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EVALUATION OF THE RETROGRADE INFLATION ANTI-G SUIT (RIAGS)

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FOR THE COMMANDER

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The Retrograde Inflation Anti-G Suit (RIAGS) was originally designed and fabricated in the early 1940's by Mr. David Clark and Dr. Earl Wood as The Progressive Arterial Occlusion Anti-g Suit. Testing of this suit on the Mayo Clinic centrifuge revealed that the suit provided more g protection than the fighter pilot of the era needed (+2.9 gz relaxed). This technology was revisited in 1987 by the Armstrong Laboratory and culminated in the development of a new version of the technology using modern methods and materials. The new suit consisted of a retrograde inflating anti-g suit which inflated cephaladward, arterial occlusive cuffs for the arms, and capstan sleeves. These suit combinations were compared to the standard Air Force issue CSU-13B/P anti-g suit. Endurance testing of the current suit involved exposing subjects to a continuous +4.5 to +7 gz Simulated Aerial Combat Maneuver. Results from this study showed the RIAGS with capstan sleeves provided the maximum amount of protection to the subject in terms of endurance ($p<0.013$), followed by RIAGS alone ($p<0.058$), Standard CSU-13B/P and RIAGS with occlusion cuffs ($p=0.28$). In addition to the protection issue, RIAGS with sleeves also proved to be the most comfortable of all the g suit combinations evaluated.

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Anti-g Suit, Arterial Occlusion Cuffs, g Tolerance, Capstan Sleeves, g Endurance

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PREFACE

Research on this effort was performed under the 1987 Armstrong Laboratory Director's Fund program. The Research was conducted through the Engineering Services Contract F-33615-89-C-0574 by Systems Research Laboratories Inc. The authors wish to thank the Dynamic Environment Simulator Operations Crew for their technical assistance throughout this study and a special thanks to Mr. Robert Esken and SSgt Rudolph Cartwright of the Electronics Support Group, and Dr. R.E. Van Patten for his efforts in developing this program. We would also like to acknowledge Dr. Earl Wood and the David Clark Co. who provided technical guidance in developing the new version of the Retrograde Inflation Anti-g Suit (RIAGS).

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INTRODUCTION

The development of the Retrograde Inflation Anti-G Suit (RIAGS) was accomplished as part of a Laboratory Director's Fund program. The main thrust of this program was to exploit the engineering technology of the previously developed progressive arterial occlusion suit (PAOS) designed by Mr. David Clark and Dr. Earl Wood in 1943. Initial work with this suit showed a significant increase in g tolerance of +2.9 gz when compared to other suits of the era. A description of the original suit and studies were reported by Wood et al (2,3,4). Although this suit provided superior protection, the aircraft of the 1940's did not require the degree of protection this suit provided. Because the new version of PAOS did not employ arterial occlusion of the legs, it was renamed the Retrograde Inflation Anti-G Suit (RIAGS) in 1989, to avoid any confusion about the operation of the suit. The original PAOS design was resurrected because of the g induced loss of consciousness problem in USAF aircraft and the suit's apparent inprovement in g protection over the standard CSU-13B/P anti-g suit.

The approach used in the current suit development was to fabricate a modern version of the original design using current state of the art materials and fabrication technologies. Materials used in the fabrication of the new suit included nylon which was used in the restraint fabric which covered the outside of the suit and interdigitating tapes of the capstan sleeves, as well as the fabric of the sleeves. In addition, nylon was used in the arterial occlusive armcuffs, side fasteners, g-suit material, and capstan sleeve adjustment lacing. Anti-g suit bladders were comprised of urethane-coated nylon while the armcuffs and capstan bladders were constructed of urethane film. Self-sealing quick disconnect fittings were used to facilitate reconfiguration of the suit for use with the optional capstan sleeves and armcuffs. Bladder fabrication consisted of ultrasonically sealing the lightweight urethane material which resulted in minimal weight and bulk.

