SMART AIRCREW INTEGRATED LIFE SUPPORT SYSTEM (SAILSS)

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INTRODUCTION

Pilots of high performance aircraft are exposed to high levels of positive acceleration ($+G_z$). This leads to an increase in the pressure in the blood vessels of the lower body, as blood from the upper part of the body shifts into these lower vessels. The pooling of blood in the lower extremities translates into reduced cardiac output. Cardiovascular system reflexes respond by increasing heart rate to maintain adequate blood flow to the central nervous system in an attempt to preserve normal brain function. The physical symptoms of $+G_z$-stress range from petechial hemorrhages to loss of vision and, eventually, G-induced loss of consciousness (G-LOC), with its potentially fatal consequences.

G-LOC is considered to be a random event. To date, no physiologic variable has been definitively linked with a "predisposition to G-LOC." In a 1986 survey, 12% of Navy pilots reported G-LOC in flight; the U.S. Air Force reported 18 accidents (14 fatalities) due to G-LOC (1982-90). The goal of current G-LOC research is its prediction in flight to either avoid it or implement a pilot/aircraft recovery.

The Naval Air Warfare Center Aircraft Division (NAWCAD) and its associated contractors have developed a prototype system capable of providing aircrew life support/protection. This system is called the Smart Aircrew Integrated Life Support System (SAILSS). SAILSS will optimize aircrew performance while they are exposed to G_z, altitude, temperature and dehydration stresses. "Smart" refers to the use of biofeedback, which optimizes life support equipment function to the individual aircrew's physiologic and cognitive state. The ultimate **SAILSS** design will assess aircrew status through unobtrusive physiologic sensors mounted in the helmet, mask and garments, by monitoring respiratory activity, electrocardiogram (ECG) and electroencephalogram (EEG). The **SAILSS** approach factors these data with G history (duration, level), stick input and aircraft status into a control algorithm that assesses the pilot's state. If the pilot is incapacitated, SAILSS informs other vehicle systems so that a safe escape (ejection), avoidance (missile) or recovery of the aircraft is initiated. This interface of the various vehicle systems with SAILSS will result in a unified weapon system that maintains the pilot "in-the-loop." Evaluation of the preliminary design of SAILSS was performed in the Veridian Inc. human centrifuge located at Warminster, PA, USA.

METHODS

Following is a description of SAILSS and the procedure followed for the evaluation of its preliminary design. The test plan was conducted under NAWCAD guidelines for human subject testing (1) and SECNAVINST 3900.39B.

The components of the preliminary design of SAILSS system are as follows: host laptop computer, BiologTM signal conditioning system, physiologic sensors, VME data acquisition and control system and NormalAir Garret LTD Breathing Regulation Anti-G (BRAG) Electronic Control Unit. BiologTM collects and processes physiologic signals and forwards them to the VME. The VME hosts the control algorithm that combines BiologTM data with aircraft data to estimate pilot status. This is then used to optimize operation of the g-suit or other life support equipment. The biofeedback control process occurs in real-time to enhance pilot performance throughout a mission.

Objectives were to determine if the preliminary design of SAILSS could collect clear physiologic signals under $+G_z$ stress for subsequent data analysis and if the preliminary design of SAILSS provided the appropriate biofeedback control of the BRAG by utilizing changes in blood pressure (BP), as measured by a FinapresTM.

The objective measurements in this evaluation were as follows: Acceleration: G level, onset rate, and duration; Physiologic: ECG, BP, relative changes in head-level blood content and respiration rate; and Equipment: mask cavity and g-suit pressure and g-valve command. The subjective measurement was loss of peripheral vision as a result of $+G_z$ stress. The test matrix included 5 factors (Table 1). Subjects wore either the Navy Combat Edge Ensemble (NCE) or the standard g-suit CSU-13B/P (STD) and performed anti-G Straining Maneuvers (AGSM) as required. G profiles consisted of gradual (0.1 $G \cdot s^{-1}$, GOR) and rapid (3 s rise to plateau) onset rate runs (ROR). G exposures were as follows: ROR runs to +5, 7 and 9 G_z, each lasting 10 s; GOR runs to +5 and 7 G_z; and Gillingham Simulated Aerial Combat Maneuver (SACM) runs consisting of continuous ROR exposures to varying levels of G. SACM G levels ranged from +2 to 6 G_z with 4 s plateaus at G level. The centrifuge returned to a +1.25 G, resting plateau after each exposure. Control of the g-valve included the following: standard control {(G-1)*1.5 psi} (GSTD); and biofeedback control based on changes in BP (GBIOF). Biofeedback control runs were conducted only during NCE exposures.

Table 1. Test Factors.

