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13. ABSTRACT (Maximum 200 words)

The centrifuge evaluation of the ATAGS and EAGLE was undertaken to determine which extended coverage anti-G suit would enter engineering and manufacturing development for joint service use. Eight male centrifuge subjects were used, wearing either an ATAGS, with or without pressure socks, or an EAGLE. Pressure breathing during G (COMBAT EDGE) was used with all three combinations. The combinations were randomized to eliminate any order effect. The arms of all subjects were wrapped from the wrist to the axilla with 3 in. wide elastic bandage to reduce the possibility that subjects might stop the $+G_z$ exposure for arm pain rather than for fatigue or light loss. GOR, ROR, and 5-9 SACM $+G_z$ profiles were used to compare the suits. Although not significantly different, the average number of 9G plateaus completed (endurance) for the ATAGS with socks, the ATAGS without socks and the EAGLE were 8.0, 7.8, and 6.5, respectively. Subject HR while wearing the ATAGS with pressure socks was significantly ($p=.03$) lower than HR while wearing the EAGLE during the 5G plateaus of the 5-9 $+G_z$ SACM. The perceived effort involved in the straining maneuver during the 5-9 SACM with the EAGLE was consistently, but not significantly, greater across the 9G plateaus compared to the ATAGS with pressure socks. However, there was a significant ($p=.032$) suit/time interaction between the ATAGS with pressure socks and the EAGLE. There was no significant difference in subject HR or $+G_z$ tolerance between the three G-suit combinations during the GOR or ROR $+G_z$ exposures.

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Comparative Centrifuge Evaluation of the Air Force Advanced Technology Anti-G Suit (ATAGS) and the Navy Enhanced Anti-G Lower Ensemble (EAGLE)

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ABSTRACT: The centrifuge evaluation of the ATAGS and EAGLE was undertaken to determine which extended coverage anti-G suit would enter engineering and manufacturing development for joint service use. Eight male centrifuge subjects were used, wearing either an ATAGS, with or without pressure socks, or an EAGLE. Pressure breathing during G (COMBAT EDGE) was used with all three combinations. The combinations were randomized to eliminate any order effect. The arms of all subjects were wrapped from the wrist to the axilla with 3 in. wide elastic bandage to reduce the possibility that subjects might stop the $+G_z$ exposure for arm pain rather than for fatigue or light loss. GOR, ROR, and 5-9 SACM $+G_z$ profiles were used to compare the suits. Although not significantly different, the average number of 9G plateaus completed (endurance) for the ATAGS with socks, the ATAGS without socks and the EAGLE were 8.0, 7.8, and 6.5, respectively. Subject HR while wearing the ATAGS with pressure socks was significantly (p=.03) lower than HR while wearing the EAGLE during the 5G plateaus of the 5-9 $+G_z$ SACM. The perceived effort involved in the straining maneuver during the 5-9 SACM with the EAGLE was consistently, but not significantly, greater across the 9G plateaus compared to the ATAGS with pressure socks. However, there was a significant (p=.032) suit/time interaction between the ATAGS with pressure socks and the EAGLE. There was no significant difference in subject HR or $+G_z$ tolerance between the three G-suit combinations during the GOR or ROR $+G_z$ exposures.

INTRODUCTION

Extended coverage anti-G suits (ECGS) are being developed by a number of nations (U.S., U.K., Sweden, Canada, and France) for high performance aircraft aircrew protection. Recent publications have reported the $+G_z$ tolerance benefits of the ECGS (2,5). The extended bladder coverage and more uniform pressurization of the legs provide reduced venous compliance and reduced blood pooling in the lower extremities, with improved venous return to the heart. Also, arterial blood pressure is better supported by a more uniform increase in arterial peripheral resistance.

The U.S. Air Force ATAGS program has been under development since the mid 1980s (1,4). The ATAGS was first introduced as a prototype to the flight test community for evaluation in 1988. Results from this evaluation were positive with recommendations to continue development (3). A number of improvement modifications have been made to the ATAGS and an operational evaluation occurred in 1992, utilizing both F-15 and F-16 fighter wings, and a variety of mission scenarios. Again, pilot feedback was positive, with a number of recommended modifications.

