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ADVANCES IN ANTI-G VALVE TECHNOLOGY: WHAT'S IN THE FUTURE?

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Abstract

Conventional mechanical anti-G valve technology has been overtaken by the performance of modern aircraft and will fall farther behind in new generations of fighters. This paper discusses the fundamental shortcomings of anti-G valves and presents concepts and enhancements potentially available with recently developed servovalves, concepts now under active investigation and development and closes with an overview of advanced anti-G suit concepts compatible with advanced adaptive servovalves.

Introduction: Challenges/Opportunities

In this year of 1986 we in the Biotechnology field are living in what is probably one of the most exciting periods in the history of aviation. Immediately ahead of us lie prospects of new aerospace vehicles with unprecedented performance capabilities. The Advanced Tactical Fighter, the Supermaneuverability concept for the generation-after-next, the Trans-Atmospheric Vehicle, and manned military space systems all present prospects for new biotechnology challenges and opportunities. Many of these new challenges are not shrouded in the mists of the distant future; instead, they are providing us with an ugly confrontation at this moment. It is ironic that this moment was first pointed out over sixty years ago by the first man (1) to fly a heavier-than-air craft across the English Channel:

> "It is not the resistance of material which limits the aerobatic performance of the artificial bird, but the physiologic resistance of man, who is the brain of the artificial bird."

The advent of current generation fighter aircraft and their capability for rapid onset, high sustained acceleration has lent new urgency to Bleriot's observation. Future weapon systems may well demand even more of man.

Performance Requirements for Advanced Anti-G Valves

A short look at history provides a good list of specifications. In 1944 Hallenbeck (2) observed that the optimal time for anti-G suit inflation to 5psig lay between the start of acceleration and the attainment of +3G. In 1946 Hallenbeck (3) described the principal variables of anti-G suit protection as: the pressure or pressures to which the suit is inflated, the parts of the body to be pressurized, the time of pressurization of the suit in relation to the onset of acceleration, and the order in which the various portions are pressurized.

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Conventional mechanical anti-G valve technology has been overtaken by the performance of modern aircraft and will fall farther behind in new generations of fighters. This paper discusses the fundamental shortcomings of anti-G valves and presents concepts and enhancements potentially available with recently developed servovalves, concepts now under active investigation and development, and closes with an overview of advanced anti-G suit concepts compatible with advanced adaptive servovalves.

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In 1956 Edelberg (4) noted that during the first eight seconds of an acceleration exposure, the chief function of the anti-G suit would be to produce the immediate counter-pressure necessary to restrict venous pooling.

In 1961 Wood (5) observed that the increase in peripheral vascular resistance induced by acceleration tended to be greater when the anti-G suit was inflated at the onset of acceleration.

In 1976 Burton (6,7) reported enhanced tolerance when suit inflation was begun at 1.1 or 1.5Gz and when the inflation schedule was such that 5psig in the suit was attained in less than one second; further observing that all Ss were capable of tolerating an immediate inflation of 5psig as well as a much higher overall pressure vs G inflation schedule.

To summarize: the anti-G valve for a modern high performance fighter should:

a. Raise the suit pressure to 5psig as quickly as possible; preferably in less than one second.

b. Provide a rapid-acting mechanism to raise the suit pressure to a tolerable limit to inhibit early venous pooling.

<u>Physiological Limitations of Current Anti-G Equipment</u>

Recent research at the Armstrong Aerospace Medical Research Laboratory has provided insights into the limitations of traditional equipment through the use of two-dimensional ultrasonic echocardiography. Jennings (8) conducted a study to evaluate the effect of more rapid G-suit inflation on cardiac volumes using 2-D echocardiography. Subjects were exposed to +4Gz for a period of 30 seconds under three conditions: wearing an uninflated G-suit, wearing a G-suit inflated by a pre-production Alar Products High Flow Only (HFO) valve, and wearing a G-suit inflated by the valve now in current use in the fleet.

The HFO valve inflates the anti-G suit some 33% more rapidly than the standard valve. End diastolic volume (EDV) and stroke volume (SV) decreased initially for all three test conditions, except for cardiac output (CO) when using the HFO valve. Using the HFO valve, the initial decrease in EDV, SV, and CO was less than in the other two conditions. Accordingly, a rapid acting valve augments blood return initially and is thus more effective in mitigating the effects of a rapid onset acceleration stress. Nevertheless, the combination of a conventional valve, no matter how good it is, and a conventional suit is incapable of providing protection over an extended period because it appears to act as a venous occlusion cuff. In a later section, means will be discussed by which this shortcoming might be overcome to some extent.

<u>Advanced Anti-G Valves Currently in Development</u>

<u>The Servo-controlled Anti-G Valve</u>

The first implementation of what could be designated as a pre-production version of a modern anti-G valve was sponsored by the U.S.

Navy (9). Commonly referred to as a servo-controlled rapid acting anti-G valve (SCAG) this concept is now being funded and evaluated in the Aerospace Medical Division's Tactical Life Support System (TLSS) advanced development program.

Figure 1 shows the essential features of a SCAG valve. This design makes use of a conventional pneumatic servovalve design philosophy with a low pressure pilot stage. When the electronic controller sends a signal to the torque motor, the control flapper closes the vent, admitting reference pressure to the diaphram actuator, lifting the poppet valve off its seat and admitting air to the suit pressure line. At 1G, the state of the device is as shown in Figure 1, with the pilot actuator vented to atmosphere and the reference pressure source closed off.

