AD-A059 521 TECHNOLOGY INC SAN ANTONIO TEX F/G 6/11

ENGINEERING TEST AND EVALUATION DURING HIGH G. VOLUME II. ANTI---ETC(U)

JUN 78 R W THOMPSON, L J MEEKER, G L WILSON F41609-75-C-0026

UNCLASSIFIED SAM-TR-78-11 NL

1 OF 1

AD A059521

END

DATE FILMED

12-78

DDC

Report SAM-TR-78-11

16 7930

17 12

ENGINEERING TEST AND EVALUATION DURING HIGH G

Volume II: Anti-G Valves

Roy W. Thompson, [redacted].
Larry J. Meeker, [redacted]S.
Gary L. Wilson, [redacted]S.
Arnold G. Krueger
Paul E. Love
Technology Incorporated
511 West Rhapsody Drive
San Antonio, Texas 78216

12 85p.

June [redacted]978

Final Report for Period 1 Febr[redacted]975 - 30 Sept[redacted]976

Approved for public release; distribution unlimited.

15 F41609-75-C-0026

Prepared for

USAF SCHOOL OF AEROSPACE MEDICINE
Aerospace Medical Division (AFSC)
Brooks Air Force Base, Texas 78235

NOTICES

This final report was submitted by the Life Sciences Division of Technology Incorporated, 511 West Rhapsody Drive, San Antonio, Texas 78216, under contract F41609-75-C-0026 with modifications P00001 through P00007 and A00001, job order 7930-12-13 with the USAF School of Aerospace Medicine, Aerospace Medical Division, AFSC, Brooks Air Force Base, Texas. Dr. Sidney D. Leverett, Jr. (SAM/VNB) was the Laboratory Project Scientist-in-Charge.

When U.S. Government drawings, specifications, or other data are used for any purpose other than a definitely related Government procurement operation, the Government thereby incurs no responsibility nor any obligation whatsoever; and the fact that the Government may have formulated, furnished, or in any way supplied the said drawings, specifications, or other data is not to be regarded by implication or otherwise, as in any manner licensing the holder or any other person or corporation, or conveying any rights or permission to manufacture, use, or sell any patented invention that may in any way be related thereto.

This report has been reviewed by the Information Office (OI) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

SIDNEY D. LEVERETT, JR., Ph.D.
Project Scientist

BRYCE O. HARTMAN, Ph.D.
Supervisor

ROBERT G. MCIVER
Brigadier General, USAF, MC
Commander

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: SAM-TR-78-11	2. GOVT ACCESSION NO. / 3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle): ENGINEERING TEST AND EVALUATION DURING HIGH G Volume II: Anti-G Valves	5. TYPE OF REPORT & PERIOD COVERED: Final 1 Feb 1975 - 30 Sep 1976
	6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s): Roy W. Thompson, M.S.; Larry J. Meeker, B.S.; Gary L. Wilson, M.S.; Arnold G. Krueger; and Paul E. Love	8. CONTRACT OR GRANT NUMBER(s): F41609-75-C-0026
9. PERFORMING ORGANIZATION NAME AND ADDRESS: Technology Incorporated, 511 West Rhapsody Dr., San Antonio, Texas 78216	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: 62202F 7930-12-13
11. CONTROLLING OFFICE NAME AND ADDRESS: USAF School of Aerospace Medicine (VNB), Aerospace Medical Division (AFSC), Brooks Air Force Base, Texas 78235	12. REPORT DATE: June 1978
	13. NUMBER OF PAGES: 82
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)	15. SECURITY CLASS. (of this report): UNCLASSIFIED
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

Appendixes (A - R) apply to the entire TEHG series: Volumes I, II, and III.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Acceleration	Performance of anti-G valve
Aircrew protection	Pneumatic system
Anti-G valve	Protection in G environment
Equipment in jet aircraft	Anti-G valve test protocol

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

In this second volume of a three-volume study report, a protocol for testing anti-G valves is described and the test results from 6 specimens are reported. The test items include 2 inservice USAF units, 2 RAF units and 2 prototype experimental units (electronic and fluidic). A suggested standardized performance evaluation protocol for future applications is proposed.

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

SECURITY CLASSIFICATION OF THIS PAGE(When Data Entered)

SUMMARY

At the USAF School of Aerospace Medicine (USAFSAM), the Biodynamics Branch (VNB) has the responsibility of developing, testing, prototyping, evaluating, and recommending all methods of improving G tolerance in aircrew members flying fighter attack aircraft. The VNB physiologic studies use various sustained G levels; and human subjects are tested during simulated aerial combat maneuvers, under repetitive G, or under other G exposures that may become part of the Air Force mission (e.g., space-shuttle launch and reentry studies). Hence the general objective of the "Engineering Test and Evaluation During High G" (TEHG) program, for which Technology Incorporated served as contractor, has been to provide engineering data in support of the USAFSAM/VNB mission.

All work was performed in the VNB Human Centrifuge Facility. The three resulting volumes, plus appendixes, then underwent the necessary revision and editing by the USAFSAM Medical Editing Branch:

Volume I, Data Evaluation Techniques and Equipment Tests, SAM-TR-78-10, summarizes the TEHG program and provides information on data acquisition systems, mathematics and data analysis, and specific equipment evaluation.

Volume II, Anti-G Valves, SAM-TR-78-11, affords detailed descriptions of the anti-G valve test protocol, definition of curves, specific anti-G valve evaluations, and standardized anti-G valve test protocol.

Volume III, Anti-G Suits, SAM-TR-78-12, also affords detailed descriptions of the anti-G suit test protocol, definition of curves, and specific anti-G suit evaluations, as well as anti-G protective system field-test procedures and supplemental pneumatic lever anti-G suit evaluation.

The Appendixes, because of their size, could not be included in any of the TEHG volumes. However, microfiche copies of all of the Appendixes (A - R) are available through: The Strughold Aeromedical Library, Documentation Section, Brooks AFB, Texas 78235.

P R E F A C E

As Project Scientist of Contract F41609-75-C-0026, I would like to acknowledge Ms. Ena Borden Shaw (of our Medical Editing Branch) for the outstanding manner in which she critically, and expertly edited this technical report. It was a very time-consuming project--requiring technical skills and dedication, on the part of Ms. Shaw, that enabled the USAF School of Aerospace Medicine and Technology Incorporated to produce such a useful document.

SIDNEY D. LEVERETT, JR., Ph.D.
(Contract Monitor)
Chief, Biodynamics Branch
Crew Technology Division
USAF School of Aerospace Medicine

:tion
No. Page

CONTENTS (cont'd.)

TABLES

ENGINEERING TEST AND EVALUATION DURING HIGH G

VOLUME II:

ANTI-G VALVES

1. INTRODUCTION

In this volume are described the various facets of the anti-G testing program, and the relevant results from the "Engineering Test and Evaluation During High G" (TEHG) program, as well as the Standardized Anti-G Valve Test Protocol. The six valves tested were: the Hymatic VAG 110-006; the Hymatic VAG 110-007; the ALAR 88535-8400A; the Bendix FR139A2; a prototype USAFSAM Electronic Anti-G Valve; and a prototype Honeywell Fluidic Anti-G Valve.

Much of the instrumentation and data analysis, and many other pertinent details, were common to our other TEHG efforts. Because the information in this volume has been so presented that it can stand alone, some repetition of material from the other volumes has been unavoidable. Detailed study of the results in Volume II may therefore require reference to Volumes I and III, and to the appropriate Appendixes.

1.1 Background of Anti-G Valves

The anti-G valve is a major component of a system devised to increase the combat effectiveness of the crewmen of high-performance aircraft. It is intended to assist in anti-blackout protection procedures necessary for these crewmen during periods of sustained high G. The purpose of the acceleration protective system is to maintain adequate arterial blood pressure at the level of the visual centers during pullout and other $+G_z$-producing maneuvers. If adequate arterial blood pressure and flow are not thus maintained, the result is a decrease in visual acuity, accompanied by narrowing of the field of vision, and followed by loss of consciousness. The present anti-G protective systems (of which the anti-G valve is a part) have evolved from efforts to modify the severity of visual disturbances, spatial disturbances, and physical discomfort encountered during periods of sustained high G.

EDITOR'S NOTE: The Appendixes (A - R) concern the entire TEHG series, rather than any one volume. Hence, all of these Appendixes apply to, and supplement, Volumes I, II, and III. (Information on how to order all, or part, of these Appendixes appears at the close of each volume.)

1.2 Function of Anti-G Valves

The anti-G valve is always used in conjunction with an inflatable anti-G protective garment. Generally, this anti-G "suit" has airtight bladders sewn into the calf, thigh, and abdominal regions. The calf bladders are connected to the thigh bladders of their respective legs through filling ducts; and the thigh bladders are, in turn, connected to the abdominal bladder. An inlet hose is connected to the abdominal bladder, and this inlet hose connects the anti-G suit to the anti-G valve. The function of the anti-G valve is to inflate the bladders of the anti-G suit with air supplied by a suitable source. This air is usually provided by bleeding air from some compressor stage of the aircraft jet engine. The anti-G valve regulates the air pressure in the bladders of the anti-G suit, and the pressure to which these bladders are inflated is proportional to the $+G_z$ forces of the aircraft at that instant.

During sustained high G, there is a tendency toward pooling of the blood in the lower extremities and in the abdominal region. This pooling effect tends to decrease the intracerebral blood pressure, thereby affecting the crewmembers' visual centers and other important cerebral functions. The anti-G valve will (when connected to a properly fitting suit) provide a crewmember with anti-blackout protection by inflating the suit bladders to such pressures as will apply enough force to the legs and abdomen to inhibit pooling and raise the intracerebral blood pressure.

1.3 Operation of Anti-G Valves

The anti-G valve is a special type of pressure regulator that delivers an output pressure proportional to the $+G_z$ forces acting upon its control elements at that instant.

The standard type of anti-G valve utilizes a movable mass as the acceleration sensing element. This mass is alined so that it applies force to the pressure regulating elements (usually a spring-loaded diaphragm and valve arrangement) proportional to the $+G_z$ forces. At some designated $+G_z$ threshold, usually around $+2\ G_z$, the force exerted by the mass supplies the necessary force to open the inlet valve. The inlet valve allows air to flow into the anti-G suit; and, as the suit pressure increases, the back force exerted on the diaphragm increases, tending to counteract the force applied by the movable mass. When the suit pressure reaches the level that causes the mass force and diaphragm force to cancel, flow ceases. A relief valve arrangement is also incorporated into the anti-G valve. The relief valve functions to limit the maximum suit pressure, usually from 8 to 11 psig.

