents. This led to the rapid development of centrifuges.

A G-suit does not so much increase the G-threshold, but makes it possible to sustain high G longer without excessive physical fatigue. Pilots still need to practice the 'G-straining maneuver' that consists of tensing the abdominal muscles in order to tighten blood vessels so as to reduce blood pooling in the lower body. High G is not comfortable, even with a G-suit. In older fighter aircraft, 6 G was considered high, but with modern fighters 9 or even 10 G can be sustained aerodynamically making the pilot the critical factor in maintaining high maneuverability in close combat.

A 'G Suit' is a special garment and generally takes the form of tightly-fitting trousers, which fit either under or over (depending on the design) the flying suit worn by the aviator or astronaut. The trousers are fitted with inflatable bladders which, when pressurized through a G-sensitive valve in the aircraft or spacecraft, press firmly on the abdomen and legs, thus restricting the draining of blood away from the brain during periods of high acceleration. In addition, in some modern very high-G aircraft, the Anti-G suit effect is augmented by a small amount of pressure applied to the lungs (partial pressure breathing), which also enhances resistance to high G. The effects of Anti-G suits and partial pressure breathing are straightforward to replicate in a simulator, although the continuous G forces themselves can only be produced artificially in devices such as centrifuges.

Various designs of G-suit have been developed. They first used water-filled bladders around the lower body and legs. Later designs used air under pressure to inflate the bladders. These G-suits were lighter than the fluid-filled versions and are still in extensive use. However, the Swiss company Life Support Systems AG and the German Autoflug GmbH collaborated to design the new Libelle suit for use with the Eurofighter Typhoon aircraft, which reverts to liquid as the medium and improves on performance. The Libelle suit is under consideration for adoption by the United States Air Force. [1]

If blood is allowed to pool in the lower areas of the body, the brain will be deprived of blood leading to temporary hypoxia. Hypoxia causes first a brownout (a dimming of the vision), also called grey-out, followed by tunnel-vision and ultimately a blackout (unconsciousness), that is G-induced Loss of Consciousness or 'G-LOC'. The danger of G-LOC to aircraft pilots is magnified because on relaxation of G there is a period of disorientation before full sensation is re-gained.

G-LOC has resulted in a number of fatalities in which the aircraft and crew are lost. There is a need for high-G training and this can be accomplished in a man-rated centrifuge training system. Such systems are made by AMST Systemtechnik in Austria (Austria Metall SystemTechnik), the Environmental Tectonics Corporation (ETC) and in the USA.

As early as 1917, there were documented cases of loss of consciousness due to g-forces in pilots.

In 1931 a Professor of Physiology from the University of Sydney described a new way of determining the center of gravity of the human body. This made it possible to describe the displacement of mass within the body under acceleration.

With the development of high-speed monoplane fighters in the late 1930s, G-effects in combat became more critical. In the Battle of Britain in 1940, some German aircraft had foot-rests above the rudder pedals so that the pilot's feet and legs could be raised during

combat, in which large use of the rudder was often not necessary but turning inside the opponent, was.

The first G-suit was developed by a team led by Dr.Wilbur R. Franks at the University of Toronto's Banting and Best Institute in 1941. This used water filled bladders around the legs and two Marks were developed:

- **The Franks Mark I suit was for the RAF) and was for Hurricane and Spitfire pilots.**

- **The Franks Mark II was for the USAF and RCAF). U.S. pilots tested it during 1944, but found the water system uncomfortable and were issued an air-inflatable design known as the Berger suit from September 1944.**

- **During the 1939-45 war the German Henschel Hs 132 jet and US XP-79 Flying Ram both had prone positions to minimize blood pooling in the legs.**
- **After the 1939-45 war, the British experimented with prone flying positions on a highly modified Gloster Meteor F8 fighter.**
- **However, other difficulties associated with prone piloting and the development of a practical g-suit for a normal seating position terminated the experiments.**

Air-based G-suits were very common in NATO aircraft of all nations from the 1950s onwards and are still in common use today.

Later jets such as the BAe Hawk, F-16 Falcon, F-18 Hornet, Eurofighter Typhoon and the Dassault Rafale can sustain high-G for longer periods, and are therefore more physically demanding. However, by using a modern g-suit a pilot can now be expected to sustain flight forces of up to 9 G without blacking out.

