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Libelle Self-Contained Anti-G Ensemble: Overcoming Negative Transfer

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LIBELLE SELF-CONTAINED ANTI-G ENSEMBLE: OVERCOMING NEGATIVE TRANSFER

Michael T. Hoepfner, Marian C. Schultz, and James T. Schultz

ABSTRACT

G-suits have changed over the years since Dr. Wilbur Franks invented the first anti-g suit. For the past decade the United States Air Force has been using the Combat Edge ensemble and the associated L-1 straining maneuver. The Air Force is now testing the Libelle Self-contained Anti-G Ensemble (SAGE); it uses a unique Libelle Straining Maneuver (LSM). The suit and the straining maneuver were determined to be valid; however, the effects of negative transfer must be addressed or it will have a significant impact on the success of this program.

LIBELLE SELF-CONTAINED ANTI-G ENSEMBLE: OVERCOMING NEGATIVE TRANSFER

There is a revolution occurring in the fighter pilot community. There are fighter pilots flying sorties in the United States, Germany, France, and Sweden without connecting an anti-g suit to the aircraft. These are not navigation training sorties, or low g intercept sorties; but dogfights—Dogfights that would incapacitate an unprotected fighter pilot. So how are these pilots able to fight at nine g's without ever connecting an anti-g suit to the aircraft? These pilots are flying with the Libelle G-Multiplus Self-contained Anti-G Ensemble (SAGE). The Libelle anti-g suit does not require the traditional aircraft bleed air system, but rather relies on hydrostatic pressure. This suit is currently in Operational Test and Evaluation (OT&E) by the U.S. Air Force at the 85th Test and Evaluation Squadron (TES), located at Eglin AFB, Florida.

The Need for Anti-G Protection

World War I saw the beginning of the dogfight. Planes would turn as quickly as possible so that they could point their machine guns at the adversary and shoot him down before the "bandit" could do the same. In some of these early combat reports pilots reported loss of vision or "blackout in the air" as they would call it (Hess, 1999). The reason for this "blackout" was unclear and remained unstudied until World War II.

In the twenty years following World War I, aircraft became much more advanced—they were faster, more powerful, and much more maneuverable. As a result, during World War II these "blackouts" became more numerous and severe in nature. German "Stuka" dive-bomber pilots reported losing consciousness; while at the same time there was an increase in unexplainable aircraft accidents. For some reason, pilots were passing out under high g loads (Dickey & Theil, 2001). During this period the study of G induced Loss Of Consciousness (G-LOC) and anti-g protection was born.

The Physics and Physiology

Whenever any object changes direction, the force of inertia attempts to keep that object following along the same path. In fighter aircraft, the same holds true. When the aircraft is rapidly turning the pilot is pushed down in the seat as his body is attempting to continue along its' original path. The exact same sensation one would experience at the bottom of a roller coaster hill. This force is measured in terms of the force of gravity. Sitting in a chair one experiences one times the force of gravity or one g. On the most extreme roller coasters, one could experience momentary forces of three g's. If an individual weighed 150 pounds at one g, they would weigh 450 pounds at three g's. However, in today's modern fighter aircraft, pilots regularly sustain nine g's for sustained periods of time. A 150-pound pilot would weigh 1,350 pounds, and his 20-pound cranium would weigh 180 pounds! All this time his heart is trying to pump oxygenated blood (which now weighs nine times as much) up into his brain. Obviously, the heart will not be able to supply as much blood at nine g's as it would at one g (Gawron, 1998). When the brain does not receive its required amount of oxygenated blood, several detrimental things begin to occur.