The Navy has a parallel program to satisfy their needs for an improved anti-G suit. The Navy suit has been labeled the Enhanced Anti-G Lower Ensemble (EAGLE). The U.S. Department of Defense (DOD) will purchase one enhanced coverage G-suit for both services; therefore, it was necessary to evaluate and compare both suits (ATAGS and EAGLE) for $+G_z$ protection.

METHODS

There are significant differences between the ATAGS and the EAGLE. The ATAGS has a smaller abdominal bladder than the standard CSU-13B/P anti-G suit and the leg bladders completely enclose and pressurize the legs and feet. The EAGLE abdominal bladder is the same size as the CSU-13B/P and the leg bladders completely enclose and pressurize the upper and lower legs down to the flight boot; however, the knees and feet are unprotected. Figure 1 illustrates the Navy EAGLE on the left and the Air Force ATAGS on the right.

This study was accomplished using the Armstrong Laboratory (AL) human centrifuge at Brooks AFB, TX. Seven male centrifuge subjects were recruited from the AL centrifuge subject panel. An additional subject was obtained from the Naval Air Warfare Center (NAWC) centrifuge panel. Each subject was familiarized with the ATAGS, the EAGLE and COMBAT EDGE (pressure breathing during $+G_z$) gear on the centrifuge using the upright, 15° ACES II seat.

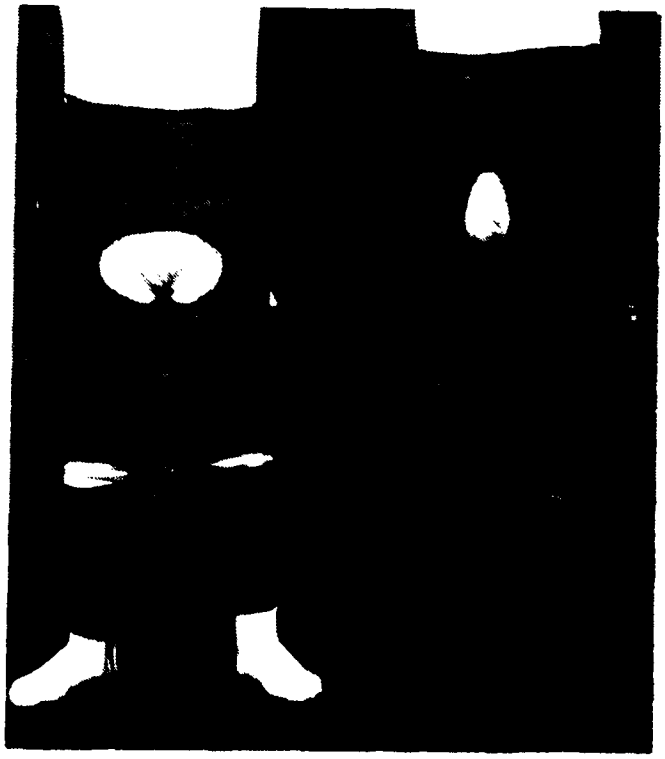

Figure 1. The Navy Enhanced Anti-G Lower Ensemble (EAGLE) of the left and the Air Force Advanced Technology Anti-G Suit (ATAGS) of the right.

For data collection, each subject was instrumented with a sternal and a biaxillary ECG lead system and fitted with either an EAGLE or an ATAGS, with or without pressure socks. Pressure breathing during $+G_z$ (COMBAT EDGE) was used with all three combinations. The combinations were randomized (counterbalanced) to eliminate any order effect. The arms of all subjects were wrapped with 3 in. wide elastic bandage with approximately 1 in. overlap, starting at the wrist and extending to the axilla. The arm wrap reduced the possibility that subjects might stop the $+G_z$ exposure for arm pain rather than for fatigue or light loss. The experimental criteria for terminating a $+G_z$ exposure was 100% loss of peripheral lights (PLL), 50% dimming of central lights (CLD) or fatigue, whichever came first. Additional criteria for termination were pain, discomfort, technical problems, or the standard cardiac rate and rhythm criteria. All $+G_z$ exposures were monitored by a physician.

Anti-G suit pressure started at 2G and increased at a rate of 1.5 psi/G, while PBG started at 4G and increased at a rate of 12 mmHg/G to a maximum of 60 mmHg at 9G.