The standard anti-G valve operates on strictly mechanical and physical principles. Once the valve is designed and constructed, the resulting suit inflation schedule is fixed. There are no external adjustments.

Two prototype anti-G valves designed around fluidic principles and electronic principles were tested during the TEHG program. These valves are used in research because they offer considerable flexibility in programming almost unlimited variations of inflation schedules.

1.4 Monitoring Procedures for Testing Anti-G Valves

An especially constructed stand that bolts to the floor of the USAFSAM/VNB human centrifuge gondola is used for testing anti-G valves. A metal disc, ruled in degrees, is incorporated into the test stand. This disc contains mounting holes for anti-G valves, and may be rotated. The anti-G valve (when mounted to the disc) may accurately be placed in any desired alinement to the $+G_z$ forces developed during testing. When the anti-G valve is mounted onto the test stand and the test stand is in place in the gondola, the anti-G valve under test is in the same plane as the gondola accelerometer.

For valve testing at the lower pressure and flow requirements, the gondola air supply is used with an in-line air dryer and filter which is installed ahead of the anti-G valve being tested. The gondola air supply can be controlled by a solenoid valve remotely operated from the control console. The pressure of the gondola air supply is controlled by the regulator mounted on the compressor located in the sub-pit. For source pressures between 70 psig and 80 psig, the compressor-mounted regulator is used; but, for lower pressures, another regulator is mounted downstream from the gondola air source.

Higher source pressures and flow rates utilize a cylinder, of compressed air, fitted with a pressure regulator. Especially fabricated removable mounting pedestals are used to install the air cylinder in the centrifuge gondola. The air cylinders are standard "K bottles" containing 220 standard cubic ft (SCF) air at 2200 psig. A solenoid valve is placed in-line between the pressure regulator and the instrumentation portion of the test stand. The solenoid valve is mounted on the test stand, and is remotely controlled from the console by sending low current signals through the slip-ring pairs to a relay in an especially constructed control box. The solenoid valve serves to conserve the air during the periods between test runs when "K bottles" are used as the air source.

The source pressure is measured downstream from the solenoid valve, just ahead of the anti-G valve. A "T" is utilized and is placed in-line to decrease the flow impedance. The pressure transducer used to measure source pressure is a Taber Teledyne type 176 which has a measurement range of 0-500 psig. Direct current (dc) excitation is provided by a closely regulated 9-V supply, designed and built inhouse especially to be used for this purpose. The input to the 9-V supply is provided by the dc power supply mounted in the gondola.

Immediately following the anti-G valve is a T, placed in the output line to facilitate the measuring of the output pressure (suit pressure) delivered by the anti-G valve under test. The suit pressure transducer is a Giannini model 451212-4 with a measurement range of 0 - 30 psia. Direct current excitation is provided by an Electrostatics Inc. Model 10-1515 ±15 VDC power supply, mounted on the test stand.

Downstream from the point of suit-pressure measurement, the output plumbing divides into two branches. Each branch is plumbed into a remotely operated solenoid valve which is electrically arranged so that either one branch or the other may be selected, but not both simultaneously. A flowmeter (flow transducer) is installed just downstream from each solenoid valve. The smaller flow transducer is a Datametrics Model 1000 -.25 N which has a measurement range of 0 - 1 SCFM, and the other flow transducer is a Datametrics Model 1000 - 2B with a measurement range of 0 - 60 SCFM. This arrangement allows remote selection of flow measuring ranges during testing. Each flow sensor is especially matched with its own Datametrics Model 800-LM linear flow meter. The two flow paths are reunited after leaving their respective flow meters, and the air flow delivered by the anti-G valve is then allowed to flow into the atmosphere or into an anti-G suit, depending upon which portion of the testing is being conducted.

Acceleration is monitored using the Page Engineering Model CA19R-20G-131 accelerometer (i.e., the master accelerometer) that is permanently installed in the centrifuge gondola. The accelerometer output is permanently patched to a slip-ring pair reserved for that purpose. When closer resolution is desired, the output pair is paralleled at the patch panel on the console. One set provides input to a preamplifier "standard amp" spanned to provide full-scale measurement; and the other set inputs into a preamplifier spanned to provide 2 - 10 times the gain of the standard amp.

The output signals from the source pressure transducer, the suit pressure transducer, and the two flow transducers are patched into a small patch box mounted on the test stand. The patch box connects to a shielded cable and through a connector providing access to 8 slip-ring pairs. This arrangement allows faster setup times, as most transducer outputs remain permanently patched.

After all of the required transducer outputs are patched through to the control console, they are then sent to their respective signal conditioner (preamplifier). For acceleration and acceleration expanded channels, a Brush preamplifier Model 4215 70 is used. The high gain of the Brush model 4215 70 preamplifier is also required for conditioning the source pressure transducer output signal. The flow transducers and the suit pressure transducer utilize a Brush model RD 4215 10 preamplifier as their signal conditioner. The suit pressure signal is sometimes expanded for better resolution, and a gain of 2 - 20 times that of the "standard amp" is easily attainable with a Brush Model RD 4215 10 preamplifier in this capacity. All primary spanning and calibration adjustments take place at the control console using the signal conditioners just listed.

The outputs from the signal conditioners (preamplifiers) are paralleled at the patch panel. One branch of the output is input to the Brush Mark 200 strip-chart recorder at the control console, and the other branch is sent to the data collection center patch panel. At the data collection center the conditioned signals are offset adjusted and attenuated to the signal level of ±1.0 V for full-scale reading. The Sangamo 3500 magnetic tape recorder has a full-scale input capability of ±1.4 V; however, the reduced scale is used to assure the recording of unpredicted over-scale data.

The data recorded on analog magnetic tape are monitored, using the playback function output as input to the Brush recorders at the data center.

2. TEST PROTOCOL FOR ANTI-G VALVES

The objective of this test protocol is to describe the uniform approach for investigating the performance characteristics of anti-G valves under various acceleration environments. Because of the wide variety of design approaches and specifications represented by the valves, no attempt is made to present a protocol that is specifically applicable to all valves, or to quantify the parameters measured. Instead, this section presents the general methods used for testing anti-G valves during TEHG. Quantification of the test was dictated through two processes: first, by mutual agreement between the respective staffs of VNB, the Biometrics Division (USAFSAM), and Technology Incorporated; and second, by the test results, which indicated the areas of operation that required either more intense investigation or deletion from the testing program. (The idiosyncracies of each valve protocol are discussed in the appropriate subsection of section 4.)

2.1 Test Configurations

Two basic test configurations were used for evaluating anti-G valves. The first (Fig. 1) was used only for flow tests (refer to section 2.3). The second (Fig. 2) was identical to the first configuration except that an anti-G suit and a mannequin had been added. (The transducers and data-handling equipment are also discussed in Vol. I.)

Two pressure-source configurations were used. The first, for lower source pressures and flow requirements, utilized the compressed air line presently installed in the centrifuge gondola. The second pressure source, utilizing a standard "K bottle," was used when greater source pressures and higher flow rates were required. A remotely controlled solenoid valve was installed to conserve air when "K bottles" were used as the pressure source.

The anti-G valve was mounted on a circular plate which was scaled and indexed in degrees. This plate, which could be locked in angular position, was used while testing the sensitivity of anti-G valves to mounting angles. This circular plate was mounted on a test stand and, when the test stand was bolted in the centrifuge gondola, the anti-G valve was closely alined with the gondola accelerometer. Also mounted on the test stand were flow sensors, control boxes, power supplies, and pressure transducers.

When an anti-G suit was utilized as part of the testing procedures, it was fitted to a fiberglass mannequin. The mannequin was oriented to simulate a pilot, in a seat, with his feet on the rudder pedals.

EDITOR'S NOTE: Available, on p. 80, is a selective list (plus definitions) of the "Abbreviations, Acronyms, and Symbols" used throughout this volume.

2.2 Parameters Monitored

2.2.1 Source Pressure (P_S)

A source pressure transducer, located downstream from the solenoid valve, was used to monitor the pressure supplied to the inlet part of the anti-G valve. The transducer port was located in an especially constructed T to minimize errors due to pressure drop caused by restrictions in the air line or by venturi effects. A Taber Teledyne (0 - 500 psig) transducer was used to monitor this parameter.

2.2.2 Suit Pressure (P_V)

A suit pressure transducer, located immediately downstream from the anti-G valve, monitored the pressure supplied by the valve to the remainder of the pneumatic system. The transducer port was located in an especially constructed T to minimize errors resulting from pressure drop through the interconnecting tubing and from venturi effects. A Giannini Model 451212-4 (0 - 30 psia) transducer was used to monitor the suit pressure.

2.2.3 Air Flow (F_V)

Flow was monitored by a Datametrics Model 1000-2B having an effective measurement range of 0.6 - 60 SCFM. The flow sensor was mounted downstream from the P_V transducer.

2.2.4 Acceleration (G_Z)

The Z-axis acceleration (i.e., perpendicular to the floor of the gondola) was monitored by the Page Engineering Model CA19R-20G-1311 accelerometer which is presently used for most investigations on the USAFSAM human centrifuge.

2.2.5 Valve Angle

The valve under test was attached to the circular plate and mounted on the test stand in such a position that, when the disc was indexed to the zero degree mark, the vertical axis of the valve was perpendicular to the floor of the gondola.

The circular plate was attached to the test stand at its center and could be firmly set at any desired angle.