If the brain does not receive sufficient oxygen carrying blood, it enters into a state know as "static hypoxia." To fighter pilots static hypoxia has varying degrees and associated levels of danger. During the initial stages, visual acuity begins to decrease. Pilots lose their vision in different ways. Some pilots report this loss of vision as a dimming sensation; some as a loss of color discrimination, while others experience "tunnel vision." If the brain continues to be deprived of oxygenated blood, total vision loss will ensue. This is the proverbial "blackout." During blackout, the pilot is still aware of his surroundings. The pilot can hear, respond to radio calls, and process information; but cannot see. At the extreme state of static hypoxia the pilot passes out. The pilot is completely unconscious and incapacitated. After blood flow returns to the brain the pilot will begin to wake up, but will be confused and disoriented for a period of time ranging from a few seconds to almost a minute—conscious, but still incapacitated in terms of aircraft control. This phenomenon is known as G induced loss of consciousness, or G-LOC. During relatively slow g onset rates, the pilot will experience vision loss prior to G-LOC, and therefore will be able to lower the g level prior to G-LOC. However, with the high g onset rates of today's advanced fighter aircraft, the pilot can transition to G-LOC faster than the body can experience the visual symptoms of impending G-LOC (Gawron, 1998). The blood is no longer supplying the brain with much needed oxygen; it is pooling in the pilot's legs and buttocks.

As g levels increase the blood weighs more and more. The heart has an amazing ability to increase its output through rate (pulse increases) and volume (blood pressure increases), but like any muscle, it has its' limits. When these limits are exceeded, the heart is unable to produce enough power (blood pressure) to force the blood to flow from the lower extremities to the head. Once this balance of pressures is lost, blood will begin to pool in the lower extremities (Gawron, 1998). During World War II, scientists in Canada recognized the physiology of what was occurring and began studying ways to prevent this pooling of blood. They hypothesized that if they minimizing the pooling of blood in the pilots' legs (by increasing external pressure), blood would be unable to flow excessively down to the legs. Therefore, the blood would be forced to higher levels in the body—namely the brain. The idea was to prevent G-LOC or as a minimum, delay the onset of symptoms (The University of Toronto led Canada's Efforts in Aviation Medicine, 2002).

Evolution of the Anti-G Suit

Wilbur Franks, a research scientist in Canada, noted that under high centrifugal forces some test tubes would break. However, if they were first placed inside a larger tube filled with water, the tubes would not break. He further experimented by placing mice inside water filled condoms. Mice that were inside the water filled condoms could survive high centrifugal forces, but the unprotected mice died. He thought pilots could use these same principles as well (The University of Toronto led Canada's Efforts in Aviation Medicine, 2002).

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Figure 1. **Wilbur Franks with a 1950's version of the anti-g suit. Retrieved 10 July, 2002 from http://www.newsandevents.utoronto.ca/bios/history27.htm.**

Early Anti-G Suits

Franks in the early 1940's applied this principle to pilots. With assistance of the electrical engineering department at the University of Toronto, he created an outer suit filled with water called the Frank's flying suit (Leary, 2000). Figure 2 shows this suit. The results were astounding, "...our planes performed feats of aerobatics deemed impossible without the pilots blacking-out." Pilots employed this suit fir the first time during the Royal Navy North African amphibious assault in 1942 (The University of Toronto led Canada's Efforts in Aviation Medicine, 2002). The anti-g suit was born. Over the years these suits have undergone many changes, but the function has remained the same.

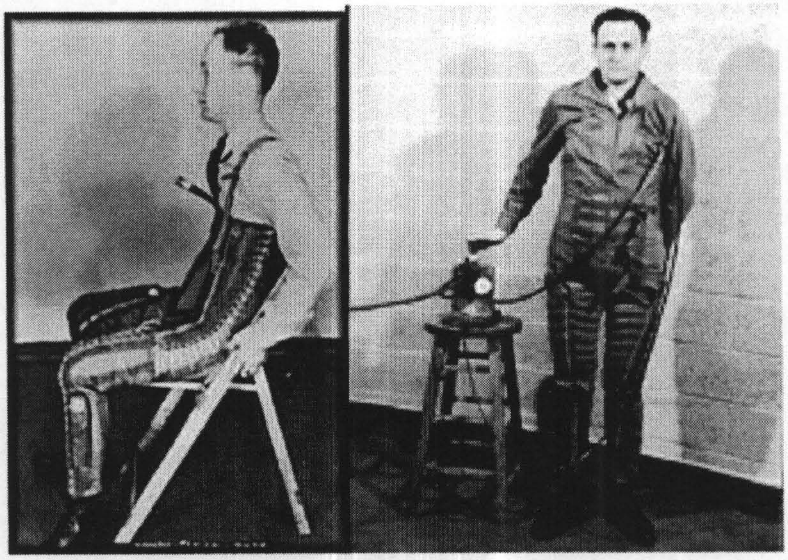

Figure 2. Wilbur Franks' first water filled anti-g suit called the Frank's flying suit. Retrieved 11 July, 2002 from http://www.drdc-rddc.dnd.ca/history/hist1b_e.html.