Astronauts wear similar G-suits to aviators but face different challenges due to the effects of microgravity. Aviator G-suits apply uniform pressure to the lower legs to minimize the effects of high acceleration but research from the Canadian Space Agency[2] implies there might be a benefit in having a suit for astronauts that uses a "milking action" to increase blood flow to the upper body.

When pushing a modern jet fighter through its paces, being in a tight squeeze can be a good thing.

Many of today's military aircraft accelerate so quickly and turn so rapidly that they meet or exceed the physical limits of their pilots. And a new generation of higher-performance jets soon to join air forces around the world promises to worsen the problem, making it even harder for the human component of these weapon systems to keep up with the mechanical.

The human body, for all its extraordinary capabilities, is just not made to take 6, 8 or 12 times the normal force of gravity. And its responses to this assault, from impaired vision to loss of consciousness, can prove fatal if they occur in the air.

Researchers working with the world's leading air forces are trying to develop better countermeasures to the gravitational acceleration, or so-called G forces, that can knock out a pilot within seconds of a tight turn at high speed. These acceleration or deceleration forces, expressed as multiples of gravity, or G's, force blood from the upper part of the body -- including the brain -- to the legs and feet, and also impair breathing.

Not only are scientists working on improved versions of gravity-fighting gear, like air-inflatable pressure pants and anti-G suits that push blood up to the head, but some are also testing radically different flight suits that simulate immersing the body in water to counteract acceleration forces. Swiss developers of the new suit, called Libelle, say channels of fluids encased in the garment help it simulate the protective effects a fetus enjoys floating in a womb.

Dr. Fred Buick, a physiologist with the Canadian Defense Ministry who recently helped develop a new anti-G system for his nation's pilots, said the new work was resulting in the first major upgrade in gravity protection since World War II. ''Most of the suits in use now are just minor variations of what they developed then,'' Dr. Buick said.

''There was some truly pioneering research in the effects of acceleration and G-forces on pilots, and what to do about it, 50 and 60 years ago,'' he said, ''but there was no way to practically apply many of these ideas. Now we have the technology to implement some of these designs.''

Many experts say research in protection from gravitational forces still lags far behind the development of new super-maneuverable aircraft like the American F-22 Raptor, the multinational Eurofighter Typhoon, the Rafale in France and the Swedish Gripen. These fighters are so fast and nimble that improperly protected pilots can lose consciousness in dogfights or evasive maneuvers before any of the usual warning signs of trouble appear, they said.

Pilots first complained about the effects of gravitational acceleration during World War I when some suffered vision impairment and occasional loss of consciousness when pulling out of dives. But it did not become a major problem until World War II, when planes became sturdy and powerful enough to subject pilots briefly to acceleration forces that built up to the equivalent of six to eight times normal gravity.

If a force of 4 to 6 G's is sustained for more than a few seconds, blood pressure in the head drops rapidly, starving the brain and initially impairing vision. Under these conditions, pilots first experience loss of color vision, or gray-out, then narrowing tunnel vision followed by blackout. Tests show that blackouts can last 15 to 20 seconds, and it can take a pilot another 30 seconds to a couple of minutes to recover from an episode of this gravity-induced loss of consciousness, termed G-LOC. In a battle or when flying low to the ground, such episodes can be fatal.

The rate at which acceleration increases also plays a critical role in tolerating the effects of G forces. If ''G-onset'' is gradual, the pilot will notice early symptoms, like impaired vision, and can break off a dangerous maneuver or take countermeasures. But many fighters today are so quick that they can accelerate to 12 G's in less than a second, preventing pilots from sensing any warning signs before blackout.

The groundwork for countering these gravitational forces was laid during World War II, when researchers found that the downward rush of blood could be alleviated with special pants that applied pressure to the abdomen and legs to keep blood in the head and upper body.

The first workable anti-G suit, successfully tested in 1941, was developed by a Canadian team led by Dr. Wilbur R. Franks. The suit, a set of overalls tightly laced to a pilot's body from his ankles to the top of his chest, consisted of two layers of rubber with water in between. Although cumbersome and impractical, the suit protected a pilot from forces of 6 G's or more when the downward pressure on the water caused by acceleration created enough force to counteract the downward rush of blood in the body.

Dr. Franks then developed zippered pants with air-inflated bladders to squeeze the stomach and legs, and that evolved into the first production G-suit. Most current systems still use this approach, with interconnected inflatable bladders powered by air pressure generated from the plane and G-sensitive valves that apply and release pressure when needed.