Anti-g Suit Operation

The maximum operating pressure of the various components of the RIAGS was 12 psi for the arterial occlusion cuffs and the g-suit which was comprised of a series of ten bladders which inflated from the ankles to the abdomen (Figure 1). Both the capstan sleeve (left of picture) and the occlusion cuff (right of picture) are shown here for demonstration. When evaluated, the subject wore either both sleeves or both cuffs. The capstan sleeves were designed to hold a maximum pressure of 30 psi. The reason for the extremely high pressure for the capstan sleeves is the pressure ratio between the capstan pressure tube and the material of the sleeve which applies pressure to the skin in a 5:1 ratio (1).

Interconnecting g-suit bladders of the RIAGS enabled the resultant pressure in various sections to be adjusted via the use of clamps. This allowed the progressive pressure gradients and fill times to be manually manipulated. This suit still inflated in a retrograde fashion cephaladward (foot to head), but did not apply arterial occlusive pressures to the thighs as did the original suit. The RIAGS suit does not utilize pressure socks or other counter pressure devices for the feet. Arterial occlusive armcuffs were still an optional part of the suit, as were the capstan sleeves. The capstan sleeves contained pneumatic capstan tubes integrated lengthwise via interdigitating tapes, so as to tighten the sleeves around the arms when the capstan tubes were pressurized. This was similar in design to the capstan-type partial pressure suits used for high altitude protection in the late 1950's.

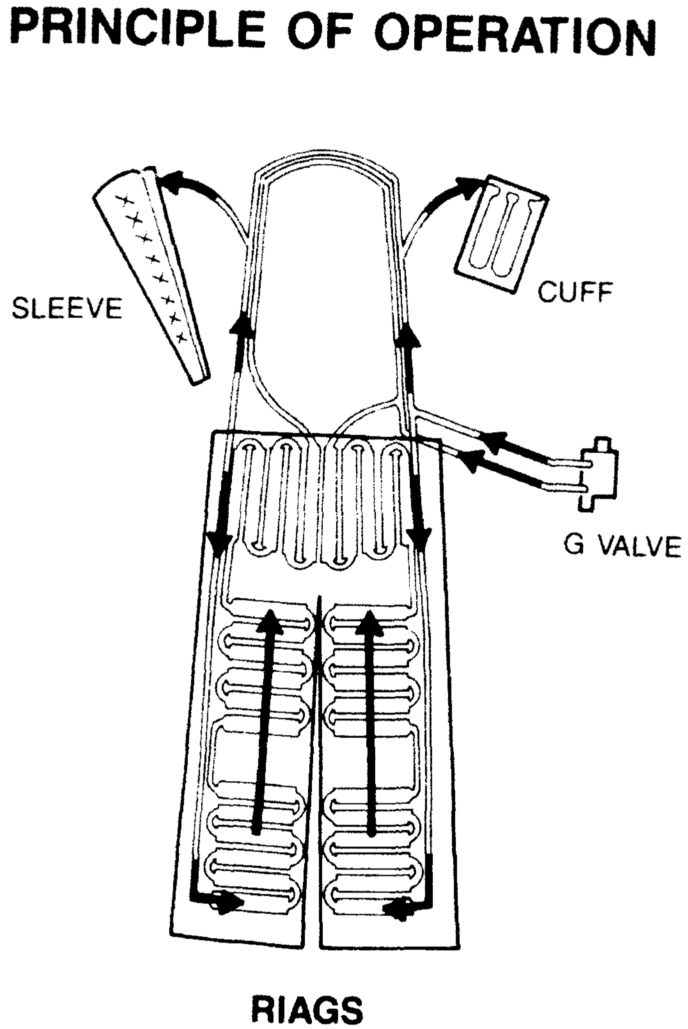

Figure 1. Principle of operation for the retrograde inflation anti-g suit (RIAGS).

The pressure applied to the underlying arms by the tightened sleeve fabric is accomplished by inflating the capstan tube. The design approach of the capstan sleeves offers the typical pneumatic bladder advantages in that it is low profile, lightweight, causes minimal thermal burden, and has a low pressurization volume. One problem is, however, that arm movement is restricted when the tube is fully pressurized.