Current Anti-G Suits

Today the basic physiology of anti-g protection remains the same. Increase pressure around the lower extremities to prevent blood pooling, and perform an anti-g straining maneuver. The mechanics of this straining are beyond the scope of this paper, but its' purpose is to increase blood pressure. Today's aircraft use high-pressure bleed air from the engine. Figure 3 shows the basic configuration of an anti-g suit used until the mid-1990s. Notice how the only protection is around the legs. The physiological mechanism had not changed. In the early 1990s a new approach was taken. In addition to providing pressure around the legs and physically increasing blood pressure through a fatiguing anti-g straining maneuver, increased blood pressure would be provided via additional apparel and pressure assisted breathing (Gawron, 1998).

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Figure 3. Anti-g trousers. Retrieved 11 July 2002 from http://www.dfrc.nasa.gov/trc/careers/life/life.html.

Air Force physiologists theorized that if blood pressure were to be increased by artificial means, the pilot would not need to strain as hard to maintain consciousness. Figure 4 shows the current anti-g suit called Combat Edge. Combat Edge has two important additions: First, high-pressure air is forced into the mask. By having higher pressure in the lungs, blood pressure will increase assuming lung volume does not increase like an inflated balloon. To prevent the lungs from dangerously expanding, a vest is added to provide support against the torso (Gawron, 1998). It is important to understand that the Combat Edge ensemble does not increase g- tolerance; it only makes it less strenuous.

Figure 4. Combat Edge anti-g ensemble. Retrieved 10 July 2002 from http://www.flug-revue.rotor.com/FRheft/FRH9908/FR9908d.htm.

Despite its' universal acceptance as the Air Force anti-g ensemble for high performance aircraft, there are disadvantages to using Combat Edge. First is thermal stress. Obvious a large, bulky suit, constructed of non-porous material is going to be warm. A second problem is breathing technique. In order to raise blood pressure, own must strain against a close epiglottis (Gawron, 1998). This makes it impossible to speak while under high g. Some limited communication is possible; however, it will be at the cost of reduced g protection. This inability to communicate under high g is one of the greatest problems requiring attention today for the high g regime. The German company Libelle is attempting to address this problem.

Libelle G-Multiplus

A dragonfly can pull more g's than any other animal on the planet; during its' flying maneuvers a dragonfly pulls more than 30 g's! This is because its' cardiac system is surrounded by a fluid filled sack—the same concept as the Frank's flying suit (Leary, 2000). The process appears to have come full circle, and once again experimentation with liquid filled g-suits is underway.

Reinhard, a former Swedish fighter pilot, experimented with an anti-g suit filled with 6.5 gallons of water (Dickey & Theil. 2001). It is intuitively obvious that a suit similar to the Frank's flying suit would be impractical in today's fighter aircraft; however the basic premises of fluid dynamics can be used in our favor without the incredible weight of a fluid filled suit. Libelle (which translates to dragonfly), a German company, is marketing a fluid filled suit; but with most of the fluid removed. Only one-half gallon of water remains.

Concept

The physiology of squeezing the legs remains the same; however, the mechanism is completely different. Today's g-suits use pressurized air pumped into bladders to squeeze the legs. As seen in Figure 5, this requires high-pressure air from the engine, plumbing from the engine, a regulator, and a connection from the aircraft to the suit.