The following $+G_z$ exposure sets were used for all subjects:

1. A gradual onset run (GOR at 0.1 G/sec) to 9 $+G_z$ or terminating criteria. The subjects were relaxed throughout the exposure and the anti-G suit was inflated.
2. A series of 15 sec duration rapid onset runs (ROR at 6G/sec) beginning at 3 $+G_z$/15 sec and progressing at 1G increments until terminating criteria were reached. Two minutes of rest were allowed after each ROR exposure. The highest $+G_z$ level was duplicated for reproducibility, followed by another $+G_z$ exposure reduced by 0.5 $+G_z$ to define tolerance within 0.5 $+G_z$. The subjects were relaxed throughout the ROR exposures and the anti-G suit was inflated.
3. A repeated 5-9 $+G_z$ simulated aerial combat maneuver (SACM) to exhaustion, light loss criteria, or a maximum of ten 9 $+G_z$ peaks. The subjects were required to strain as necessary to maintain peripheral vision. The anti-G suit was inflated. During the 5 $+G_z$

plateaus the subjects were asked to categorize their subjective level of effort during the previous 9 $+G_z$ plateau, on a scale of 0-10 (modified Borg scale).

Five minutes of rest were allowed between sets 1,2 and 3. Each subject was asked to complete a subjective questionnaire (Table 1, modified Likert scale) after the SACM profile.

All $+G_z$ exposures were conducted within the limits of an approved generic acceleration protocol and AFR 169-3. The subjects read and signed the informed consent statement for the generic acceleration protocol as well as the informed consent statement for this protocol.

Analysis of Variance was used to evaluate the objective data of heart rate, relaxed ROR and GOR $+G_z$ tolerance, and endurance time during the SACM. Also evaluated were the subjective level of effort data during the SACM and the data from the questionnaire completed at the end of the SACM (Table 1).

TABLE 1 SUBJECTIVE QUESTIONNAIRE

1. PERCEIVED LEVEL OF G PROTECTION

1	2	3	4	5	6	7	8	9
Terrible		Below Average		Average		Good		Excellent

2. STRAINING EFFORT DURING THE RUN

1	2	3	4	5	6	7	8	9
Extreme		Moderate		Average		Slight		None

3. COMPARED TO BEFORE THE RUN WHAT IS YOUR PERCEIVED LEVEL OF FATIGUE

1	2	3	4	5	6	7	8	9
Much Worse		Worse		Same		Less		Much Less

4. PERCEIVED LEVEL OF SWEATING

1	2	3	4	5	6	7	8	9
Extreme		Moderate		Average		Slight		None

5. PERCEIVED LEVEL OF HEAT STRESS

1	2	3	4	5	6	7	8	9
Extreme		Moderate		Average		Slight		None

6. OVERALL COMFORT DURING THE RUN

1	2	3	4	5	6	7	8	9
Terrible		Below Average		Average		Good		Excellent

RESULTS

ROR and GOR $+G_z$ Tolerance and Heart Rate (HR) The eight subjects completed all of the GOR and ROR $+G_z$ exposures with the three suit combinations. There was no significant difference in subject relaxed $+G_z$ tolerance or HR between the three anti-G suit combinations during the GOR or ROR $+G_z$ exposures (Table 2).

TABLE 2 +G, TOLERANCE AND HEART RATE

	GOR			ROR		
	G Tol	HR		G Tol	HR	
		Control	Peak		Control	Peak
ATAGS w socks	7.0±1.6	94±11	116±8	5.8±1.2	93±12	114±9
ATAGS w/o socks	7.5±1.3	89±9	123±14	6.3±1.2	89±11	115±11
EAGLE	7.2±1.5	92±19	123±15	5.8±1.0	91±22	111±14

All data are mean±SD, n=8
GOR = gradual onset rate (.1G/sec)
ROR = rapid onset rate (6G/sec)
HR = heart rate

SACM Endurance and HR. Two of the eight subjects performed poorly during the SACM (only two 9G plateaus, each) and their data were not included in any of the SACM analyses. Also, data were not evaluated after the sixth 9G plateau because the sample size dropped below 5 subjects beyond that point. Table 3 illustrates the subject completion history of the 9 $+G_z$ SACM plateaus for the three suit combinations.