Arterial occlusion armcuffs are pneumatic bladders enclosed in nylon fabric. The cuffs fit in a circumferential manner around the arms and were placed proximal to the deltoid muscle. The cuffs were similar in design to standard blood pressure cuffs. The new version of this suit is described in the Statement of Work dated April 1987 from the David Clark Co.(5).

The following describes the methods and results from g-endurance testing which compared the RIAGS alone, RIAGS with capstan sleeves, and the RIAGS with arterial occlusive armcuffs (Figure 2) to the standard cutaway CSU 13B/P anti-g suit (Figure 3).

Figure 2. RIAGS with capstan sleeve (right arm) and arterial occlusive cuff (left arm).

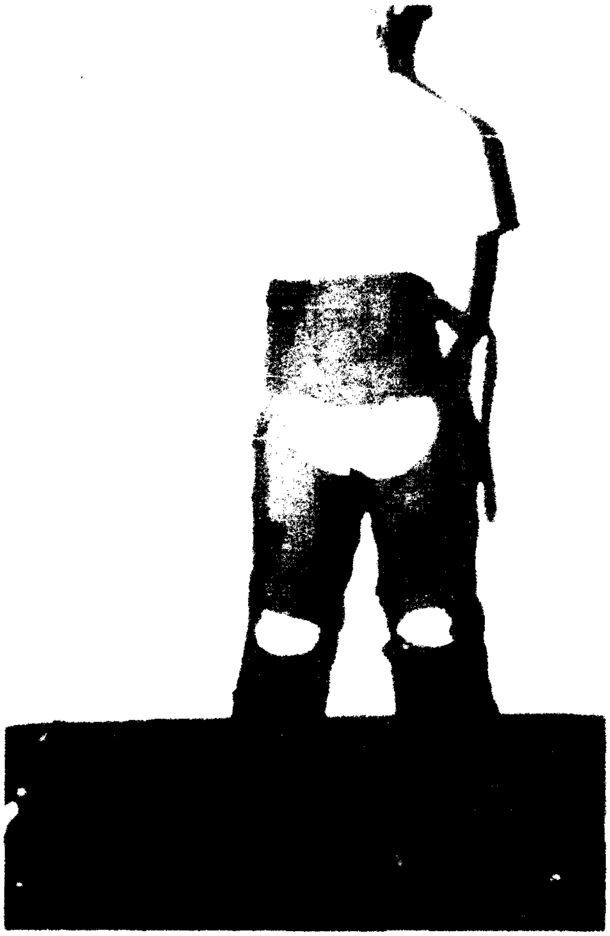

Figure 3. Standard CSU-13B/P anti-g suit.

METHODS

Subjects

Subjects participating in this study were volunteers from the Sustained Acceleration Stress Panel. Four males and three females participated. All subjects had been briefed on the experiment and had given informed consent prior to their participation in this study. Subjects ranged in age from 23 to 40 years.

Equipment

Subjects wore standard-issue flight suits and boots for all standard CSU-13B/P g suit exposures, and long underwear, a T-shirt, and flight boots when testing the RIAGS conditions. The reason for this change in personal equipment was that the RIAGS was designed to be worn underneath a modified flying coverall. Subjects were instrumented with a standard three-lead ECG and donned a PCU-16 parachute harness (to be used for emergency egress only) prior to entering the centrifuge cab. After entering the centrifuge, the subject was seated in a facsimile of an ACES II seat with a 30 degree seat back angle and secured with a five point connection quick-disconnect restraint harness. In addition to the ECG, arterial oxygen saturation was measured non-invasively using a Nellcor N-200 pulse oximeter and a specially modified ear clip which attached to the subject's ear at eye level. Arterial oxygen saturation was monitored throughout the g exposure.

The centrifuge evaluation involved comparing the RIAGS full coverage g suit alone, RIAGS with arterial occlusion cuffs, RIAGS with capstan sleeves, and the current Air Force issue standard cutaway CSU-13P/B anti-g suit (or standard suit). None of the RIAGS conditions included foot coverage.

Experimental Design

All g-suit conditions were randomized across subjects using the experimental test matrix illustrated in Table 1.

TABLE 1. TEST MATRIX.