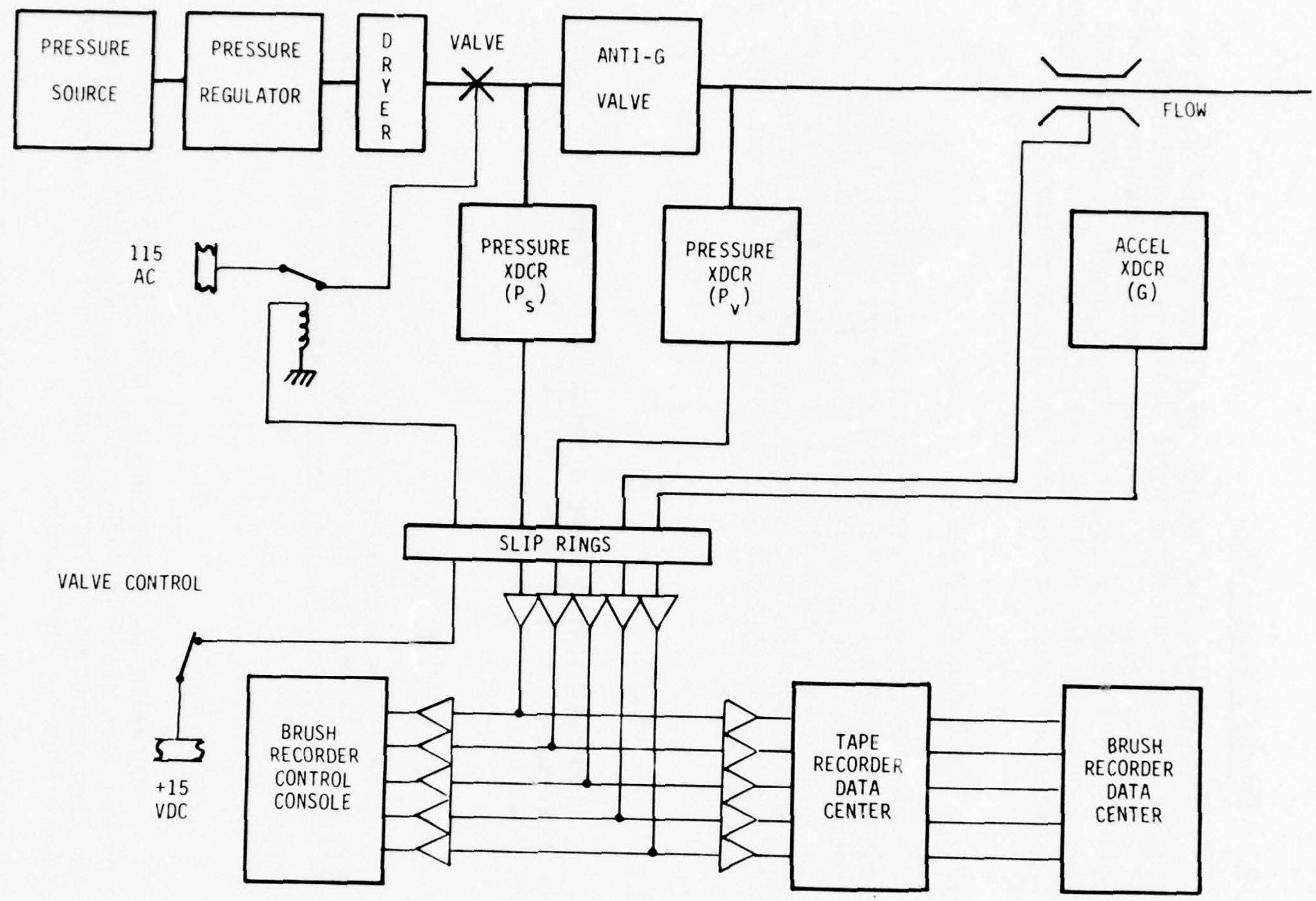

Figure 1. The open-flow test configuration for evaluating anti-G valves. [AC = alternating current; NC = normally closed; NO = normally open; P_S = source pressure; P_V = suit pressure; VDC = volt (direct current); and XDCR = transducer]

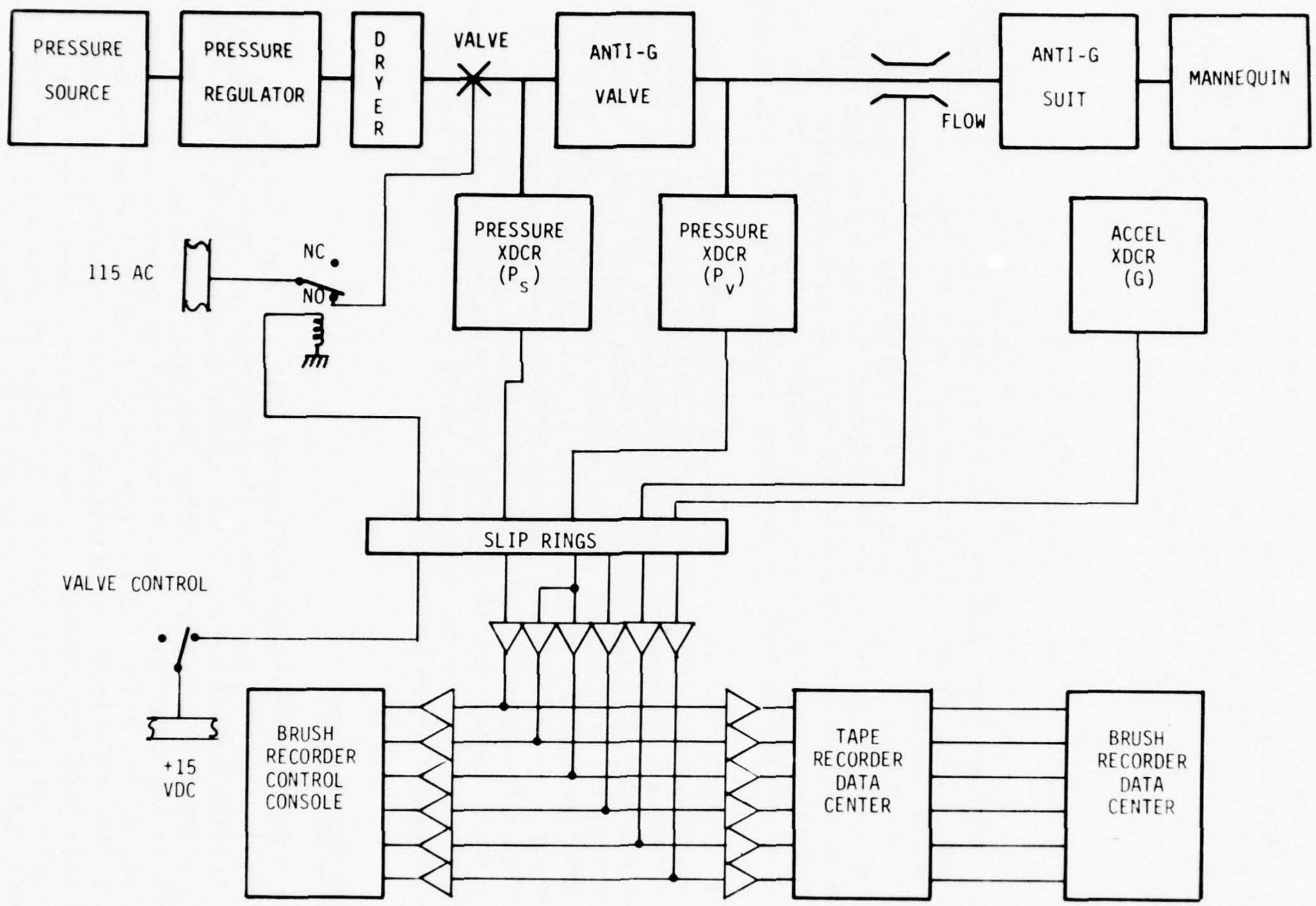

Figure 2. The dynamic test configuration for evaluating anti-G valves. [See Fig. 1 legend for key to abbreviations.]

2.2.6 Suit Volume (V_S)

The suit volume was adjusted by changing the suit used and/or changing the fit of the suit on the mannequin. A standardized technique was developed to determine the suit volume. This technique consisted of pressurizing a known volume to a known initial pressure, evacuating the anti-G suit with a mild vacuum, and then slowly pressurizing the suit to 5 psig from the known volume. The suit volumes were calculated from the pressure drop in the known source volume.

2.2.7 Signal Conditioning and Recording

For the majority of the data recorded during these tests, the standard techniques were utilized for tests conducted on the USAFSAM human centrifuge. These techniques involve not only the passage of electrical signals through slip rings to the control console where they are amplified or attenuated, as necessary (recording the more important of the conditioned signals on the Brush recorder at the console)--but also filtering and re-scaling the signals in the data center, recording the reprocessed signals on magnetic tape, and monitoring the output of the tape recorder playback on one or both of the Brush recorders in the data center.

The suit pressure (P_V) was monitored on an expanded scale when improved resolution was required. This technique involved paralleling the output signal of the pressure transducer into two signal-conditioning amplifiers. One amplifier was scaled to monitor the full range of the output signal, and served as a baseline standard for the second amplifier. The gain of the second amplifier was set and calibrated at 5 - 20 times the gain of the "standard amp," and the direct current offset capability was used to "chase" the signal to the value of interest. The resulting signal was used to study small variations in relatively large signals (especially where dead band and hysteresis were of interest), while the "standard amp" provided a true parameter value monitor.

2.3 Test Description

The 5-phase performance evaluation test for anti-G valves (described in this section) was originally submitted to USAFSAM/VNB as a protocol for testing anti-G valves. Two valves were tested (the VAG 110-007, and the ALAR) using this procedure. After the data of the two anti-G valves were reviewed, it was determined that significant information was gained only from Phases I, IV, and V. Data from Phases II and III were insignificant and had the additional disadvantage of being collected piecemeal, thus causing data handling problems in the computer. Hence the 5-phase performance evaluation test was modified by deleting Phases II and III, thereby becoming the 3-phase test--in which Phase I remained intact; Phase IV became the new Phase II; and Phase V became the new Phase III.

2.3.1 Maximum Flow Capacity (Phase I)

This test was utilized to determine the maximum flow capability of the anti-G valve under test. The test setup in Figure 1 was used. Three source pressures were used for one major variable, consisting of the design maximum, the design minimum, and the optimum value for the valve being tested. Where the design optimum operating pressure was not known, a pressure close to the median value was chosen. A minimum of three sets of data were taken at each source pressure. Each data run consisted of a stepwise G profile from 1 G to a maximum of 10 G. The G level at each step was maintained for a minimum of 10 sec in order to permit the data to stabilize.

2.3.2 Output Pressure Sensitivity (Phase II, later deleted)

The purpose of this test was to measure the dead band in the anti-G valve's response to changes in output pressure. The test setup is shown in Figure 2, with the exception that a suitable leak (bleed orifice) was installed in the valve output line near the suit hose connector. The major variables for the test were (1) acceleration, (2) source pressure, and (3) valve angle. The source pressures selected were the same as those utilized in Phase I. A minimum of three sets of data were taken at each source pressure, using the same acceleration profile as Phase I. The leakage rate was controlled by the bleed orifice. Two extra runs were made at the median source pressure with the anti-G valve misalined with the G vector at two different angles.