TABLE 3 COMPLETION OF SACM 9 +Gz PLATEAUS

	Number of Subjects
ATAGS w socks > EAGLE:	4 of 6
ATAGS w socks = EAGLE:	2 of 6
ATAGS w socks < EAGLE:	0 of 6
ATAGS w/o socks > EAGLE:	5 of 6
ATAGS w/o socks = EAGLE:	0 of 6
ATAGS w/o socks < EAGLE:	1 of 6
ATAGS w socks > ATAGS w/o socks:	3 of 6
ATAGS w socks = ATAGS w/o socks:	2 of 6
ATAGS w socks < ATAGS w/o socks:	1 of 6

The average (±SD) number of 9G plateaus completed (endurance) by the six subjects while wearing the ATAGS with pressure socks, the ATAGS without pressure socks, and the EAGLE were 8.0±1.9, 7.8±1.9, and 6.5±1.0, respectively.

significant, although the difference between the ATAGS with pressure socks and the EAGLE had a p value of .066. There was no significant difference in HR during the 9G plateaus between the three suit combinations. However, HR during the 5G plateaus in subjects wearing the ATAGS with pressure socks was significantly (p=.03) lower than HR while wearing the EAGLE (Figure 2 and Table 4).

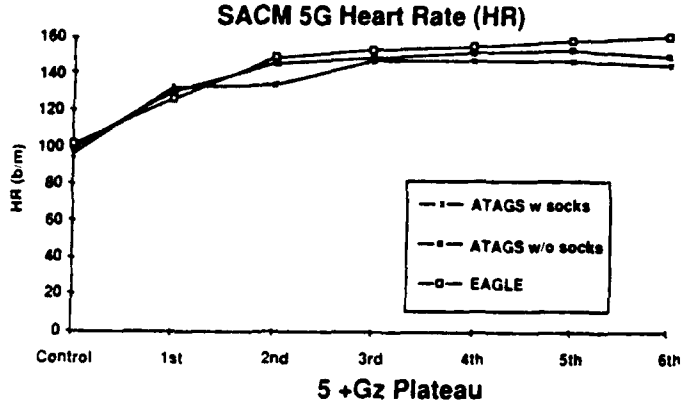

Figure 2. The mean heart rate from six subjects during the 5 $+G_z$ plateaus of the SACM. The heart rate for ATAGS with pressure socks was significantly (p=.03) lower than EAGLE

TABLE 4 SACM HEART RATE

5 +G, Plateau

	Control	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th
ATAGS w socks	97 ±14	132 ±12	134 ±14	147 ±19	147 ±20	147 ±20	143 ±22	144 ±29	150 ±31	148 ±33	134 ±3
ATAGS w/o socks	100 ±12	130 ±10	146 ±21	148 ±23	151 ±26	152 ±25	149 ±24	149 ±26	151 ±25	1157 ±29	192 —
EAGLE	101 ±12	126 ±10	148 ±16	153 ±22	154 ±22	157 ±25	160 ±26	142 ±30	162 —	162 —	— —

9 +G, Plateau

	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th
ATAGS w socks	148 ±15	151 ±19	151 ±19	152 ±20	151 ±19	149 ±20	160 ±25	150 ±31	153 ±30	138 ±6
ATAGS w/o socks	152 ±14	154 ±19	155 ±20	157 ±22	157 ±20	156 ±20	156 ±22	154 ±24	162 ±25	192 —
EAGLE	153 ±13	153 ±17	154 ±23	157 ±25	159 ±25	160 ±26	146 ±20	163 —	— —	— —

Data are mean±SD
SACM = simulated aerial combat maneuver
Data from 7th, 8th, 9th and 10th five- and nine-G plateaus were deleted from statistical analysis since n dropped below 5.

Level of Effort During the SACM Perceived effort involved in the straining maneuver during the 5-9 SACM in subjects wearing the EAGLE, was consistently, but not significantly (p=.079), greater across the first through the sixth 9G plateaus, compared to the ATAGS with pressure socks (Figure 3 and Table 5). However, there was a significant (p=.032) suit/time interaction between the ATAGS with pressure socks and the EAGLE, which explains the progressive rise in perceived effort during the SACM in subjects wearing the EAGLE (Figure 3).