Subject	Conditions vs Test Subject			
1	B	D	A	C
2	A	C	B	D
3	D	C	B	A
4	C	B	A	D
5	D	A	B	C
6	A	C	D	B
7	B	D	C	A
8	D	A	B	C

A = Standard CSU-13B/P Anti-g Suit
B = RIAGS Alone
C = RIAGS With Cuffs
D = RIAGS With Capstan Sleeves

An Alar Hi-Flow anti-g valve was used to provide g suit inflation during all g exposures. The arterial occlusion cuffs and capstan sleeves were inflated to a pre-set pressure of 5 psi as the g profile passed through +4 gz, and remained inflated to that pressure until the g level was less than +4 gz. Pressure in the sleeves and cuffs was controlled using two electric solenoid valves which were computer activated via the voltage output from an accelerometer.

G Profiles

This experiment was conducted in the Dynamic Environment Simulator, a 19 foot radius multi-axis man-rated centrifuge located at Wright-Patterson AFB, OH (Figure 4). Acceleration profiles for this study included a +4 gz 30 second warm-up run followed by at least 1 minute of rest at baseline (about +1.4 gz). This was followed by a 0.5g sec onset, +4.5 to +7 gz simulated aerial combat maneuver (SACM) profile (Figure 5) which ran continuously until the subject reached a peripheral light loss endpoint (defined as a visual field less than 60 degrees), or fatigue.

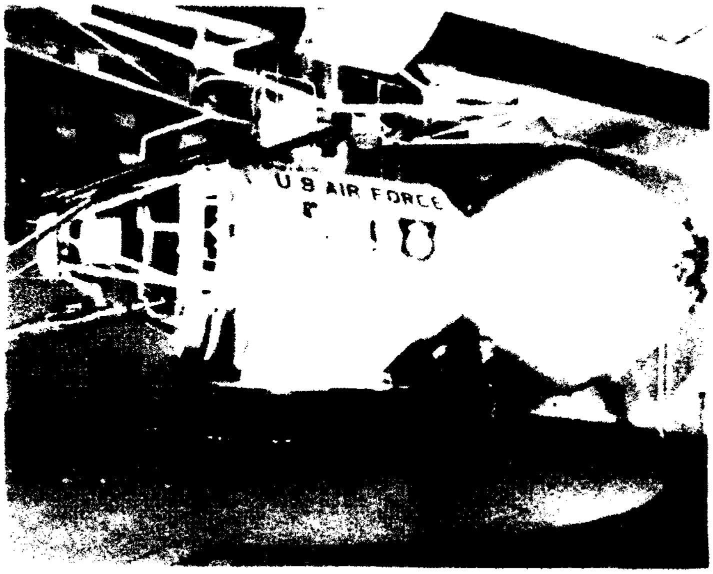

Figure 4. Dynamic Environment Simulator.

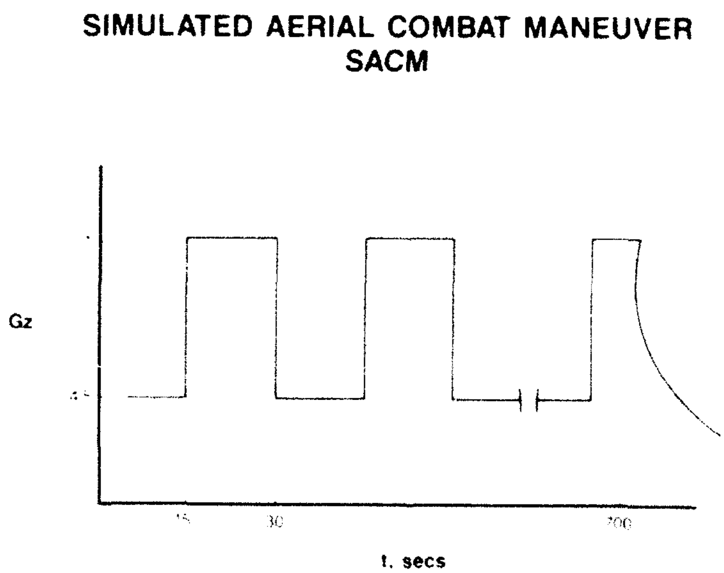

Figure 5. Simulated aerial combat maneuver.