Another defense against G forces developed then and still used now is a forced-breathing technique called the anti-G straining maneuver. This tolerance-increasing technique, which can be extremely tiring if used often, involves rapid breathing followed by holding a breath for several seconds while simultaneously tightening leg and stomach muscles.

To ease the strain of this maneuver and to aid breathing, researchers developed a technique called positive pressure breathing, which involves forcing pressurized air into a pilot's lungs through a face mask. While the method improved G-tolerance, it also could lead to lung damage through over inflation. To counteract this, the United States Air Force introduced a system called Combat Edge in the early 1990's. This combines positive pressure breathing with a counter pressure vest to protect the chest.

The Air Force is testing a new Advanced Technology Anti-G Suit, or Atags, which it expects will replace the current suit that uses inflatable bladders and stretch fabric. Atags, which is expected to be used with the new F-22 fighter, surrounds the legs and covers the entire lower body in one air-pumped garment. Research indicates these uniform-pressure pants coupled with the Combat Edge system increase crew high-G endurance by 350 percent.

Lt. Col. Don Diesel of the Air Force, who evaluates G-suit technology for the Air Expeditionary Force Battlelab at Mountain Home Air Force Base in Idaho, said G-suits combined with Combat Edge had proved highly effective in protecting pilots. But he said these pneumatic systems, with their valves, pumps and switches, added complexity and weight to the aircraft. ''It would be good to have something simpler that worked as well or better,'' he said.

One such advance could be the Libelle suit, being developed by Life Support Systems, a Swiss company. The single-piece, full-body suit, which has been tested by the Swiss and German air forces and underwent United States Air Force trials this summer in Texas and California, uses long tubes filled with fluid to combat high-G acceleration forces.

Andreas Reinhard, the physicist and former Swiss Air Force pilot who invented the suit and has been developing it for 12 years, said the Libelle worked using the same principles as a full-body water suit -- only with most of the water removed. The suit is called Libelle (pronounced lee-BELL-uh) after the German word for dragonfly, the only animal that can withstand 30 G's of lateral force because its cardiac system is surrounded by a liquid-filled sac.

''Like an unborn child immersed in liquid is protected from stress, so is a pilot wearing this suit,'' Mr. Reinhard said. His first prototype suit used seven gallons of liquid sandwiched between two layers of material to protect subjects in high-G centrifuge tests. ''The job of the last 10 years has been to reduce the liquid and increase the efficiency and comfort of the suit,'' he said.

The latest Libelle looks like a tight form-fitting wetsuit with two tubes running from neck to ankle down the front and another two down the back. Another set of tubes goes down the outside of each arm, from shoulder to wrist. The tubes, which Mr. Reinhard calls liquid muscles, have a diameter of about two inches at the top and taper down to about one and a half inches at the bottom and are filled with about a quart and a half of liquid.

The other integral part of the double-skinned suit is the material making up each layer between which the tubes run, he said. Under a tough, nonstretching outer fabric of synthetic fiber is a stretchable waterproof membrane.

Under high-G acceleration, hydrostatic forces increase the pressure of the fluid at the bottom of the tubes, causing them to swell and apply tension to the suit fabric, which tightens to prevent the rush of blood to lower parts of the body. The self-contained suit tenses and releases instantly in response to G-forces and requires no external regulators or valves, Mr. Reinhard said, and balances pressures at every point of the body just as total water immersion would.

''The suit simulates what happens in water without all the water,'' Mr. Reinhard said. Pilots testing the suit in centrifuges have withstood 12 G's of acceleration without a special breathing apparatus like a Combat Edge because the whole body is protected, he said. Subjects still use the anti-G breathing maneuver in high-G situations, he said, but it is not as stressful as with conventional anti-G suits and they can converse normally without positive pressure breathing interfering.

Col. Peter Demitry of the Air Force, the director of the Air Combat Command's Human Systems Integration Division, who flew in a Libelle suit this summer, said pilots did not feel the pressure changes at high-G as much when wearing the new suit. ''You get into kind of an equilibrium state, matching the pressures of the fluid in the suit with the fluid in the body,'' he said.

Pilots also seem to be able to move their arms more easily in the Libelle and report much less fatigue after flights, Colonel Demitry said. ''But the big thing is that pilots can talk at 8 or 9 G's, which is difficult when using a positive pressure breathing system,'' he said.

Air Force officials conducting the tests said much more development work on the Libelle suit was needed before they could recommend buying it. ''But we are pleased, so far, with what the suit is doing,'' Colonel Demitry said.