



# **A PULSATING ANTI-GRAVITY SUIT FOR ACCELERATION PROTECTION: SYSTEM DESCRIPTION AND PRELIMINARY EXPERIMENTS**

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| <p>This communication describes a system designed to study the feasibility of augmenting tolerance to acceleration stress using external pressure pulsations synchronized to the electrocardiogram.</p> <p>The system, known as synchronized pulsating anti-gravity suit, consists of a modified G Suit, a controller and a pneumatic subsystem. The modified suit has individual bladders for calf, thigh, and abdomen with separate inlet/outlet ports. A microcomputer controls the synchronization, phasing and sequencing of pressure pulses in the bladders. Desired high and low pressures are obtained using feedback of pressure signals to a set of comparators. Solenoid valves and related circuitry regulate the flow of air in and out of the bladders. Results based on the centrifuge experiments suggest the feasibility of obtaining improved tolerance with a synchronized pulsating suit.</p> |                                                  |                                                                                   |                                |
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# A PULSATING ANTI-GRAVITY SUIT FOR ACCELERATION PROTECTION : SYSTEM DESCRIPTION AND PRELIMINARY EXPERIMENTS

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## ABSTRACT

This communication describes a system designed to study the feasibility of augmenting tolerance to acceleration stress using external pressure pulsations synchronized to the electrocardiogram.

The system, known as synchronized pulsating anti-gravity suit, consists of a modified G suit, a controller and a pneumatic subsystem. The modified suit has individual bladders for calf, thigh, and abdomen with separate inlet/outlet ports. A microcomputer controls the synchronization, phasing and sequencing of pressure pulses in the bladders. Desired high and low pressures are obtained using feedback of pressure signals to a set of comparators. Solenoid valves and related circuitry regulate the flow of air in and out of the bladders. Results based on the centrifuge experiments suggest the feasibility of obtaining improved tolerance with a synchronized pulsating suit.

## INTRODUCTION

Use of a standard anti-G suit, muscular straining maneuvers and positive pressure breathing are the most commonly used methods of increasing tolerance to acceleration stress. The standard anti-G suit consists of interconnected bladders for calves, thighs and abdomen. This suit is inflated to a pressure equal to  $1.5(G_z - 1)$  psi, where  $G_z$  is the acceleration in the head-to-foot direction. The pressure applied to the suit prevents pooling of blood in the lower extremities, increases blood pressure in the central circulation and provides G protection of approximately 1G [2]. Certain muscular straining maneuvers and positive pressure breathing, when combined with anti-G suit, increase the tolerance by nearly 2 G [9]. However, the protection provided by these methods is still insufficient, considering the capabilities of today's high performance aircraft.

External counterpulsation, a form of SEP, has been used as a cardiac assist modality in clinical setting [6]. When properly phased, this form of SEP can produce increased cardiac output, diastolic arterial pressure, coronary flow and

venous return, and decreased systolic pressure and cardiac oxygen consumption. This technique has been used as a noninvasive treatment for cardiogenic shock and as early treatment of myocardial infarction [1]. The cardiovascular benefits of SEP suggest that this method may be useful for augmenting G tolerance by augmenting cerebral blood flow and enhancing venous return.

The concept of using SEP as a means of increasing G protection has previously been investigated [8] but the results were inconclusive, due to equipment limitations. Our earlier theoretical study, using a nonlinear computer model of the cardiovascular system, indicated that SEP might provide increased G protection [7]. More recently, the idea has received further support from other laboratories [10].

The system described in this communication was designed to determine the proper operational characteristics for increased G tolerance. This system will be referred to as pulsating anti-G suit (PAGS). This system has options for choosing different schemes of inflation/deflation sequences, and levels of pressurization. The system requirements included: 1) synchronization of the pressure pulsations to a physiologic signal, say ECG, 2) control of the phasing of the pulsations in the cardiac cycle (systolic or diastolic), 3) individual control of timing and levels of pressurization of bladders and 4) control of the high and low pressure limits ( $P_H$  and  $P_L$ ) during pulsation as a function of G level, so that

$$P_H = P_m + 0.5 \times P_p \quad (1) \text{ and}$$

$$P_L = P_m - 0.5 \times P_p \quad (2),$$

where  $P_m$  is the mean pressure which is a function of  $G_z$  and  $P_p$  is the peak-to-peak excursion around the mean value.

The PAGS system, developed to meet the above requirements was tested on human subjects in a Dynamic Flight Simulator at the Naval Air Development Center (NADC), Warminster, PA.

## SYSTEM DESCRIPTION

The major subsystems of PAGES are: a modified G suit, a pneumatic subsystem and a controller. The modified suit was constituted of five separate nonconnected bladders: one for each calf, one for each thigh and one for the abdomen. It was obtained by modifying the standard Navy anti-G suit to provide individual inlet/outlet ports to each bladder.