Data Collection

Physiological and g-suit data were transmitted from the cab of the centrifuge to the various data collection devices via slip rings (rotating plates and a stationary plate connected with brushes). Remote video cameras provided a front and side view of the subject throughout the experiment. Video images of the subjects were recorded on 0.5 inch VHS tape using a Panasonic video cassette recorder. Subjects were in constant communication with investigators and the physician using a microphone attached to the restraint harness and a speaker mounted to the rear of the subject's seat. Oxygen saturation values, suit pressure, cuff and sleeve pressure, heart rate, and g-level were digitized, recorded, and stored on magnetic tape using a SEL computer. Data were also recorded in real time on a Gould 4000 brush recorder. Finally, subjects were asked to rank the four suits in terms of comfort during acceleration.

RESULTS

Statistical Analysis

The total time at g for the SACM for the three RIAGS conditions were compared to the standard cutaway CSU-13 B/P using the standard t-test which revealed that subjects wearing the RIAGS with sleeves had significantly longer SACM endurance times than the standard suit ($p < 0.013$ see Figure 6).

RESULTS

ACCELERATION ENDURANCE MEANS.

RIAGS vs STANDARD ANTI-G SUIT

N = 7

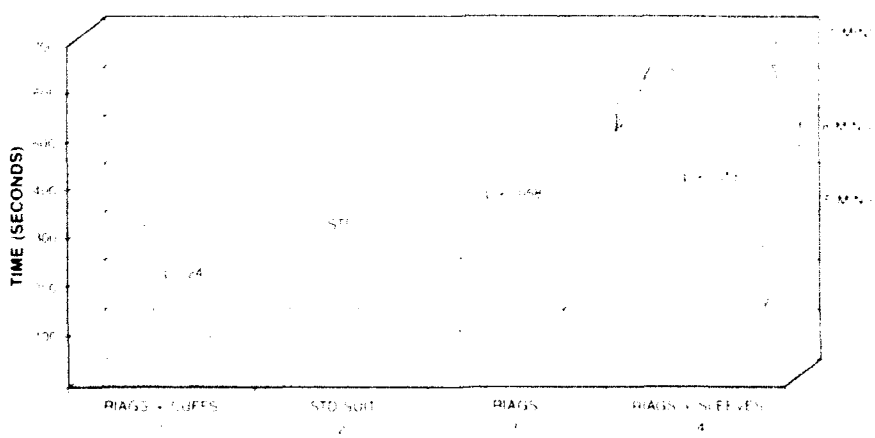

Figure 6. Total Time at SACM.

RIAGS alone neared significance ($p < 0.058$). The RIAGS with cuffs was not statistically significant when compared to the standard g suit ($p = 0.28$). The total time at g was actually shorter for the RIAGS with cuffs condition when compared to any of the other suit conditions. The total number of high g peaks endured by each subject are shown in Table 2.

TABLE 2. NUMBER OF HIGH g PEAKS ENDURED

Subject:	RIAGS w/Cuffs	Standard Suit	RIAGS Alone	RIAGS w/Sleeves
A	10	10	10	17
B	5	10	17	14
C	11	7	14	22
D	4	7	14	11
E	11	14	18	27
F	3	4	X	4
G	5	5	5	7
avg. peaks	7.0	8.1	13.0	14.6

X = missing data

Subjective Data:

Subjects ranked the overall comfort of each suit. Table 3 shows the comfort ranking of each suit condition, as well as the mean acceleration time of the seven subjects for each of the suit conditions. Subjects rated RIAGS with sleeves as being the most comfortable followed by RIAGS alone, the CSU-13 B/P, and RIAGS with cuffs. Subjects reported their dissatisfaction with the arterial occlusion cuffs during the post acceleration debriefing. These complaints were mainly related to the following: tingling of the hands and fingers, decreased dexterity of the fingers, and in some cases flank pain. All of these symptoms could be attributed to arterial occlusion over long durations (up to four minutes). Pahysiological measures (heart rate, arterial oxygen saturation, suit pressure, and g levels are reported elswhere (6).