2.3.3. Acceleration Sensitivity (Phase III, later deleted)

The purpose of this test was to determine the dead band and hysteresis in the anti-G valve's response to acceleration. The test setup in Figure 2 was used. The major variables for the test were (1) acceleration, (2) source pressure, and (3) valve angle. The source pressures selected were the same as those used for Phases I and II. A minimum of three sets of data were taken at each source pressure. Each set consisted of very slow changes in acceleration (i.e., 0.01 G/sec) between:

(a) 1 G to "cut in" plus 0.5 G

(b) "cut in" plus 0.5 G - 1 G

(c) 2.5 G - 3.5 G

(d) 3.5 G - 2.5 G

(e) 3.5 G - 4.5 G

(f) 4.5 G - 3.5 G

(g) Etc., to the selected maximum G level.

A similar run was made at each of the valve angles (at the same source pressure) studied in Phase II.

2.3.4 Slow Response Continuous Operating Characteristics (Phase IV, later Phase II)

The purpose of this test was to measure the dynamic dead band and hysteresis of the valve and to develop a dynamic response baseline for comparison with high acceleration response data (Phase V). The test setup shown in Figure 2 was used. One variable in this test was acceleratio In the original 5-phase protocol, this was the only variable exercised. Upon conversion to the 3-phase protocol, two other variables were added. The second variable was source pressure. Tests were run at each of the selected maximum, minimum, and median source pressures. The third variable was valve angle. The volume of the anti-G suit used in this test was set at the mid-range value selected for Phase V. A minimum of three iterations of a trapezoidal G profile was run with 0.1 G/sec onset and offset rates at each source pressure and at each selected angle.

2.3.5 High Acceleration Response (Phase V, later Phase III)

The purpose of this test was to evaluate the ability of an anti-G valve to follow rapid changes in acceleration. The test setup shown in Figure 2 was used. The major variables for the test were (1) acceleration, (2) source pressure, (3) suit volume, and (4) valve angle. The majority of the tests were run using a trapezoidal G profile (T) using three onset and offset rates representing minimum (MN), median (MD), and maximum (MX) values of interest for that valve. Three iterations were run at each onset and offset rate for the combinations of source pressure, suit volume, and valve angle (Table 1). The same source pressure values used in Phase IV were used for these tests. Three suit volumes were selected to span the design capabilities of the valve. An additional set of three iterations were run at the median source pressure and suit volume for each of the valve angles used in Phase IV. Performance tests were also run using a simulated aerial combat maneuver (SACM) acceleration profile with: (1) the minimum source pressure and maximum suit volume; (2) the maximum source pressure and minimum suit volume; (3) the median source pressure and median suit volume; and (4) a selected valve angle and the median source pressure and suit volume.

TABLE 1. PHASE V TEST CONDITIONS FOR ANTI-G VALVES

	G profile	G rate	Source pressure	Suit pressure	Valve angle	Set No.
21 Runs	T	MN	MN	MN	0	1
	T	MD	MN	MN	0	2
	T	MX	MN	MN	0	3
	T	MN	MX	MN	0	4
	T	MD	MX	MN	0	5
	T	MX	MX	MN	0	6
	ACM	--	MX	MN	0	7
21 Runs	T	MN	MD	MD	0	8
	T	MD	MD	MD	0	9
	T	MX	MD	MD	0	10
	ACM	--	MD	MD	0	11
	ACM	--	MD	MD	10	12
	T	MD	MD	MD	10	13
	T	MD	MD	MD	20	14
21 Runs	T	MN	MN	MX	0	15
	T	MD	MN	MX	0	16
	T	MX	MN	MX	0	17
	ACM	--	MN	MX	0	18
	T	MN	MX	MX	0	19
	T	MD	MX	MX	0	20
	T	MX	MX	MX	0	21

ACM = aerial combat maneuver; MN = minimum; MD = median; MX = maximum; and T = trapezoidal G profile.

3. DEFINITION OF CURVES

The majority of data resulting from anti-G valve testing on the TEHG program were recorded on analog magnetic tape, digitized, and processed through the computational facilities of the USAFSAM Data Processing Branch (BRP). The results of those computations were graphic representations of the various characteristics and parameters monitored. Due to the quantity of data, these graphs have been bound in separate appendixes for the respective valves (i.e., Appendixes C - G).

4. SPECIFIC ANTI-G VALVE EVALUATIONS

4.1 Performance of the Hymatic VAG 110-006

The Hymatic VAG 110-006 (designed and produced by the Hymatic Engineering Co., Ltd., Redditch, England) was the first valve assigned to the TEHG team for evaluation. Because earlier manned tests using the 006 had raised a question concerning the proper functioning of this valve, two groups of tests were now performed. In order to obtain a response in the shortest time possible, a set of empirical static tests were run. Later, a standard test protocol was initiated.

4.1.1 Description of the VAG 110-006

The VAG 110-006 is essentially identical to the VAG 110-007 in theory of operation (spool valve), capabilities, and specifications. The major areas of difference between the two valves are the physical layout of the assembly and the design of the relief valve.

The VAG 110-006 is physically different from the VAG 110-007 in that the inlet and outlet connections are both located on the same side of the valve assembly, and that at 1.02 lb (0.46 kg) the VAG 110-006 is slightly lighter.

The VAG 110-006 is fitted with a double area, spring-loaded relief valve. The relief valve and valve seat are tapered so that, when closed, the relief valve presents an area of 0.196 $in.^2$ (3.21 cm^2). The cracking pressure of this valve is 9.5 - 10.5 psig. Once the relief valve has started to open, the effective area increases (because of the tapered seat) to 0.601 $in.^2$ (9.85 cm^2) and the relief valve is forced to the "wide open" position. The reseating pressure for this relief valve is about 6.5 psig. The VAG 110-006 relief valve is capable of flowing 50 SCFM at 12 psig.

4.1.2 Static Test Results of the VAG 110-006

Static tests of the 006 were run using the standard anti-G valve instrumentation configuration, except that the flow meters were not monitored, and data were not recorded on tape. Since it was suspected that this valve was not functioning properly, an empirical rather than a formal protocol was initiated. (A complete annotation of these tests was submitted to VNB in April 1975, along with the control room Brush chart records, and is not repeated here.)

Initial testing involved manual excitation of the valve through the press to test area with no definitive results. This effort was succeeded by a series of tests using brass weights sequentially applied to the press to test area to simulate acceleration stimulus. These tests led to two conclusions. First, the relief valve was sticking, resulting in a catastrophic performance failure. Second, while the valve functioned properly up to and including a simulated 5 G, above that value it developed excessive dead-band hysteresis and data variance.

After permission was received from the contract monitor, the valve was completely disassembled and a sticky residue was found throughout. The source and composition of this contaminant were not determined. All parts were meticulously cleaned using 70% alcohol as a solvent, and no trace of the residue was detectable when the valve was reassembled. It should be noted here that all tests on this valve used gondola air and the design normal pressure of 72 ± 5 psig. The gondola air was filtered first at the compressor and again on the TEHG test stand (refer to section 2). Subsequent to cleaning, the static tests were resumed. The linear function of the valve appeared to improve significantly, resulting in a reasonably linear operation up to approximately 8 G. Above that point, the valve output exhibited significant dead band, hysteresis, and variance, although at reduced levels compared to the first test results. The relief valve operation was still unacceptable. After permission was received from the contract monitor, the relief valve was disassembled, lightly greased with a silicon base compound, and reassembled. After this action, the valve appeared to be functioning normally with the possible exception of the dead band, hysteresis, and variance of the output above 8 G.

One of the interesting characteristics of this valve was the oscillatory operation of the relief valve. Although only one valve was tested, it is reasonable to assume that this oscillation would occur any time the relief valve flow capacity exceeded the ability of the source pressure to supply air at approximately 6 psig. Relief valve flow capacity exceeding the source capacity was, of course, a desirable characteristic in terms of pilot protection. During the static tests, the relief valve was observed to cycle between approximately 10.2 psig and 6.2 psig. These values might be expected from the physical description (already given in section 4.1.1). As the flow through the relief valve exceeded the capacity of the pressure source, the pressure dropped below the relief valve closing pressure. After the valve closed, if G stress was still applied, the pressure immediately rose to the relief valve cracking pressure, and the cycle was repeated.

4.1.3 Dynamic Test Results of the VAG 110-006

Subsequent to static testing, a standard five-phase test protocol was initiated, starting with Phase III. Less than 10% of these tests had been completed when it became obvious that the valve had started sticking again. The dead-band characteristics above 7 G were the first indications of failure, followed by the relief valve sticking at high G. After consultation with the contract monitor, it was decided to abandon testing and return the valve to Royal Air Force Institute of Aviation Medicine (RAF/IAM).

Because very little testing was completed, data are not available for analysis. Two observations can be made. First, before the relief valve started to stick, it exhibited oscillatory characteristics almost identical to those described in the static tests. Second, on one occasion the valve oscillated during initial suit pressurization, varying between 1.5 psig and 2 psig for an acceleration stimulus varying between 2.25 G and 5 G. This phenomenon was not repeated, and its cause was not determined.

4.2 Performance of the Hymatic VAG 110-007

The VAG 110-007 anti-G valve (designed and produced by The Hymatic Engineering Co., Ltd., Redditch, England) uses a mass spring system for sensing acceleration (G) force and for regulating anti-G suit pressure. As the G forces alined with the vertical axis of the valve (G_z) are encountered, the mass is forced down to bear against a pressure-centered spool valve. As the spool valve moves out of the neutral (center) position, air pressure is applied to the suit outlet and to the bottom of the spool valve. When the required pressure is reached, the opposition pressure against the spool valve plus the spring force against the mass return the spool valve to the neutral position, thereby venting pressure through a port at the bottom of the valve assembly. When the G force is reduced, the opposition pressure moves the spool valve out of the neutral position and vents pressure until the G force and suit pressure are balanced, returning the spool valve to the neutral position.

The VAG 110-007 is designed to actuate (i.e., begin to apply suit pressure) at 1.75 - 2.25 G_z. The suit is then pressurized at a nominal rate of 1.25 psig/G. The design specifications for the VAG 110-007 require 1.8 - 2.3 psig at 2.5 G_z, and 8.5 - 9.4 psig at 8.0 G_z.

