Computer design of biofeedback controller for an Anti-G suit under G stress

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ABSTRACT

Anti-G suit and positive pressure breathing during G (PBG) are protective methods to increase the G tolerance of an pilot. Recent crashes of aircrafts because of G induced loss of consciousness (G-LOC) indicate that current straining maneuvers plus above counter measures are inadequate. The profile of pressurization is not according to actual blood pooling of an aircraft pilot. Therefore, an attempt has been made to design a biofeedback controller for an anti-G suit using SIMILINK part of MAT lab software. Ramp signal generator was used to simulate blood pooling in the leg segment of an aircraft pilot. The blood pooling and G force signals were combined by logic theory and fed as input signals to the controller. The resultant signal was converted to a digital code in the priority encoder and then converted into analog signal. This analog signal passed through the pressure selector depending on which suit pressure is generated. The computer design made the working of an anti-G suit into close loop operation taking blood pooling as physiologically input signal to the controller. The output of controller selects suit pressure in the range of 100-170 mm Hg for the blood pooling upto 100 ml. Other suit pressure ranges are 175-225 mm Hg, 325-400 mm Hg, 450-525 mm Hg, and 500-600 mm Hg for the blood pooling upto 200, 300, 400, and 500 ml respectively. Anti-G suit deflates as soon as blood pooling falls below defined range. The computer technique has resulted in giving flexibility in the design of biofeedback controller and optimized the performance of an anti-G suit. The findings may be used to develop a practical biofeedback controller for an anti-G suit.

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KEY WORDS : Anti-G suit, G-LOC, Blood pooling, Computer design and Biofeedback controller

There are various lacunae in the standard anti-G suits. The exact profile of inflation and deflation has not been defined according to the blood pooling of the aircraft pilot. No feedback signal from the body of a pilot is incorporated for monitoring of G-suit pressurisation. Presently anti-G suit is being used with additional countermeasures such as Positive Pressure Breathing during G (PBG) and Anti-G Straining Maneuvers (AGSM). The major problem with the use of the AGSM is that it is fatiguing. Further, it severely limits the duration of high G. The PBG applied in combination with extended coverage anti-G suit (Advance anti-G suit) was found to be responsible for generating the arm pain in pilots [1]. The arm pain has forced the termination of the test runs and has the potential to cause serious decrement in the pilot's ability to function effectively during high-G flight.

Various countermeasures provide an improvement in G protection but still are not effective for +9 G and above. Therefore, this urgent problem of G-level and duration tolerance needs to be investigated further.

Present paper describes a totally new approach of computer design of biofeedback controller to optimize the functioning of an anti-G suit. The computer design is nothing but computer simulation using special software package. The word simulation means many things to many people.

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But precisely simulation means "the act of representing some aspects of the real world by numbers or symbols which may be easily manipulated to facilitate their study" [2]. The simulation of biofeedback controller has been carried out using SIMULINK part of MATLAB software package.

Material and Methods

Anti-G suit

The anti-G suit invented by David Clark in World War II remains operational today with only minor changes [3]. The G-suit is considered the basic component of anti-G protection system. It is composed of five interconnected bladders covering the legs and abdominal region. These bladders are pressurized during increase in G (controlled by anti-G valve) with air from jet engine compressor. Properly fitted anti-G suit provides protection upto 0.5 G. Thereafter, suit pressure is increased by 75 mm Hg/G to a maximum suit pressure of about 500 mm Hg. The inflation of bladders of the G-suit must be completed within one second after obtaining the maximum G level.

Computer and Software

Pentium-IV computer was used during the design of biofeedback controller for an anti-G suit.

The MATLAB 12 was loaded on the Pentium-IV computer. It consists of various sub software such as Control System, Neural Network, Signal Processing, Filter Design, Simulink etc. The SIMULINK software package is being used everywhere for modeling, simulating and analyzing dynamic systems. It supports linear and non-linear modelling in continuous time or hybrid of two [4].

Design of Biofeedback Controller

Ramp signal generator was used to simulate blood pooling in the lower extremity of a pilot as shown in Fig 1. The simulated blood pooling is in the range of 100-500 ml. Acceleration and gravitational force of earth were represented in terms of G units and defined as optional input signals to the biofeedback controller. G forces and their effect were simulated using signal generator, priority encoder and aircraft's dynamic model.

(a) G-forces acting on the pilot

A part of simulation was used from Aerospace examples of SIMULINK demonstration. Inputs to aircraft's dynamic model were taken from outputs of signal generator and constant source. Output variation generator simulates variation in the vertical velocity (feet/sec) and pitch rate (rad/sec). Elevator deflection has been determined using simulation of controller and actuator. Vertical gust (w) and rotatary gust (q) were found using Dryden Wind gust model [4]. Finally, the vertical velocity and pitch rate has been determined using aircraft dynamic model. Pilot G forces have been determined using the following expression:

$$N_Z=[(dq/dt)*22.8+q*U_o-(dw/dt)]g..........(1)$$

Where w = Vertical velocity, q = Pitch rate,

g = Acceleration due to gravity,
U_o = Constant input, t = time

The expression was simulated using blocks of differentiation, gain, multiplier, subtractor and divider.

(b) Blood pooling and gravitational signals

This block has input signal (I_{n1}) as gravitational force in terms of G unit acting on pilot. It has been categorised into five different levels, 0-2 G, 2.1-4.1-6 G, 6.1-8 G and 8.1-11G. Second input (I_{n2}) was taken from simulation of blood pooling. It has also been categorised into five different levels, 100 ml, 200 ml, 300 ml, 400 ml and 500 ml. Logical operator (OR gate) was applied between first levels of pilot G forces and blood pooling. Similarly rest four levels also have OR logic gate. Simulation of inflation (air going inside suit) and deflation (air going outside from suit) is also shown in the computer design.