The G-suit filling schedule (suit pressure versus +Gz) is defined by the electronic controller making use of the accelerometer inputs, and the pressure feedback loop. The electronic controller can be either analog or digital in design philosophy.

In order to avoid the complication and expense of providing a pressure feedback sensor in the G-suit, the feedback pressure is sensed at the valve outlet. In order to compensate for the differences in pressure-time histories between the valve outlet and the suit inlet, a time delay circuit is incorporated in the feedback transducer line. This time delay thus forces the electronic controller to drive the valve wide open briefly in order to achieve conformance with the specified G vs pressure schedule. It should be noted that the specified schedule is of the same type as was traditionally used for anti-G valves; that is to say that it is essentially linear with respect to acceleration and does not address the issue of acceleration onset rate. The performance of this type of valve could be improved by incorporating rate sensitivity and a modified time delay algorithm.

SCAG valves have recently undergone testing on the high onset rate School of Aerospace Medicine centrifuge. The performance of the valve is good, and it is one of the two valves able to meet or exceed the inflation schedules desired in the TLSS specification.

The Bang-Bang Servo Anti-G Valve

The SCAG valve just discussed is what is called, in control theory terms, a proportional controller. The output of the valve is proportional to some control signal. There is another type of controller, such as the thermostat on an air conditioner, which is called a "bang-bang" controller. This type is either on or off, depending upon the presence or absence of a control signal.

The bang-bang servo anti-G valve (BBSV) was developed at the Harry G. Armstrong Aerospace Medical Research Laboratory with funding provided by the Crew Escape System Technology Advanced Development Project Office

(CREST ADPO) and transitioned to the Aeronautical Systems Division Life Support System Program Office for flight testing.

The BBSV was designed strictly in accordance with the two design criteria set forth above: rapid inflation to five pounds per square inch, and subsequent inflation to the highest permissible pressure in the early portion of a high onset rate episode. Secondary criteria involved a least cost, least risk, least aircraft interface approach. The objective of the effort was to achieve a quick and effective retrofit for the F-16.

The development of the BBSV is described in (10) which is in the open literature. Further details regarding this effort are being sequestered under Critical Technology restrictions. The behavior of the BBSV can, however, be summarized briefly in that by suitable means it is a valve that is sensitive to both acceleration rate and magnitude. If the sensed acceleration on the aircraft is in excess of approximately +1.5Gz and if the onset rate exceeds approximately 1.5G/sec a solenoid is used to drive an HFO valve to the full-open position for a period of 2.5 seconds. This length of time is sufficient to assure that any size G-suit will be inflated to the maximum pressure permitted by the regulating portion of the valve. Figure 2 shows the BBSV (on the right) compared to a standard valve (on the left) and the initial development prototype based on a High Flow Ready Pressure valve (center). The guarded toggle switch on the top panel is an on-off switch (normally on with the guard closed). The other toggle switch is an electrical press-to-test switch. The BBSV contains the sensing accelerometer and associated control electronics within the package shown in Figure 2; the only aircraft interface required is access to 28VDC at 1 ampere.

Human testing has demonstrated (10) the enhanced protective effect of the BBSV. At the present time it is undergoing evaluation in the TLSS program, and is the other of the two valves noted above that is capable of meeting and exceeding the TLSS specification for performance. Flight testing of this valve is being conducted by the Life Support SPO and by the AFTI/F-16 ADPO. Transition to 6.4 development is anticipated in CY-1986.

Adaptive 1553 Interfaced Servovalve

An in-house development effort is being jointly pursued by the Armstrong Aerospace Medical Research Laboratory and the Air Force Wright Aeronautical Laboratory (AFWAL/FII) to develop a full digital servovalve interfaced with the 1553 digital multiplex bus and the flight control system int he AFTI/F-16.

The dedicated microprocessor associated with this valve design will allow the system to respond to flight control inputs in order to achieve the most rapid response possible. Provision will be incorporated in the design for interfacing with advanced concept anti-G suits, and by virtue of the associated software, the valve will "know" the current and antecedent acceleration history of the aircraft.

Future Directions in Anti-G Suit Design

A sequentially inflating anti-G suit is currently under development at the Armstrong Aerospace Medical Research Laboratory. Microprocessor technology makes it possible to take another approach to the hardware problems that have plagued earlier development efforts in this area.

In this suit, the calf bladders are siamesed, but the thigh and abdominal bladders are separately controllable. The microprocessor software makes it possible to control the pressurization (through feedback loops) in each bladder, and to control the phasing between bladder inflation. The prototype suit uses individual solenoid valves, controlled from the input/output ports on the microprocessor, for bladder pressurization.

When the prototypes are ready for centrifuge testing, the behavior of the suit will be assayed by two-dimensional echocardiography in order to optimize the inflation and phasing algorithm. An attack on the fundamental problem of conventional anti-G suits is also planned. A suit of this type, controlled by an adaptive or "smart" control program can easily be configured to provide periodic episodes of high pressure "milking" action during extended G exposures to, hopefully, overcome the inevitable compromise of venous return observed in conventional suits. By phased, sequential inflation from the calves upward, it should be possible to materially assist venous return periodically during sustained maneuvering.

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