Since the VAG 110-007 uses a spool valve, pressure is constantly being bled through the valve assembly when the spool valve is in the neutral position (i.e., when the suit pressure/G force is balanced, or at less than, 1.75 G_z). This bleed rate varies with source pressure. The maximum design bleed rate is from 8.8 SCFM at 1 G_z to 9.9 SCFM at 8 G_z with a source pressure of 170 psig. The bleed rate would be 2.2 SCFM at 1 G_z with a source pressure of 70 psig. The VAG 110-007 is fitted with a manual shut-off valve operated by a handle, at the front of the valve assembly, which closes off the air supply when anti-G valve operation is not desired.

The VAG 110-007 is fitted with a spring-loaded relief valve designed to "crack" at between 9.4 psig and 10.5 psig. The relief valve has sufficient flow capability to limit suit pressure to a maximum of 12 psig at 170 psig supply pressure.

The VAG 110-007 is designed to operate with a maximum supply pressure of 170 psig, and has been shown to operate properly with supply pressures as low as 20 psig. The valve is fitted with a flexible boot at the top which allows the G sensing mass to be manually depressed and provides a functional test feature.

The physical dimensions of the valve assembly are approximately 5.9 x 2.5 x 4.4 in. (14.9 x 6.5 x 11.1 cm). The VAG 110-007 weighs approximately 1.1 lb (0.5 kg).

4.2.1 Test Summary of the VAG 110-007

The VAG 110-007 was tested using the five-phase protocol. The data resulting from these tests are contained in Appendix C (Phase I data, pp. 1-9; Phase II, pp. 10-24; Phase III, pp. 25-304; Phase IV, pp. 305-312; and Phase V, pp. 313-496).

The 007 design minimum and maximum source pressures--20 psig and 170 psig, respectively--were the determining factors for setting the span of pressures during testing. Median source pressure was 80 psig. Suit volumes of 6 liters (minimum), 9 liters (median), and 12 liters (maximum) were used in Phase V testing, but the median volume was used in Phases II, III, and IV. Early tests indicated the 007 did not function well when the spool valve was alined 20° on either side of the G_Z vector. As a result, maximum "off axis" tests were run using 15°. Median "off axis" tests used 10°.

4.2.2 Open-Flow Capacity of the VAG 110-007

The results of Phase I open-flow tests of the VAG 110-007 are in Appendix C (pp. 1-9). These open-flow tests were conducted with a normal length of hose, attached downstream from the flow meter, and terminated by female connectors matching those used for CSU series Air Force anti-G suits. The tests were conducted using three source pressures, including the design minimum of 20 psig, the design maximum of 170 psig, and a median pressure selected at 80 psig.

Using a source pressure of 20 psig, the curve exhibited an interesting plateau characteristic, as may be seen in Appendix C (pp. 1-3). Flow began at approximately 2.15 G, and increased rapidly to 14.1 SCFM at 3.5 G. This flow level was maintained until approximately 4.25 G, and then increased in a relatively linear fashion to 18.2 SCFM at 5.5 G. This flow level was maintained to approximatley 8.5 G, after which it rose gently to greater than 20 SCFM at 10 G. The differences between minimum and maximum flow values (ΔF), recorded in Appendix C (p. 3), suggest that these plateaus are real and repeatable data. The maximum ΔF recorded was 1.125 SCFM at 8 G, and averaged approximately 0.8 SCFM.

The flow curve resulting from the 80-psig tests exhibited a dip in flow at high G which could not be explained, despite a review of the valve's design, the test protocol, and the test fixture. Flow started at approximately 2.05 G and made a sharp rise to 11.6 SCFM at 2.75 G. Flow increased in a relatively linear fashion to approximately 26.3 SCFM at 7.75 G. The output dipped to 19.55 SCFM at 9.25 G, and then increased in a linear fashion to 24.8 SCFM at 10 G. A review of the ΔF values (shown in Appendix C, p. 6) suggests that this dip was real, repeatable data. The maximum ΔF recorded, 1.4 SCFM at 7125 G, decreased through the dip to 1.18 SCFM at 8.6 G. The average ΔF is approximately 1.1 SCFM.

The open-flow data resulting from a source pressure of 170 psig exhibit the same plateau characteristics as the data using a source pressure of 20 psig. Flow began at approximately 1.85 G and increased rapidly to 13.7 SCFM at 3.75 G. This flow rate was maintained through 4.75 G and then increased linearly to 9 G and beyond, attaining a value of 21.8 SCFM at 10 G. The ΔF values ranged from a maximum of 1.56 SCFM at 2.45 G to a minimum of 0.66 SCFM at 7.75 G, thus averaging 1.02 SCFM.

No explanation was developed for the plateau or dip characteristic of these curves. The VAG 110-007 exhibited the highest flow characteristics of those mass spring type valves tested during this program. These data suggest an unusual capability to handle large suit volumes and to respond quickly to high-G onset rates.

4.2.3 Pressure Hysteresis Tests of the VAG 110-007

These tests were originally designed to detect the output pressure sensitivity (a feedback parameter) of the valves (i.e., a measure of the ability of a valve to detect changes in suit pressure under steady G conditions). Pressure leaks were installed in the valve output line, and extensive experimentation was conducted on several valves using various leak rates and G application techniques. Two complete sets of data (i.e., the 007 and the ALAR) were processed through computer analysis to verify the team's visual examination of the records. These tests were deleted from the protocol in later valve tests.

The results of 007 pressure hysteresis testing are available in Appendix C (pp. 10-24). A fixed orifice leak was installed in the suit pressurization hose, and resulted in leak rates of approximately 0.5 SCFM at 10 G and 0.12 SCFM at 2 G. The data indicate a general decrease in 6σ as the source pressure rises. It is further suggested that any dead band in the output pressure sensitivity of the 007 valve is either masked by other data sources, and/or is below the sensitivity of the instrumentation available to measure it.

4.2.4 Phase III Tests of the VAG 110-007

The results of Phase III testing of the 007 valve are contained in Appendix C (pp. 25-304). Phase III of the five-phase protocol was principally interested in steady state, dead band, and hysteresis characteristics under various conditions. After the data of two anti-G valves had been reviewed, it was determined that no significant information had been gained over that available from Phase IV tests. Phase III data had the additional disadvantage of being collected piecemeal, resulting in a number of data-handling problems in the computer. The significant information which has been gleaned from 007 Phase III tests was incorporated into the 007 Phases IV and V data.

4.2.5 P-G Profile End Points of the VAG 110-007

The end points of the pressure per acceleration (P-G) profile define the useful range of acceleration over which the valve may be used. The low-pressure end of the P-G profile is defined as the "cut-in" point (i.e., that value of G at which the valve starts to apply pressure to the suit). The high-pressure end is defined by the relief valve actuation. It should be understood that the relief valve, the function of which is to protect the subject in case of valve failure, is not normally operational.

The 007 cut-in pressure varied between 1.7 G and 2.37 G during these tests, with the majority of values occurring at approximatley 2 G. As might be expected, no change occurred in cut-in point with respect to the volume of the suit being inflated. A definable difference was noted in cut-in point with respect to the onset rate of the test. Using 0.5 G/sec onset rates, pressure was applied at 1.84 G, as compared to an average of approximately 2 G for both 1 G/sec and 1.5 G/sec onset rates. The relationship between source pressure and the application of pressure to the suit is inversely proportional and very nearly linear. The average cut-in using 20-psig source pressure is 2.08 G, while averages for 80-psig and 170-psig source pressures are 1.97 G and 1.80 G, respectively. As already noted, the 007 is designed to cut in between 1.75 G and 2.25 G. Although there were instances of cut-in pressure falling outside the designed values (both high and low), all averages fell within the design specifications.

A review of the 007 design suggests that no change in relief valve operation is normally expected with respect to source pressure, suit volume, or onset rate. For reasons which cannot be explained at this point, the relief valve consistently opened and closed at higher suit pressures when 80-psig source pressure was used, averaging almost 1 psig higher. As might be expected, under identical conditions the relief valve closed an average of 0.51 psig lower than the cracking pressure. It was also evident that the 007 relief valve was sensitive to the angle of valve alinement with respect to the G vector. The cracking pressure increased when the relief valve was on the "up" side of the valve, and decreased on the "down" side. All of the angle tests made on the 007 were conducted with the relief valve on the "down" side. The data were not sufficient to document the difference in operating pressure resulting from angle, but it appears that a 0.5 - 0.75-psig pressure increase or decrease will result from a 10° angle. A wide dispersion of relief valve operating pressures was also observed. The maximum three-run average of operating pressures was 10.7 psig, and the minimum was 7.76 psig.

4.2.6 Compliance of the VAG 110-007 with MIL-V-9370D

The VAG 110-007 valve was evaluated between 2-1/2 G and 8-1/2 G (the linear region) for compliance with Military Specifications (Mil. Spec.) MIL-V-9370D [available through the Aeronautical Standards Groups (ASG), 8719 Colesville Rd., Silver Spring, Md. 20910]. Data graphically representing the valve's response are recorded in Appendix C (pp. 305-496). In Table 2 are shown the results of the comparisons.

It should be noted that the 007 was not originally designed to comply with MIL-V-9370D. However, static testing of the same serial number indicated the actual response complies with that Mil. Spec.

The valve's performance not only is within the requirements of MIL-V-9370D for G-onset rates up to 1 G/sec, with a source pressure of 80 psig or more, but also is acceptable for angles up to 10°. For angles $\phi \leq 10^\circ$, the valve performs according to the relation: $P_\phi = P_0 \cos \phi$. At 15°, the valve's response becomes a strong function of internal friction, as well as angle, and is no longer able to maintain a linear response.

TABLE 2. COMPLIANCE OF THE VAG 110-007 ANTI-G VALVE WITH MIL-V-9370D

G Onset	Source Pressure (psig)		
	20	80	170
0.1	OK	OK	OK
0.5	Slightly out at 8 G	OK	OK
1.0	OK	OK	OK
1.5	Out at 8 G	X	X
1 at 10°		Slightly low at all G	
1 at 15°		X	

X = the valve response was out of the Mil. Spec requirements over 50% of the study range, and by a significant amount.

4.2.7 Sigma Analysis of the VAG 110-007

Using the sigma evaluation techniques (of Vol. I, section 3.9), the following quantities have been calculated for the VAG 110-007 anti-G valve:

(1) $\bar{\sigma}_p(V_t)$ = the deviation in the valve data due to pressure dead band.

(2) $\bar{\sigma}_g(\frac{dG}{dt}, \phi_z, V_s, P_s, V_t)$ = the net deviation in the valve data.