(c) Pressure level selection for an Anti-G suit

The output of logical operator goes high if either blood pooling signal is high or pilot G forces is high. If output of logical operator 1 is high, then multiplexer selects pressure level in the range of 100-170 mm Hg and same amount of air/O_2 is passed into anti-G suit from sources for blood pooling of 100ml. Other pressure ranges, 175-225 mm Hg, 325-400 mm Hg, 450-525 mm Hg, and 500-600 mm Hg have been defined for blood pooling levels of 200, 300, 400 and 500 ml respectively. Anti-G suit is made to deflate if selected pressure level falls below the previous level.

Results and discussion

The computer design has resulted in the working of an anti-G suit into close loop operation considering the blood pooling as physiological input signal to the controller. The output of simulated biofeedback controller selected suit pressure in the range of 100 -170 mm Hg for the blood pooling of 100 ml. Other selected suit pressure ranges are 175 - 225 mm Hg, 325- 400 mm Hg, 450 - 525 mm Hg, and 500 - 600 mm Hg for the blood pooling of 200, 300, 400, and 500 ml respectively. Anti G-suit deflated as soon as blood pooling reduced from the defined value.

Biofeedback is a training technique being developed by experimental and clinical psychologists to enable an individual to gain some element of voluntary control over autonomic body functions. In the present thesis, a biofeedback controller has been designed to optimize the functioning of an anti-G suit. The Electrical Impedance Plethysmography (EIP) technique has extensive applications in the field of aerospace medicine [5, 6]. The electrical impedance of leg segment has been considered as an input signal which controlled inflation and deflation of bladders of the anti-G suit. The impedance was varied according to simulated blood pooling in leg segment and fed back to the controller for the correction of pressure level of anti G-suit [7]. The correlation was sufficiently reproducible to be useful in arriving at the biofeedback strategy.

Conclusion

The computer design of biofeedback controller has resulted in the working of an anti-G suit into close loop operation taking blood pooling

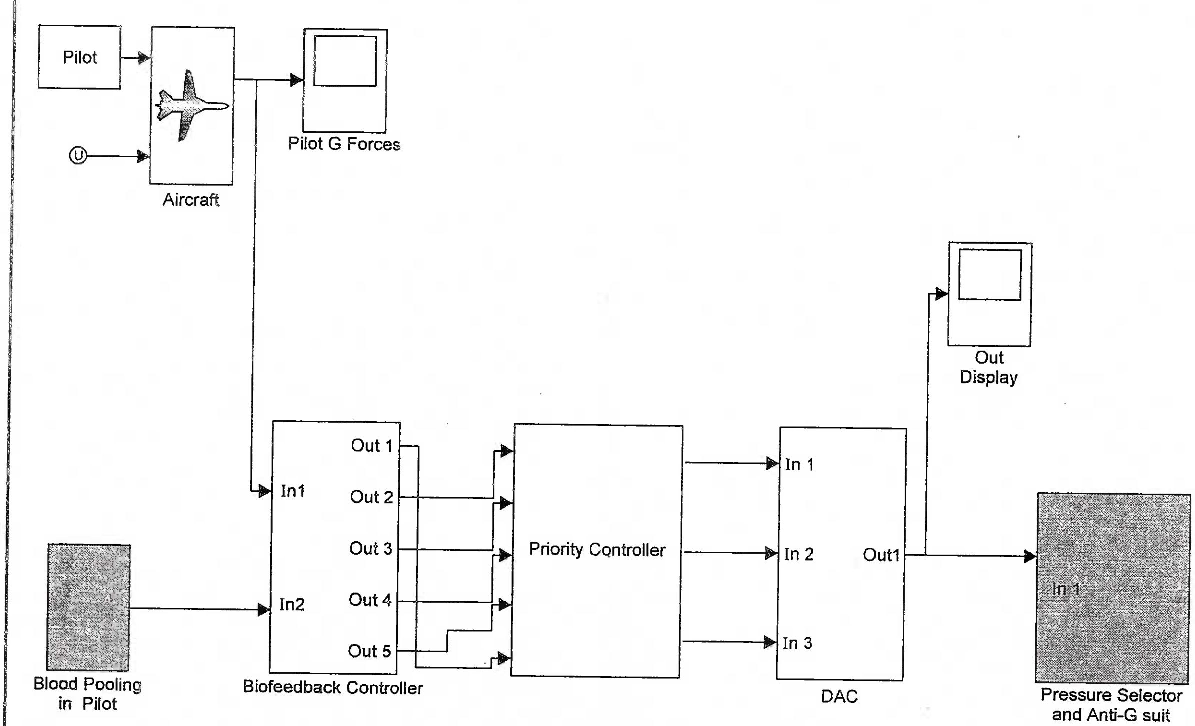

Fig:1 Computer design of biofeedback controller for an anti-G suit as a physiological input signal to the controller. Pressurisation levels proposed for an anti-G suit against blood pooling in the legs of a pilot has also been presented in the present paper. The simulated blood pooling in the range of 0-500 ml was divided into five successive upper levels as 100, 200, 300, 400 and 500 ml. The minimum and maximum pressures of air, which are already applied in the anti-G suit according to gravitational forces, have been proposed to the different levels of blood pooling of the pilot. If these proposed levels of air are pumped into the anti-G suit, then corresponding blood pooling will vanish. A desired time-magnitude profile for inflation and deflation of anti-G suit has been arrived at, to counter blood pooling occurring during simulated high G conditions.

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