Questionnaire Response **The Perceived Level of G Protection** (Question 1, Table 1) was significantly greater for the ATAGS with pressure socks than the EAGLE (p=.023). Moreover, the **Perceived Level of Fatigue** (Question 3, Table 1) was significantly less for the ATAGS with pressure socks than for the EAGLE (p=.042).

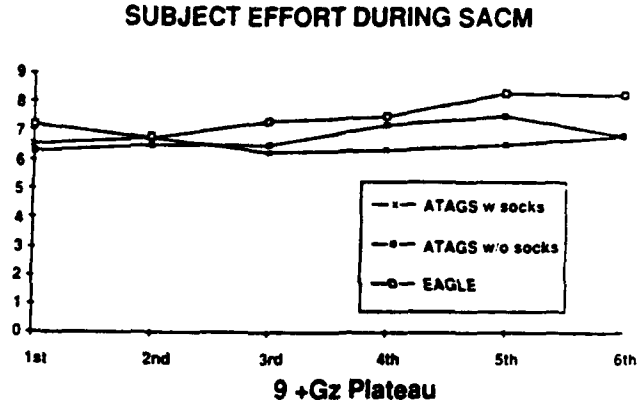

Figure 3. Subject straining effort during the 9 $+G_z$ plateaus of the SACM. There was a significant (p=.032) suit/time interaction between ATAGS with pressure socks and EAGLE illustrated by the progressive rise in the EAGLE data compared to ATAGS with pressure socks.

TABLE 5 SUBJECTIVE EFFORT DURING THE SACM

9 +G, Plateau

	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th
ATAGS w socks	6.5 ±2.3	6.7 ±1.5	6.3 ±1.8	6.3 ±2.3	6.5 ±2.9	6.8 ±3.3	5.3 ±3.2	5.3 ±4.2	5.3 ±4.2	3.0 ±1.4
ATAGS w/o socks	6.3 ±2.3	6.5 ±1.9	6.5 ±2.2	7.2 ±2.6	7.5 ±2.4	6.8 ±2.2	7.0 ±2.2	7.5 ±2.1	7.3 ±3.1	10.0 —
EAGLE	7.2 ±2.2	6.8 ±1.9	7.3 ±1.2	7.5 ±1.1	8.3 ±2.1	8.2 ±2.6	7.7 ±2.9	6.0 —	— —	— —

Data are mean±SD effort during the specific 9G plateau on a scale of 0-10. Data from 7th, 8th, 9th and 10th plateaus were deleted from statistical analysis since n dropped below 5.

DISCUSSION

An ECGS such as the ATAGS or the EAGLE, when compared to the standard CSU-13B/P anti-G suit, provides advantages such as improved comfort, and improved $+G_z$ protection through increased peripheral resistance and augmented venous return to the heart. However, there are also potential disadvantages such as increased heat load in hot environments and reduced mobility without proper design. Both of these potential problems are being addressed and can be prevented with improved materials and/or suit design.

The 1-1.5 $+G_z$ difference between the GOR and ROR relaxed tolerance data of Table 2 are consistent with previous data from this and other laboratories. An explanation for the difference in ROR data from this study and that reported by Prior (5) is not readily available. This study used an ROR onset rate of 6G/sec, whereas, the RAF IAM study used an onset of 1G/sec. Other factors which may contribute to the data discrepancy are: different pool of subjects; differences in anti-G suit and pressure breathing equipment and pressure schedules (pressure schedules were not specified in the RAF IAM report);and protocol procedures, such as possible differences in the rest period between ROR exposures.

The significant increases in heart rate and level of effort during the SACM with the EAGLE, compared to the ATAGS with pressure socks, indicate that the ATAGS with pressure socks provided greater $+G_z$ protection. These data were supported by the questionnaire responses of a perceived improvement in $+G_z$ protection and a perceived decrease in fatigue using the ATAGS with pressure socks compared to theEAGLE. However, the lack of strong differences across the whole test procedure emphasizes the need for an operational comparison using high performance aircraft pilots and subjective questionnaires like Table 1 which cover topics such as comfort, perceived protection, straining effort, etc.

The SACM used in this study was obviously not operationally relevant; however, it has been useful for a number of years in providing a stressful and fatiguing environment that could be used to evaluate $+G_z$-protective equipment and techniques that were designed to reduce fatigue and extend pilot combat engagement time.

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