$\bar{\sigma}_g$ is a function of onset rate, angle, source pressure, suit size, and valve type.

(3) $\bar{\bar{\sigma}}_g{}^2$ = the average variance in the valve data as a function of a limited number of variables.

All values in Tables 3 and 4 are expressed in psi and psi^2, respectively. (For the VAG 110-007 anti-G valve, $\bar{\sigma}_p$ = 0.0283 psi. The $\bar{\sigma}_g$ values are listed in Table 3.)

TABLE 3. NET STANDARD DEVIATION OF VAG 110-007 VALVE DATA
(Values are expressed in psi)

INCREASING ACCELERATION

$\frac{dG}{dt}$ \ V_s	M_1: P_s=20	M_1: P_s=170	M_2: P_s=80	M_3: P_s=170	M_3: P_s=20
0.5	0.236158	0.159300	0.159725	0.104424	0.070149
1.0	0.130049	0.128425	0.169664	0.112929	0.131173
1.5	0.155053	0.199784	0.165905	0.318687	0.336349
$\emptyset_1$			0.207167		
$\emptyset_2$			0.224383		

DECREASING ACCELERATION

$\frac{dG}{dt}$ \ V_s	M_1: P_s=20	M_1: P_s=170	M_2: P_s=80	M_3: P_s=270	M_3: P_s=20
0.5	0.584890	0.220838	0.080539	0.107430	0.117524
1.0	0.505751	0.127596	0.125745	0.126210	0.169708
1.5	0.617839	0.132678	0.145780	0.190379	0.694558
$\emptyset_1$			0.127510		
$\emptyset_2$			0.105543		

The variable notation is defined as follows:

VARIABLES

V_t = VAG-007

P_s = 20, 80, or 170 psig

$V_s = M_1, M_2, M_3$ —

- M_1 = small suit volume = 6 liters
- M_2 = medium suit volume = 9 liters
- M_3 = large suit volume = 12 liters

$\phi_z = 0^\circ, 10^\circ$, or 15° —

- $\phi_1 = 10^\circ$, with $\frac{dG}{dt} = \pm 1$
- $\phi_2 = 15^\circ$, with $\frac{dG}{dt} = \pm 1$

$\frac{dG}{dt} = \pm 0.5, \pm 1.0$, or ± 1.5 G/sec

Pressure variance as a function of a limited number of variables, $\bar{\bar{\sigma}}^2(\frac{dG}{dt})$ and $\bar{\bar{\sigma}}^2(V_s, P_s, S)$, is presented in Table 4. The values calculated provide a simple comparison of the variance in the valve data as a function of an isolated variable.

TABLE 4. PRESSURE VARIANCE OF VAG 110-007 VALVE DATA
(Values are expressed in psi^2)

$\bar{\bar{\sigma}}_g^2$ (0.5) = 0.0245	$\bar{\bar{\sigma}}_g^2$ (-0.5) = 0.0844
$\bar{\bar{\sigma}}_g^2$ (1.0) = 0.0184	$\bar{\bar{\sigma}}_g^2$ (-1.0) = 0.0665
$\bar{\bar{\sigma}}_g^2$ (1.5) = 0.0612	$\bar{\bar{\sigma}}_g^2$ (-1.5) = 0.1822
$\bar{\bar{\sigma}}_g^2$ (M_1, 20, +) = 0.0322	$\bar{\bar{\sigma}}_g^2$ (M^1, 20, -) = 0.3265
$\bar{\bar{\sigma}}_g^2$ (M_1, 170, +) = 0.0273	$\bar{\bar{\sigma}}_g^2$ (M^1, 170, -) = 0.0276
$\bar{\bar{\sigma}}_g^2$ (M_2, 80, +) = 0.0273	$\bar{\bar{\sigma}}_g^2$ (M_2, 80, -) = 0.0145
$\bar{\bar{\sigma}}_g^2$ (M_3, 170, +) = 0.0417	$\bar{\bar{\sigma}}_g^2$ (M_3, 170, -) = 0.0116
$\bar{\bar{\sigma}}_g^2$ (M_3, 20, +) = 0.0451	$\bar{\bar{\sigma}}_g^2$ (M_3, 20, -) = 0.1750

Several conclusions may be drawn from the data in Tables 3 and 4:

(1) The VAG 110-007 is NOT a "tight" valve, especially at low source pressures. Here, $\bar{\sigma}_g$ = 0.5 psig translates into a 6σ of 3 psig. Several σ_g's are in excess of 0.5 psig with a 20-psig source pressure and negative onset rates.

(2) With the exception of a 20-psig source pressure, the valve's sensitivity is fairly constant over all onset rates, suit sizes, and the higher source pressures.

4.2.8 Response Hysteresis of the VAG 110-007 Valve

Hysteresis is a classic measurement of the quality of regulation in any system. In the case of anti-G valves, hysteresis is determined by subtracting the pressure at a point in G during a decreasing acceleration profile from the pressure at the same G value in an increasing profile. (The data reported here were derived from Appendix C, pp. 305-496.)

The hysteresis of the 007 varied as a function of all variables tested. The onset rate had the greatest effect, as might be expected--while the suit volume had the least effect, which was not expected. The majority of the hysteresis that was measured occurred below 5 G, with consistently large hysteresis values between 1 G and 2.5 G at all onset rates.

Hysteresis from Phase III data (where the onset rate was approximately 0.01 G/sec) averaged less than 0.1 psig--essentially a measure of the steady-state response of the 007. As the onset rate increased, the hysteresis increased proportionally, yielding average values for all conditions and experiments of approximately 0.3 psig for 0.1 G/sec onset, 0.7 psig for 0.5 G/sec, 1.1 psig for 1 G/sec, and 1.63 psig for 1.5 G/sec onset rate.

Variations in hysteresis with respect to the suit volume were not as large as expected. The average value for all conditions and experiments at minimum volume was 1.08 psig, at mid-volume was 1.1 psig, and at maximum volume was 1.25 psig.

The angle of alinement of the valve with respect to the G vector had a larger than expected effect, yielding 51% more hysteresis than expected at 10° and 59% more than expected at 15°. This finding is a strong indication of the frictional effects in operation when the valve is inclined to the G vector.

The real surprise in 007 hysteresis was the variation with respect to source pressure. It might be expected that hysteresis would be inversely proportional to the flow capacity of the valve, whereas almost the exact opposite was true. The increase in hysteresis was very nearly a linear, direct proportion to the source pressure! For a source pressure of 20 psig, the average hysteresis for all conditions and experiments was 0.9 psig; for 80 psig, an average of 1.1 psig hysteresis; and, for 170 psig, an average of 1.43 psig. No explanation for this phenomenon was developed.

4.2.9 ACM Response of the VAG 110-007 Valve

The best overall comparative measurement of valve performance was derived from the SACM test. These tests were designed to simulate assumed best, worst, and median case conditions in an aircraft (i.e., maximum source pressure with minimum suit volume, minimum source pressure with maximum suit volume, and median source pressure with median suit volume). In addition, one set of SACM's was run at the median angle tested. The best measure of error from these tests came from the difference in pressure between the actual suit pressure results and the ideal suit pressure (refer to section 3). Of the two curves of this type, the more valuable was that plotted with respect to the integral of G with respect to t. By using this value as the abscissa, the area under the curve was weighted in direct proportion to the instantaneous magnitude of G stimulus. The integral of the differential pressure values on this curve is a relative measure of the suit pressure error during the run.

It must be emphasized that this value is <u>not</u> an absolute measure of error, but a relative measure. When scales are compatible, however, this integral provides a direct comparison of the magnitude of errors between runs and between valves. In the case of the 007, the 20-psi source pressure (i.e.. worst case) SACM's yielded a value of 93.95 and an absolute value of 120.95. These values indicate that 89% of the error resulted from the actual pressure being less than the ideal pressure. The 80-psig data yielded values of -5.25 and 84.25, thus indicating that the error was almost evenly distributed and that a small majority was caused by <u>excess</u> pressure. The runs at an angle of 10° actually had a small reduction in total error, yielding 22.51 and 83.41, indicating the angle compensated for the normal over-pressure response of the VAG using 80-psig source pressure. The best case ACM (i.e., source pressure equal to 170 psig; suit volume equal to 6 liters), which yielded an integral value of 21.15 and an absolute integral value of 60.95, yielded the best response data for the ACM tests.

4.3 Description of the ALAR 8400A Anti-G Valve

The ALAR 8400A Anti-G valve (designed and produced by ALAR Products, Inc., Macedonia, Ohio) uses a mass spring system for sensing acceleration and regulating anti-G suit pressure. Source pressure, ranging from 30 to 300 psig, is connected to the inlet fitting on the left side of the valve. As acceleration force (G_Z) is encountered, the mass at the top of the valve is forced down against the spring and bears against a diaphragm regulator assembly and a valve stem, thus opening a flow path to the suit outlet at the right of the valve. As suit pressure builds up in the suit, back pressure against the diaphragm reduces flow until the G_Z force and the suit pressure are balanced, at which time the valve is closed. As G_Z force is reduced, the spring moves the mass assembly and diaphragm upward, thus opening the exhaust valve and relieving the suit pressure until G_Z force and pressure are again matched. When the valve is returned to a 1 G_Z condition, the valve vents the suit back to ambient pressure.

The ALAR 8400A is designed to actuate (i.e., to begin to apply suit pressure) between 1.5 G_Z and 2.0 G_Z. The design requires that the suit be pressurized to between 0.1 psig and 1.2 psig at 2 G_Z, and to stay within a linear pressure band through 8.7 - 11.0 psig at 10 G_Z.

This anti-G valve is fitted with a spring-loaded relief valve with sufficient flow capacity to limit the suit pressure to 11 psig with 300-psig source pressure. The relief valve is designed to open between 8.7 psig and 11.0 psig.

The ALAR 8400A has an exposed button at the top of the valve assembly which allows the G-sensing mass to be depressed manually and provides a functional test feature.

4.3.1 Test Summary of the ALAR Valve

The ALAR was tested using the five-phase protocol. The data resulting from these tests are contained in Appendix D (Phase I data, on pp. 1-8; Phase II, on pp. 9-23; Phase III, on pp. 24-303; Phase IV, on pp. 304-311; and Phase V, on pp. 312-494).

The ALAR design minimum and maximum source pressures--30 psig and 300 psig, respectively--were the determining factors for setting the span of pressures used during testing. The median source pressure used was 125 psig. Suit volumes of 6 liters (minimum), 9 liters (median), and 12 liters (maximum) were used in Phase V testing; and the median volume was used for Phases II, III, and IV. The "off axis" tests were run using a median angle of 10° and a maximum of 20°.