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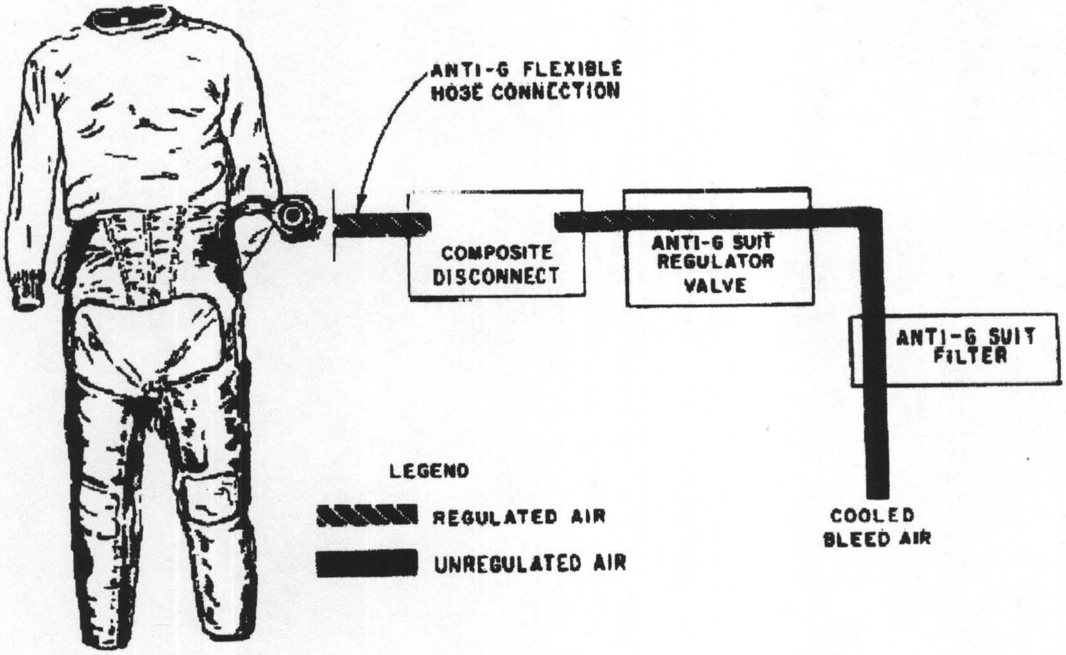

Figure 5. Typical anti-g system. Retrieved 10 July, 2002 from http://www.tpub.com/ase2/2.htm.

The suit developed by Libelle, called the G-Multiplus Self-contained Anti-G Ensemble (SAGE), uses fluid dynamics to squeeze the legs. A Libelle SAGE suit has two liquid filled tubes called "liquid muscles" that run the length of the pilot's body. One liquid muscle runs from the upper chest, down the front of the torso, and all the way down the front of the leg to the ankle. The second tube runs down the pilot's back to his ankle. The liquid muscles are enclosed in a non-stretchable suit that covers the entire body, replacing the standard flight suit. There are additional liquid muscles in the arms, but they are there for pilot comfort, not g protection.