TABLE 3. COMFORT RANKINGS (N=7)

SUIT Condition	Most Comfortable	Mean Time Performing SACM
RIAGS with Sleeves	1	657 sec
RIAGS Alone	2	467 sec
Standard suit	3	322 sec
RIAGS with Cuffs	4	284 sec

DISCUSSION

Re-evaluation of the RIAGS technology in terms of endurance rather than a g tolerance enhancement modality produced some very interesting results. The use of capstan sleeves in addition to the full coverage RIAGS provided the greatest amount of protection and enabled subjects, on average, to increase their g endurance by 5.5 minutes compared to the standard CSU-13B/P and by 3 minutes compared to the RIAGS alone. A possible explanation for this increased endurance is that the capstan sleeves prevented blood from pooling into the arms, while the RIAGS minimized pooling in the legs. Pooling was observed in the feet of some subjects since booties or pressure socks were not evaluated with RIAGS. Several subjects reported severe petechial hemorrhages of their feet after long g exposures using the RIAGS suit (Figure 7.).

Figure 7. Petechial hemorrhage of the feet.

It is speculated that the combination of the RIAGS plus sleeves maintained blood return to the heart, cardiac output, and eye level blood pressure for longer periods of time. From a historical perspective, full coverage anti-g suits have routinely provided better g protection than cutaway versions used over the years (6,7,8,9). The average increased endurance across subjects who used the RIAGS alone, was 2.4 minutes greater than the standard anti-g suit.

This was not the case for the arterial occlusion cuffs. Unlike the short duration g environment used by Wood and others (9), which showed that arterial occlusion cuffs had an additive effect of +0.6 gz increase in tolerance, the current g endurance study shows that when arterial occlusion cuffs remain inflated for a long duration at a moderate g level, a decrement in g endurance may occur. This was demonstrated by the time spent at g with the arterial occlusion cuffs (284 sec with cuffs compared to 322 sec using the standard suit alone).

Arm pain experienced by test subjects wearing the occlusion cuffs was possibly the result of an ischemic response to having the brachial artery occluded on an average of about 5 minutes in duration. Although the complications associated with ischemia are not conducive to the flying environment because of symptoms (like tingling of fingers hand, loss of function, and frank pain), it is important to remember that the experimental constraints placed on this study dictated that the arterial occlusion cuffs would remain inflated above +4 gz and that during the SACM the cuffs remained inflated for the duration of the run. It is conceivable, however, that the use of arterial occlusion cuffs may prove effective when used in the type of g exposures typically experienced by today's fighter pilot (usually less than 5 sec seconds at peak g). This is a topic for further research. In addition, if the pressure in the cuffs was modulated (such as it is in the anti-g suit), the cuffs may be more acceptable.

The RIAGS was never evaluated for its apparent utility of cephaladward vs caudalward (footward) inflation; however, a new full coverage anti-g suit has been developed at Armstrong Laboratory, Brooks AFB, TX, called ATAGS or Advanced Technology Anti-G Suit. This suit fills in much the same manner as the CSU-13B/P but covers nearly all of the lower body including the feet (10). The ATAGS is currently being flight tested in high performance aircraft and is being developed because of its simple, but effective, design. The ATAGS is demonstrating performance comparable to the RIAGS.

CONCLUSION

RIAGS with sleeves provided the greatest degree of protection compared to both the standard anti-g suit and the other RIAGS conditions. The RIAGS full coverage anti-g suit did exhibit greater protection than the standard anti-g suit. The use of arterial occlusive arm cuffs in the long duration g environment proved to be prohibitive because of pain subjects experienced in their hands. Perhaps a reduced pressure schedule in these cuffs would lead to greater subject acceptance. The RIAGS is not recommended for further development as a g protection system; a new, lower torso/full coverage anti-g protection system called the Advanced Technology Anti-G Suit (ATAGS) is being developed for replacement of the standard anti-g suit in high performance aircraft.

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