4.3.2 Open-Flow Capacity of the ALAR Valve

The results of Phase I open-flow tests of the ALAR are available in Appendix D (pp. 1-8). These open-flow tests were conducted with a normal length of hose, attached downstream from the flow meter, and terminated by female connectors matching those used for CSU series Air Force anti-G suits. Three source pressures were used, including the design minimum of 30 psig, the design maximum of 300 psig, and a median pressure selected at 125 psig.

Using a source pressure of 30 psig, the curve exhibited a relatively linear flow increase at lower G levels (refer to Appendix D, pp. 1-2). Flow began at approximately 2.1 G and increased smoothly to 7.0 SCFM at 3.25 G. The flow then increased in a relatively linear fashion to 13.75 SCFM at 6.5 G. This flow level essentially was maintained for the remainder of the test range. The minimum and maximum (ΔF) values (recorded in Appendix D, p. 2) suggest extremely large run-to-run variations in the data. The maximum ΔF recorded, which was 5.16 SCFM at 3 G, averaged approximately 2.2 SCFM.

The flow curve resulting from the 125-psig tests exhibited the same small "hump" in flow at 3.25 G. Flow started at approximately 1.75 G and increased to 8.2 SCFM at 3.25 G. Flow increased in a relatively linear fashion to approximately 14.4 SCFM at 7.5 G. The output then dipped slightly to 14.0 SCFM at 10.0 G. A review of the ΔF values (shown in Appendix D, on p. 5) shows a significant improvement in the repeatability of the data. The maximum ΔF recorded was 2.32 SCFM at 3 G, and an average ΔF is approximately 1.4 SCFM.

The 300-psig source pressure data again exhibits the 3-G peak characteristics found in the 30-psig and 125-psig source pressure data. Flow began at approximately 1.8 G and increased to 7.9 SCFM at 3.25 G. The flow rate then increased linearly to 14.8 SCFM at 7.25 G, and essentially held that value through the remainder of the tests. The ΔF values ranged from a maximum of 1.85 SCFM at 7.0 G to a minimum of 0.38 SCFM at 3.25 G, averaging 0.85 SCFM.

4.3.3 Pressure Hysteresis Tests of the ALAR Valve

These tests were originally designed to detect the output pressure sensitivity (a feedback parameter) of the valves (i.e., a measure of the ability of a valve to detect changes in the suit pressure under steady G conditions). Pressure leaks were installed in the valve output line and extensive experimentation was conducted on several valves using various leak rates and G application techniques. Two complete sets of data (i.e., the 007 and the ALAR) were processed through computer analysis to verify the team's visual examination of the records. These tests were deleted from the protocol in later valve tests.

The results of the ALAR pressure hysteresis testing are available in Appendix D (pp. 9-23). A fixed orifice leak was installed in the suit pressurization hose, and resulted in leak rates of approximately 0.5 SCFM at 10 G and 0.12 SCFM at 2.5 G. The data indicate a general decrease in 6σ as the source pressure rises. With the exception of a hint of instability when the valve is operating at an angle to the G vector, it is suggested that any dead band in the output pressure sensitivity of the ALAR valve is masked by other data sources and/or is below the sensitivity of the instrumentation available to measure it.

4.3.4 Phase III Tests of the ALAR Valve

The results of Phase III testing of the ALAR valve are contained in Appendix D (pp. 24-303). Phase III of the five-phase protocol was principally interested in steady-state, dead-band, and hysteresis characteristics under a variety of conditions. After the data of two anti-G valves had been reviewed, it was determined that no significant information was gained over that available from Phase IV tests. Phase III data had the additional disadvantage of being collected piecemeal, resulting in a number of data-handling problems in the computer. The significant information which has been gleaned from ALAR Phase III tests was incorporated into the ALAR Phases IV and V data.

4.3.5 P-G Profile End Points of the ALAR Valve

The end points of the pressure/acceleration (P-G) profile define the useful range of acceleration over which the valve may be used. As in the case of the VAG 110-007, the low-pressure end of the P-G profile is defined as the "cut-in" point (i.e., that value of G at which the valve starts to apply pressure to the suit). The high-pressure end is defined by the relief valve actuation. It should be understood that the function of the relief valve is to protect the subject in case of valve failure, and that it is not normally operational.

The ALAR cut-in pressure varied between 1.87 G and 2.25 G during these tests, with the majority of values occurring at approximately 2 G. As might be expected, no change occurred in cut-in point with respect to the volume of the suit being inflated. A definable difference was noted in cut-in point with respect to the onset rate of the test. Using 0.5 G/sec and 1.0 G/sec onset rates, pressure was applied at averages of 2.07 and 2.02 G, respectively. The average G for pressurization during 1.5 G/sec onset rate tests was 2.15 G. There was no definable relationship between source pressure and the valve cut-in point. As already noted, the ALAR is designed to cut in between 1.5 G and 2 G. The ALAR valve initiated suit pressurization at stimuli above 2 G in approximately half of the tests conducted in this phase.

A review of the ALAR design suggests that no change in relief valve operation is normally expected with respect to source pressure, suit volume, or onset rate. However, the relief valve opening and closing pressures did show an increase proportional to the onset rate of the test (i.e., almost 0.8 psig higher at 1.5 G/sec than at 0.05 G/sec. As might be expected, under identical conditions the relief valve closed an average of 0.53 G lower than the opening point. A significant dispersion of relief valve operating pressures was also observed. The maximum three-run average of operating pressures was 9.65 psig, and the minimum was 8.23 psig.

A few cases were observed where the relief valve closed at a higher G than it opened on the immediately preceding increasing acceleration run; and this may be explained by the procedures used to effect the tests. Ascending and descending G data were taken sequentially with significant elapsed time between runs. During this separating period, the valve was subjected to stimulus of 10 G or greater, and the relief valve was venting freely. Occasionally, the suit pressure, under relief valve control, would drop below the pressure at which the valve opened. As a result, when the descending run began, the closing pressure was reached at a G level higher than that for the cracking pressure.

4.3.6 Compliance of the ALAR with MIL-V-9370D

The ALAR valve was evaluated between 2-1/2 G and 8-1/2 G (the linear region) for compliance with MIL-V-9370D. Data graphically representing the valve's response are recorded in Appendix D (pp. 304-494). Contained in Table 5 are the results of the comparisons.

TABLE 5. COMPLIANCE OF THE ALAR ANTI-G VALVE WITH MIL-V-9370D

G Onset	Source Pressure (psig)		
	30	125	300
0.1	Out at low G	Out at low G	Out at low G
0.5	Out at low G	Out at low G	Out at low G
1.0	Out at low G	X	X
1.5	X	X	X
1.0 at 10°		X	
1.0 at 15°		X	

X = the valve response was out of the Mil. Spec. requirements over 50% of the study range, and by a significant amount.

The valve's performance did not meet the requirements of MIL-V-9370D. Basically, with the exception of the 2- to 4-G range, the valve performed adequately for low G-onset rates. The ALAR valve followed the lower limit of MIL-V-9370D at slow G-onset rates. The ALAR valve is subject to a slight "drooping" effect between 2 G and 4 G prior to entering a linear region with respect to G. This drooping is accentuated with increasing G onset.

4.3.7 Sigma Analysis of the ALAR Valve

Using the sigma evaluation techniques (of Vol. I, section 3.9) the following quantities have been calculated for the ALAR anti-G valve:

(1) $\bar{\sigma}_p(V_t)$ = the deviation in the valve data due to pressure dead band.

(2) $\bar{\sigma}_g(\frac{dG}{dt}, \emptyset_z, V_s, P_s, V_t)$ = the net deviation in the valve data.

$\bar{\sigma}_g$ is a function of onset rate, angle, source pressure, suit size, and valve type.

(3) $\bar{\bar{\sigma}}_g{}^2$ = the average variance in the valve data as a function of a limited number of variables.

All values in Tables 6 and 7 are expressed in psi and psi^2, respectively.

(For the ALAR anti-G valve, $\bar{\sigma}_p$ = 0.04711 psi. The σ_g values are listed in Table 6.)

TABLE 6. NET STANDARD DEVIATION OF THE ALAR ANTI-G VALVE DATA
(Values are expressed in psi)

INCREASING ACCELERATION

$\frac{dG}{dt}$ \ V_s	M_1 P_s=30	M_1 P_s=300	M_2 P_s=125	M_3 P_s=300	M_3 P_s=30
0.5	0.113497	0.032007	0.100466	0.017506	0.105596
1.0	0.119053	0.083040	0.114029	0.054591	0.102008
1.5	0.052730	0.046492	0.048539	0.036084	0.198357
$\emptyset_1$			0.162759		
$\emptyset_2$			0.180028		

DECREASING ACCELERATION

$\frac{dG}{dt}$ \ V_s	M_1 P_s=30	M_1 P_s=300	M_2 P_s=125	M_3 P_s=300	M_3 P_s=30
0.5	0.075175	0.041692	0.056265	0.054822	0.065547
1.0	0.084975	0.031725	0.064052	0.088863	0.049072
1.5	0.167692	0.059486	0.078911	0.062453	0.129059
$\emptyset_1$			0.096259		
$\emptyset_2$			0.094359		

The variable notation is defined as follows:

VARIABLES

V_t = ALAR

P_s = 30, 125 or 300 psig

V_s = M_1, M_2 or M_3 — { M_1 = small suit size = 6 liters; M_2 = medium suit size = 9 liters; M_3 = large suit size = 12 liters }

$\emptyset = 0^\circ, 10^\circ, 20^\circ$ — { $\emptyset_1 = 10^\circ$ with $\frac{dG}{dt} = \pm 1$; $\emptyset_2 = 20^\circ$ with $\frac{dG}{dt} = \pm 1$ }

$\frac{dG}{dt}$ = ±0.5, ±1.0, ±1.5 G/sec

Pressure variance as a function of a limited number of variables. $\bar{\bar{\sigma}}_g{}^2(\frac{dG}{dt})$ and $\bar{\bar{\sigma}}_g{}^2(V_s, P_s, S)$, is presented in Table 7. The values calculated provide a simple comparison of the variance in the valve data as a function of an isolated variable.