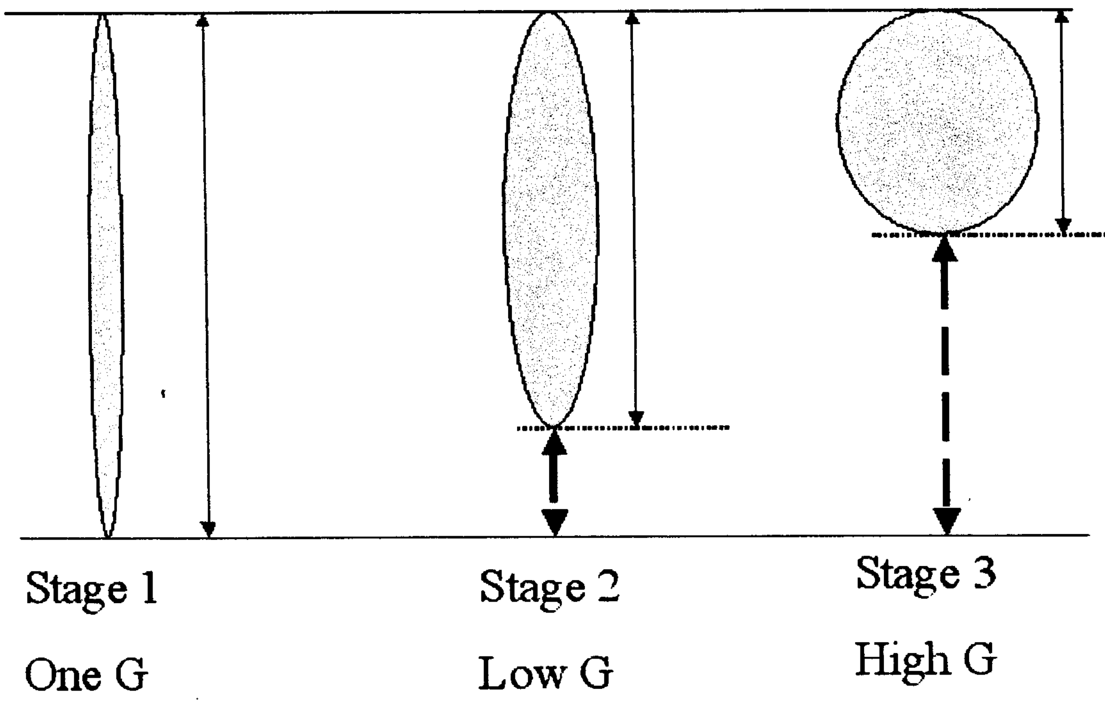

Figure 6. Cross-section of liquid muscle. From Libelle Pilots Manual, Anti-G System, Libelle G-Multiplus for USAF, 2002. Used by permission.

Figure 6 shows how the Libelle SAGE suit squeezes the legs using the liquid muscles. At one g the liquid muscle is flat, and the liquid is distributed along the entire length of the liquid muscle. As g is increased the liquid is subjected to the same hydrostatic pressure as your blood, and will attempt to flow downhill. As more liquid fills the lower portion of the muscle, the liquid muscle will change in shape from flat to round. In Figure 6, the thin line to the right of the liquid muscle shows how much of the suits circumference is made of liquid muscle. The thick dashed line shows how much the suit squeezes via reduced circumference (Pilot Manual, 2002).

Libelle Straining Maneuver

An important point with the Libelle SAGE suit is the differences in the straining maneuver. As stated earlier, with conventional pressure breathing systems the pilot strains against a closed epiglottis. However, with Libelle SAGE the strain is completely different. In fact, the closed epiglottis is counter-productive to the strain. Libelle uses a slightly different physiology to prevent blood pooling and maintain blood flow to the brain. Conventional pressure breathing anti-g suits increases total blood pressure in the entire body. Libelle SAGE maintains blood flow to brain by reducing area in the legs, but allow for venous flow to return from the legs. This allows a much better arterial blood flow to continue to the brain. Bernoulli's principle dictates straining against a closed epiglottis would increase total blood pressure. This would force more blood to the legs, and thus, there would be less arterial flow to the brain (Pilot Manual, 2002). Grunting and straining is no longer required, and speech is now possible. It is important to note that the pilots still needs to squeeze their legs, buttocks, and stomach in the strain.

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Figure 7. Libelle G-Multiplus Self-contained Anti-G Ensemble.

Figure 7 above shows a pilot wearing the Libelle SAGE suit. Notice how there are absolutely no connectors for the suit to the aircraft. The suit is self-contained, and therefore, a universally applicable system to any aircraft. In addition, because there is no requirement for aircraft bleed-air, plumbing, or regulators; any aircraft can use this system and dedicate the now free space to other on board systems. The F-22 Raptor, Joint Strike Fighter (JSF), and the new T-6 Texan trainer are all considering the Libelle SAGE for anti-g protection (G-Suits For T-6 Pilots To Reduce Loss of Consciousness Incidents During, Training, 2001).

Early Findings

Libelle Sage is currently in OT&E in the 85TES. Six F-16CJ and four F-15C pilots are evaluating the operational utility of the system. There are also ongoing tests by German by MiG-29 pilots, French Rafale and Mirage 2000 pilots, and Swedish Gripen pilots. The U.S. Air Force Test Pilot School at Edwards Air Force Base in California recently completed an initial evaluation of a prototype version of the suit (Behar, 2002). Revues have been mixed.