Label	Name	Levels
SUITYPE	G-suit Type	STD, NCE
MAXG	Maximum G	5,6,7,9
ONMTE	Onset Rate	GOR, ROR
EXPTYPE	Exposure Type	GOR, ROR, SACM
CONTYPE	BRAG Control Type	GSTD, GBIOF

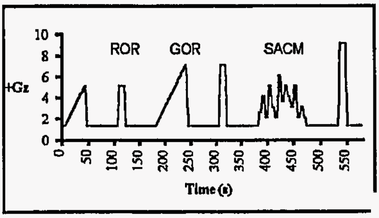

Figure 1. Acceleration profile.

The g-suit inflation and positive pressure breathing (PBG) schedules were limited to the standard parameters **of NCE.**

There were **4** study test conditions based on suit type and G-suit control. Figure **1** describes a test insertion G profile. The study included **24 runs** per subject, performed over a period of 2 days **(6 runs** per each centrifuge insertion). Four healthy, physically qualified male subjects participated in the study (weight: **77.1** ±11.5 kg; height: **174.0** ±**5.3** cm; age: 33.5 ±3.8 years and eye-heart distance: **27.7** ±1.3 cm). All but one was experienced in centrifuge testing.

RESULTS

The preliminary ***SAILSS*** design collected clear physiologic signals under $+G_z$ stress. The clarity of these signals was consistent with typical centrifuge run data, including the effects **of** AGSM performance, g-suit activation (STD, **NCE),** maximum G exposure, the time at G, the varying level of G, PBG and G onset rate. The primary problem identified during this evaluation was electrical isolation (i.e., from the VME). An additional medical isolation box **was** utilized for this purpose; however, it generated a significant amount 60 H_z noise, particularly in the **ECG.** Hence, this signal was not obtained from the BiologTM component **of SAILSS.**

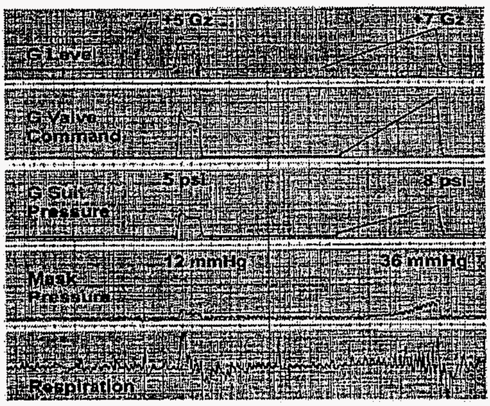

Figure 2. Example of data collected during SAILSS $+G_z$ exposure. From top to bottom trace: G level, G valve command from *SAILSS* system, resulting anti-G suit pressure, mask breathing gas pressure, respiration.

Respiration rate, head-level blood pressure and O_2 saturation at ear level were successfully measured. Relative changes in head-level blood content (temple and ear) were tracked using the BiologTM infrared plethysmograph, though the signal strength was low and susceptible to head motion artifact and required careful alignment **of** the source and detectors. The mask cavity pressure signal provided a good measure **of** AGSM respiratory effort, respiratory rate and timing. While the g-valve command signal performed successfully up to **7** psi, the signal offset made it difficult to track higher psi levels. See Figure **2** for a sample data trace. It was found that no particular control type was obviously better or worse in providing G protection. Both the STD and GBIOF feedback modes performed as expected.

DISCUSSION

Intelligent systems are currently being introduced into the air combat environment. Significant advances have been made in escape, life support and aircraft recovery. Unfortunately, these advances address the status of the aircraft, the cockpit or the environment—not the pilot. While advanced crew systems technology have made significant progress in integrating various life support systems (LSE), we remain ignorant of the status of the principal aspect of the weapon system—the pilot. Indeed, the function of equipment such as g-valves, g-suits or O_2 delivery is not based on parameters provided by that life they are to support. By assessing the psychophysiology of the aircrew, we can optimize the LSE response to address his/her requirements. SAILSS provides the means to "match" the capabilities of the pilot to the aircraft's structural envelope by not only taking into account the physiology of the weapon system but incorporating this information with the status of the aircraft and arriving at an appropriate action to optimize the pilot's performance. For example, current g-suit inflation is based solely on $+G_z$ level. So that in the event of G-LOC in-flight, the g-suit would not inflate because the aircraft may not provide the required G input. During G-LOC, or other altered states of awareness, is precisely the time when pilots need the support of their LSE. SAILSS will ensure the pilot is protected at all times against stressful environments. SAILSS also provides an opportunity to reassess the need of uninhabited air vehicles. No technological advance can replace the brain and experience of the pilot operating the aircraft. SAILSS ensures we keep these assets in the loop and directly involved with the mission at hand.

CONCLUSION

The evaluation of the preliminary design of SAILSS has proven the system to be a viable option in addressing the psychophysiologic and most principal aspect of the weapon system—the pilot. SAILSS also offers an opportunity to integrate the aircraft, the cockpit and its commander into a unified weapon system.

REFERENCES

1. Forster, E.M. 1997, Validation of the Smart Aircrew Integrated Life Support System (SAILSS), Document No. IRB-970818, NAWCADPAX Research Test Plan, Naval Air Warfare Center Aircraft Division, Patuxent River, MD.