An air supply charged an accumulator to 15 psi through a regulator. Each bladder was inflated by opening the solenoid valve between the accumulator and the bladders. The valve closed automatically when the desired pressure  $P_H$  was reached. Each bladder was deflated by venting it to atmosphere using another solenoid valve, which was closed automatically when the desired low pressure level  $P_L$  was reached.

Control of the timing, the duration, and the sequence of actuation of the solenoid valves was achieved by using an 8-bit, 6502-based microcomputer. Figure 1 shows the functional blocks of the controller hardware. Inputs to the controller were the ECG of the subject, the G level signal, and the pressure transducer outputs.

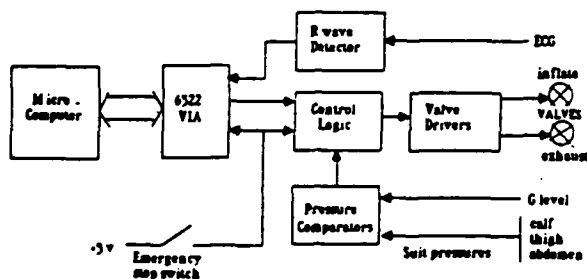


Figure 1. Functional block diagram of the controller

When an R wave was detected, the computer initiated a series of operations which included computation of event timings and generation of INFLATE and DEFLATE signals for all the bladders. On receiving the INFLATE signal from the computer, the valve control logic energized the valve drivers to initiate inflation of the suit bladders. Inflation was terminated when the pressure comparators indicated that the desired high pressure ( $P_H$ ) had been reached. Similarly, deflation was initiated by the computer-generated DEFLATE signal and terminated by pressure comparators.

An interactive module and a control module constituted the software. The interactive module allowed the user to specify a wide range of parameters for suit pressurization, such as the phasing of inflation (systolic/diastolic), duty cycle, the order of inflation of bladders (simultaneous/sequential), and the delay between inflations of two adjacent bladders for sequential mode. This module was coded in BASIC.

The real time computing tasks were performed by the control module which was coded in 6502 assembly language. These tasks included providing a clock base for measuring time intervals and scheduling various events, monitoring the incoming R wave and generating INFLATE and DEFLATE signals. In the sequenced mode of operation, appropriate delays between inflation of the bladders were also generated.

Independent control of pressures in the bladders was achieved by using three pairs of comparators (one each for calf, thigh, and abdominal bladders) and associated control logic. Outputs of the pressure transducers were compared with  $P_H$  and  $P_L$  in each pair of comparators. An output signal was generated by one of the comparators when the pressure in the bladder increased above  $P_H$ . The other comparator generated a similar signal when the pressure fell below  $P_L$ . With inputs from the computer and the pressure comparators, the valve control logic circuit provided the biphasic voltages to energize the appropriate valve drivers.

## EXPERIMENTS

The system was tested under 1G conditions in the laboratory and under various  $G_z$  acceleration levels in the Dynamic Flight Simulator (DFS) at NADC.

The laboratory tests, involving six student volunteers, were conducted in order to confirm the correct functioning of the system and to examine some of its physiological effects. Parameters varied during these tests included timing and duration of bladder inflation, delay between bladder inflations in the sequenced mode, and high and low pressure limits.

The PAGES system was then installed in the DFS and tested on seven relaxed US Navy volunteers. Based on results from the static tests, several operating modes were used including simultaneous and sequential bladder inflation and systolic and diastolic pressure application. The effects under both rapid and gradual  $G_z$  onset runs were recorded. The results of these tests have been reported elsewhere [F1,F2].

## RESULTS

The PAGS system was able to deliver pressure pulses, correctly synchronized and phased to the cardiac cycle, both in the laboratory tests and in the DFS. Although cockpit R wave detection is a much more difficult task, missed R waves in these experiments occurred in only two out of 300 runs. Doppler and plethysmographic records clearly indicated the augmentation of pressure and flow pulses produced by the pulsating suit. Of the operating modes tested, pulsations timed to correspond with cardiac systole resulted in the greatest increase in Gz protection.

Difficulties encountered with the system in these experiments often had the general effect of causing the mean suit pressure during pulsations to fall below that of the standard suit. It was found that the high and low pressure set point voltages resulted in pressures below those desired if the voltages were set to vary linearly with Gz. The sequential mode was achieved by starting calf inflation at a fixed time after the R wave, then inflating thigh and abdominal bladders after fixed additional delays. This too severely reduced the duration of abdominal bladder inflation at high heart rates. Additional problems were encountered due to delays contributed by the solenoid valves used. These difficulties can be overcome by minor changes in the hardware and software of the system.

Despite the fact that mean suit pressure in the experiments was often lower than that used with the standard suit for given Gz, the measured protection resulting from PAGS compared well with protection offered by the standard suit. Since Gz protection is directly related to suit pressure [5], the results indicate that the pulsating suit might offer a higher protection than the standard anti-G suit when equal mean pressures are maintained.

## ACKNOWLEDGEMENT

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