The largest supporters of Libelle SAGE are the German MiG-29 pilots. They have been flying with the Libelle suit for over a year and their assessment has been extremely positive. Captain Swen Jacobs said, , "With the new suit you can go for a longer time..." (Dickey & Theil, 2001, p. 72). The ten pilots from the 73rd Fighter Wing, stationed at Lagge Air Base Germany, are unanimous in their support. One of their accolades is the ability to speak while under high g. Several of the pilots are also involved in the Euro-Fighter program. The Euro-Fighter uses innovative voice recognition commands. Designers and programmers expect that 130 voice commands could be programmed into the system. However, while under high g, this technology will be unusable with current anti-g technology (Nordwall, 2001a). Not all of the early findings have been so optimistic.

The Swedish pilots are not having the success the German's are having with the Libelle SAGE. In fact, they said, "...the Libelle suit is not adequate for use in nine g aircraft, such as the Gripen" (Nordwall, 2001b, p. 63). All of their findings were based on a preliminary test in the centrifuge. Originally, six pilots were to test the system; however, only three were available. All three of the pilots were dissatisfied with the g protection provided by the Libelle SAGE suit. One experienced a G-LOC, one experienced a near G-LOC, and the third was not comfortable pulling the high g's required for the test (Nordwall, 2001b). It is interesting to note that based on the reduced sample size, and the unwillingness to complete testing, the Swedish finding were not statistically significant. The U.S. Air Forces results have also been mixed.

In the summer of 2001, the U.S. Air Force entered the group of pilots testing the Libelle SAGE. The first pilots were USAF test pilots stationed at Edwards Air Force Base in California. Three pilots, three engineers, and a physiologist comprised the test team. The suit tested was a prototype suit similar to, but not the production suit offered today (New High-Tech System to Protect Fighter Pilots, June 2001). Their results were very positive. The suit tested was not a production suit; and therefore, the conclusion was that the technological benefits justified follow-on testing. Colonel Hank Morrow, a member of the Libelle SAGE test team, in a personal interview said, "...you became a g-monster" (personal communication, H. Morrow, April 1, 2002). The 85TES is now conducting that follow-on testing, but this time they are testing the production version of the suit.

Negative Transfer

Negative Transfer is defined as, "The impeding of learning or performance in a situation by the carryover of learned responses from another situation" (Merriam-Webster Dictionary On-line, 2000). This appears to be the exact same situation that the 85TES is experiencing. The 85TES pilots underwent a very rigorous check out in the Libelle SAGE, and by the end of qualification training they were able to perform at the same level [pull nine g's] with Libelle SAGE as with Combat Edge. However, this was only under very structured situations where full attention could be given to correct LSM performance. Once situations became more dynamic, performance dropped in proportion to amount of attention they were able to divert towards proper LSM performance. Despite their complete concentration on correct LSM performance, negative transfer was seen even in the early stages of qualification training. Their subconscious desire to perform an L-1 while under stress was difficult to overcome.

Early Centrifuge Testing

Initial checkout with Libelle SAGE involved a week of training in Holloman Air Force Base's centrifuge. The purpose was to learn the mechanics of the LSM. Initially, the pilots were very impressed with the suits performance. Pilots reported very little to no light loss up to 7.5 g's (Holloman Test Reports: Libelle SAGE, 2002). Above 7.5 g's the problems with negative transfer began to arise.

