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Late Edition
New York: **Today**, mostly sunny and milder, high 78. **Tonight**, cloudy, low 65. **Tomorrow**, cloudy with showers arriving, high 76. **Yesterday**, high 74, low 57. Weather map is on Page D8

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Science Times

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High-Tech Suits Help Pilots Avoid Gravity's Perils

By WARREN E. LEARY

WASHINGTON, Aug. 21 — 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 re-

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In Modern Fighters, The Human Body Is the Weak Link

Modern fighter jets are capable of immense feats of speed and maneuverability. In the process, though, they can subject their pilots to as much as 12 times the normal force of gravity, enough to make them lose vision or even pass out. Now designers are looking for new ways to prevent these potentially lethal complications of flight.

WHAT ARE G FORCES?

When manuvering the plane, fighter pilots are subjected to powerful centrifugal forces that create far more pressure than gravity ordinarily exerts on the body. The force of gravity experienced on the ground is 1G, so pressure equal to four times the weight of gravity is 4 G's.

EFFECTS ON THE BODY

When pulling out of a turn or a dive, G forces push from the head to the feet. These positive G's overwhelm the heart's ability to pump oxygenated blood to the brain.

DECREASED PERFORMANCE
At 9 G's a pilot can barely move. The 10-pound head weighs 90 pounds, breathing becomes difficult and communicating, nearly impossible.

EYESIGHT
Eyesight fails first. Eye-level blood pressure decreases quickly. Vision dims until complete vision loss, or blackout, occurs.

BRAIN
If high G's are not reduced immediately, G-induced loss of conciousness occurs. Total incapacitation lasts 12 to 20 seconds, when the plane is flying by itself. Then it takes up to 2 or 3 minutes for the pilot to regain total control.

NECK
Many pilots report acute neck pain at high G's.

ARMS AND LEGS
Pain is common when blood pools in the arms and feet.

INCREASING G-FORCES

BLOOD FLOW ↓ ANTI-G PRESSURE ↑

INCREASING G-TOLERANCE

COMBAT EDGE
Current suits include a breathing system with a helmet, mask and vest, which work in concert to counteract G force pressure.

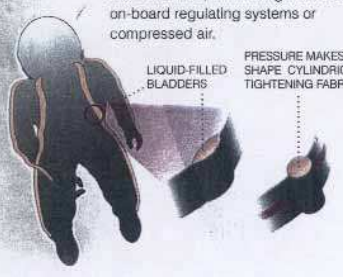
1. *A valve on the vest senses pressure created by G forces. When it goes beyond 4 G's, oxygen enriched air that the pilot is already breathing is pumped with greater pressure.*
2. *Pressurized air is simultaneously routed to the mask and mask-tensioning bladder at the rear of the helmet.*
3. *Air is also sent to the vest, which applies pressure to the pilot's chest, protecting against overexpansion of the chest under the strain of breathing pressurized air.*

A lower body suit inflates with pressurized air and constricts against the legs and lower abdomen, increasing blood pressure by pushing blood up.

STRAINING TECHNIQUES
By breathing quickly and clenching all major muscles, especially the legs and abdominals, a pilot can withstand an additional 1.5 G's worth of pressure.

THE "LIBELLE" SUIT

The Air Force is testing a liquid-filled, full-body, anti-G suit. Six tubes run from head to toe and along both arms. The tubes swell and tighten the suit under G pressure, pushing blood up. The suit is self-contained, eliminating the need for on-board regulating systems or compressed air.



Sources: U.S. Air Force, Prospective Concepts AG, Gentex Corporation

Juan Velasco/The New York Times; Photographs by U.S. Air Force

Designers Create Suits to Help Pilots Escape the Perils of Gravity

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search 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.

> In a way, suit designers recreate life in the womb.

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 overinflation. 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 counterpressure 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.

Lt. Col. Michael Sizoo, left, and Maj. Christian Ledet wear the Air Force's new antigravity suits, designed to counter the effects of rapid acceleration.