The point that pulling g's begins to become work is around 7.5 g's for most pilots. Below 7.5 the pilots are straining against the g forces, but the level of effort is not exceptionally high. It can be said that the pilots are not under physical or psychological stress. Once the pilots entered into the high g arena [7.5+ g's] a subconscious reaction began to take place. Physically, this flight regime is very difficult, even painful. Based on this knowledge, pilots are under psychological stress as well. Their bodies are preparing for a known stressful situation. In the Holloman centrifuge every one of the pilots suffered negative transfer. One hundred percent of the pilots reported light loss whenever they exceeded eight g's (Holloman Test Reports: Libelle SAGE, 2002). This light loss causes the body to respond with a "flight or fight" decision. One of three things happened: 1) Pilots continued to pull g's without adjusting their strain [via technique and/or intensity] and suffered a G induced Loss of Consciousness (G LOC); 2) They relaxed the g's to avoid the high g arena—this would be "flight" from the stressor; or 3) Pilots strained vigorously against the g and overcame the stressor—"fight." Well, what straining technique had the pilots learned first? What straining technique had they performed every time this stressful situation was encountered for more than a decade? ANSWER: They have always done an L-1, a straining maneuver that is counter-productive to success with the Libelle SAGE. Initial runs in the high g arena were not exceptional. Two of ten pilots experienced a G LOC, and the other eight reported more than 80% vision loss. All of the G LOCs and high vision loss situations were attributable to poor/incorrect

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performance of the LSM—negative transfer from the L-1 was the culprit (Holloman Test Reports: Libelle SAGE, 2002). However, by the end of the week all pilots in the Libelle SAGE program were qualified to fly with the suit.

Success in the Centrifuge

In order to qualify for flight with Libelle SAGE, all of the pilots had to demonstrate the same g tolerance as with Combat Edge. This involved four separate profiles: Profile 1: Withstand seven g's for 20 seconds; Profile 2: Withstand six g's for 20 seconds in the "check six" body position; Profile 3: Withstand a variable g profile simulating and air combat engagement. (This profile consisted of g levels that varied between five and nine [short duration at nine g's] and lasted 60 seconds); and Profile 4: Nine g's for 15 seconds. It is to be noted that all of these profiles start from one g and use rapid onsets to the g level required by the profile (Hansen, 2002). Qualification in the centrifuge was not an easy task. The pilots had to re-learn how to strain against the g's.

Learning Theory

In the early 19th century Edward L. Thorndike developed his Theory of Identical Elements. This theory stated that the amount of learning transferred between two separate but related tasks is based on the amount of similarity between the tasks. He went on to say that basis of learning a new task consists of forming connections between specific stimuli and specific actions (Transfer of Learning, October 2001). This theory on learning is what set the stage for negative transfer in the 85TES.

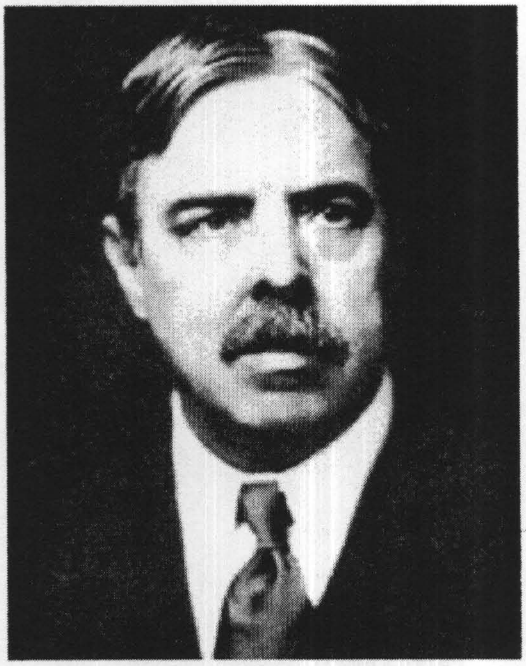

Figure 8. Edward L. Thorndike. Retrieved 15 August from http://psych.fullerton.edu/navarick/transfer.ppt.

The disassociation between similar stimuli, but different required actions was psychologically difficult to rectify. The stimuli to invoke the required action for the Combat Edge L-1 and Libelle SAGE LSM was exactly the same—high g's, loss of vision, impending GLOC, et cetera. However, the correct action to apply was different. To complicate matters, this stimulus invoked a "flight or fight" response, and incorrect application could have disastrous results—to the extreme of being fatal. Therefore, the learning process had to be slow and tedious to re-learn a habitual response.

Flight Results

Following the initial checkout in the Holloman centrifuge, the pilots were required to complete a five ride "top-off" program before flying unrestricted with Libelle SAGE. The first ride was a single ship sortie in a two seat aircraft. The Libelle SAGE pilot flew in the front seat, while a Combat Edge pilot rode in the back seat acting as a safety observer. This ride was to acquaint the pilot with Libelle SAGE in an actual aircraft without the distractions of formation flight and dynamic fight scenarios. The next four rides were normal continuation training rides. No restrictions were placed on the pilot other than a thorough revue of his LSM during the flight brief and debrief. After these five sorties the pilot was cleared for unrestricted use of the Libelle SAGE. This program was ripe for negative transfer. However, due to competing operational test requirements it was the best the unit could do without jeopardizing higher priority tests.

It is at this point two groups within the Libelle SAGE program developed. The first group had success with the Libelle SAGE and experienced minimal problems. The second group found it very difficult to utilize Libelle SAGE, and experienced significant trouble pulling more than seven g's. The differentiation between these two groups can be traced to the first three weeks of flying with Libelle SAGE after the five ride check out. The determining factor was self-assessed confidence in the Libelle SAGE. The confidence was either established or destroyed during this initial three-week period. Those that "took it slowly" generally had better results than those that "jumped in with both feet." The decision to take it slowly or aggressively was out of their realm of concern; it was determined by the 85TES test schedule.

The week following initial checkout in the centrifuge, the F-15's from the 85TES deployed to Nellis Air Force Base to participate in a Large Force Employment (LFE) exercise. This LFE scenario was extremely complex and required 100% attention to tactical decisions and airmanship. The last thing that crossed their minds was g-straining technique [they never had to think about it before]. It would be unfair to say that they did not talk about it in the flight brief. However, once the fights began it is reasonable to assume that the LSM was not given its' justifiable amount of attention. Pilots began to scare themselves.

Negative transfer loomed in the fights ahead. They were going into a situation where high-g maneuvers were expected. They knew how to execute an LSM. But they really did not have the opportunity to practice the LSM technique in a controlled environment, experience success on regular basis, and have the LSM effectiveness be reinforced into their psyche. Technically, the pilots had not learned the LSM. They knew how to perform an LSM. The difference is critical. Actual learning is the innate association between a stimulus [high g] and a response [LSM] (Transfer of Learning, October 2001). The pilots who had the opportunity to practice and re-enforce [learn] the LSM experienced much better success.

At Eglin Air Force Base the F-16 pilots assigned to the 85TES did not have the rigors of test requirements hanging to contend with as did their F-15 counterparts. They had time to experiment with the Libelle SAGE. For the next three weeks they flew simple one-versus-one sorties. The intent was to practice to LSM. They had the opportunity to have positive re-enforcement of performing a correct LSM. This positive re-enforcement was critical for success; positive re-enforcement delays the onset of a "flight or fight" response.

One needs to remember that a "flight or fight" response can be either physical or psychological in nature. However, both will have the same result most of the time. The Law of Primacy will cause the human body to revert to what it learned first—the L-1. This assumes they have actually learned the LSM, which is debatable. As result, a "Catch-22" situation ensues. Now anytime, even at lower g levels, the pilot has a psychological "flight or fight" response and the process repeats itself. Therefore, it is imperative for the Libelle SAGE pilot to first learn how to execute an LSM, and then become confident performing an LSM. The actual learning of the LSM will happen naturally over time

CONCLUSION

The law of primacy states that when under stress and experiencing a "flight or fight" response, the human body will react with what it knows best. In the stressful high g regime US Air Force pilots know the L-1 best. The transition to a new g suit, especially one which requires the pilot to respond differently when experiencing a high or sustained amount of g's, will require training on not only how to utilize the new system, but on how to overcome negative transfer effects. As with any change, whether welcomed or not, results will not always be immediate. For those pilots who are exposed to the Libelle system in the primary stage of pilot training, and never use the L-1 suit, there will be no negative transfer effects to overcome. But for those pilots who have used the L-1 suit throughout their entire career. the transition could be a challenge.

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