TABLE 7. PRESSURE VARIANCE OF THE ALAR ANTI-G VALVE DATA
(Values are expressed in psi^2)

$\bar{\bar{\sigma}}_g{}^2$ (0.5) = 0.0071	$\bar{\bar{\sigma}}_g{}^2$ (-0.5) = 0.0036
$\bar{\bar{\sigma}}_g{}^2$ (1.0) = 0.0095	$\bar{\bar{\sigma}}_g{}^2$ (-1.0) = 0.0045
$\bar{\bar{\sigma}}_g{}^2$ (1.5) = 0.0096	$\bar{\bar{\sigma}}_g{}^2$ (-1.5) = 0.0117
$\bar{\bar{\sigma}}_g{}^2$ (M_1, 30, +) = 0.0099	$\bar{\bar{\sigma}}_g{}^2$ (M_1, 30, -) = 0.0137
$\bar{\bar{\sigma}}_g{}^2$ (M_1, 300, +) = 0.0034	$\bar{\bar{\sigma}}_g{}^2$ (M_1, 300, -) = 0.0021
$\bar{\bar{\sigma}}_g{}^2$ (M_2, 125, +) = 0.0085	$\bar{\bar{\sigma}}_g{}^2$ (M_2, 125, -) = 0.0045
$\bar{\bar{\sigma}}_g{}^2$ (M_3, 300, +) = 0.0015	$\bar{\bar{\sigma}}_g{}^2$ (M_3, 300, -) = 0.0049
$\bar{\bar{\sigma}}_g{}^2$ (M_3, 30, +) = 0.0203	$\bar{\bar{\sigma}}_g{}^2$ (M_3, 30, -) = 0.0078

Several conclusions may be drawn from the data in Tables 6 and 7:

(1) The ALAR valve is "tighter" with higher source pressures, no angle, and decreasing onset rates.

(2) The ALAR valve showed mixed results with the variance in suit sizes and onset rate.

4.3.8 Response Hysteresis of the ALAR Valve

Hysteresis is a classic measurement of the quality of regulation in any system. In the case of anti-G valves, hysteresis is determined by subtracting the pressure at a point in G during a decreasing acceleration profile from the pressure at the same G value in an increasing profile. (The data reported here were derived from Appendix D, pp. 304-494.)

The hysteresis of the ALAR was affected by all variables tested. The onset rate had the greatest effect, as might be expected, while the suit volume and source pressure showed marked effects only in the extreme cases. Consistently large hysteresis values between 1 G and 2.5 G at all onset rates were characteristic, with the peak values progressing toward the 5-6 G region as the total hysteresis error increased.

Hysteresis from Phase III data (where the onset rate was approximately 0.01 G/sec) averaged less than 0.1 psig--essentially a measure of the steady-state response of the ALAR. As the onset rate increased, the hysteresis increased proportionally, yielding average values for all conditions and experiments of approximately 0.3 psig for 0.1 G/sec onset rate, 0.8 psig for 0.5 G/sec, 1.4 psig for 1 G/sec, and 2 psig for 1.5 G/sec.

Variations in hysteresis with respect to the suit volume were not as large as expected. The average values for all conditions and experiments at minimum and median volumes were 1.24 psig and 1.25 psig, respectively, and, at maximum volume, 1.61 psig.

The angle of alinement of the valve with respect to the G vector had a larger than expected effect, yielding almost twice as much hysteresis (approximately 1.5 psig) as expected.

Hysteresis variations with respect to source pressure are expected to be proportional to the flow capacity (i.e., source pressure) of the valve. In the case of the ALAR, the only marked effect of source pressure was in minimum source pressure where the valve was essentially starving. For a source pressure of 30 psig, the average hysteresis for all conditions and experiments was 1.59 psig; 125-psig and 300-psig source pressures yielded averages of 1.25 psig and 1.26 psig, respectively.

4.3.9 ACM Response of the ALAR Valve

The best overall comparative measurement of valve performance was derived from the SACM test. These tests were designed to simulate assumed best, worst, and median case conditions in an aircraft (i.e., maximum source pressure with minimum suit volume, minimum source pressure with maximum suit volume, and median source pressure with median suit volume). In addition, one set of SACM's was run at the median angle tested. The best measure of error from these tests came from the differential between the actual suit pressure results and the ideal suit pressure (refer to section 3 of this volume). Of the two curves of this type, the more valuable was that plotted with respect to the integral of G with respect to t. By using this value as the abscissa, the area under the curve was weighted in direct proportion to the instantaneous magnitude of G stimulus. The integral of the differential pressure values on this curve is a relative measure of the suit-pressure error during the run.

It must be emphasized that this value is not an absolute measure of error, but a relative measure. When scales are compatible, however, this integral provides a direct comparison of the magnitude of errors between runs and between valves. In the case of the ALAR, the 30-psi source pressure (i.e., worst case) SACM's yielded a value of -82.3 and an absolute value of 168.3. These values indicate that 74% of the error resulted from the actual pressure being greater than the ideal pressure. The 125-psig data yielded values of -102.45 and 162.25. The runs at an angle of 10° actually had a small reduction in total error, yielding -50.65 and 152.65, indicating that the angle compensated for the normal over-pressure response of the ALAR using 125-psig source pressure. The best case ACM (i.e., source pressure equal to 300 psig, suit pressure equal to 6 liters), which yielded integral values of -107.10 and absolute integral values of 171.3, yielded the worst response data for the ACM tests. However, these differences in error magnitudes do not indicate significant changes in performance quality.

4.4 Performance of the Bendix FR139A2 Anti-G Valve

The FR139A2 anti-G valve (designed and produced by the Bendix Corporation, Instrument and Life Support Division, Davenport, Iowa) is one of four valves (FR139A1, and -A2; FR140A1, and -A2) which are identical except that: the FR139 type has a straight outlet fitting, and the FR140 has a curved outlet fitting; the A1 versions have a metal orifice, and the A2 versions have a jeweled orifice.

The FR139A2 uses a mass spring system for sensing acceleration (G) force and regulation suit pressure. As G forces alined with the vertical axis of the valve (G_Z) are encountered, the mass is forced down, compressing a spring and closing a valve on the top side of a diaphragm. Pressure is constantly being bled to both sides of this diaphragm through a small orifice so that, when the valve on top of the diaphragm is closed, pressure builds up on top of the diaphragm, forcing it down, closing the dump valve, and tipping the pilot valve open. When the pilot valve opens, pressure above the main valve diaphragm drops and the main valve opens, porting pressure to the suit outlet. When acceleration (G_Z) is reduced, the spring acting on the mass opens the valve above the diaphragm and the pressure above the diaphragm drops, raising the diaphragm and opening the dump valve which vents suit pressure.

The FR139A2 is designed to actuate (i.e., to begin to apply suit pressure) at a nominal rate of 2.0 G_Z. The suit is pressurized at a nominal rate of 1.5 psig/G. (The actual suit pressure varies from 0 to 1.2 psig at 2 G_Z, and 8.7 to 10.4 psig at 8 G_Z.)

Because the FR139A2 uses differential pressure across a diaphragm for pressure regulation, there is a constant pressure bleed through the valve when the G_Z and suit pressure inputs are balanced or when less than 2.0 G_Z is applied. This bleed rate varies with source pressure. At a source pressure of 70 psig, the bleed rate would be between 0.008 SCFM and 0.0095 SCFM.

The FR139A2 is fitted with a spring-loaded relief valve designed to have a cracking pressure between 9 psig and 11 psig. This relief valve has sufficient flow to limit suit pressure to 11 psig with a source pressure of 55 psig.

The FR139A2 is designed to operate with a maximum supply pressure of 120 psig, and has been shown to operate properly with supply pressures as low as 40 psig. It is fitted with a button at the top of the valve which allows the mass to be depressed manually and provides a test feature.

The physical dimensions of the valve are 2.2 in. x 1.88 in. (5.59 cm x 4.78 cm). The FR139A2 weighs approximately 0.5 lb (1.1 kg).

4.4.1 Test Summary of the Bendix Valve

The Bendix anti-G valve was tested using the three-phase protocol. The data resulting from these tests are contained in Appendix E (Phase I data, pp. 1-9; Phase II(IV), pp. 10-49; and Phase III(V), pp. 50-232).

The Bendix design minimum and maximum source pressure--40 psig and 120 psig, respectively--were the determining factors for setting the span of pressures during testing. Median source pressure was 70 psig. Suit volumes of 6 liters (minimum), 9 liters (median), and 12 liters (maximum) were used in Phase III(V) testing, while the median volume was used for Phase II. A cursory review of the design suggests that this valve would be extremely sensitive to alinement to the G vector; however, the tests conducted did not support this conclusion. As a result, maximum "off axis" tests were run using 20°, and median "off axis" tests used 10°.

4.4.2 Open-Flow Capacity of the Bendix Valve

The results of Phase I open-flow tests of the Bendix are available in Appendix E (pp. 1-9). These open-flow tests were conducted with a normal length of hose, attached downstream from the flow meter and terminated by female connectors matching those used for CSU series Air Force anti-G suits. The tests were conducted using three source pressures including the design minimum of 40 psig, the design maximum of 120 psig, and a median pressure selected at 70 psig.

Using a 40-psig source pressure, the data (shown in Appendix E, pp. 1-3) suggest that the valve is starving for air. Flow was first recorded at 2.0 G with 0.8 SCFM, then rose in a reasonably linear fashion to 4.4 SCFM at 4.25 G. Beyond this point, the flow dropped to 3.7 SCFM at 5.4 G, and remained below 4 SCFM for the remainder of the tests. The difference in minimum and maximum (ΔF) values recorded is shown in Appendix E (p. 3). These values generally suggest a reasonably tight set of data, the 2.75- to 4-G range being an exception. The maximum of ΔF of 3.3 SCFM occurred at 3.25 G, with an average of 0.64 SCFM.

Most of the flow curve resulting from the 70-psig tests was reasonably linear with respect to G. Flow started at approximately 2.05 G and increased in a relatively linear fashion to approximately 6.1 SCFM at 7.5 G. The output then dipped slightly and remained constant for the remainder of the test. A review of the ΔF values shown in Appendix E (p. 5) suggests an unusually consistent data set. The maximum ΔF recorded was 0.52 SCFM at 2.5 G, and an average of approximately 0.45 SCFM.

The 120-psig and the 70-psig source-pressure data exhibit similar characteristics. Flow began at approximately 2.05 G, increased linearly to 7.0 SCFM at 8.2 G, then drooped to 6.96 SCFM at 9.9 G. The ΔF values ranged from a maximum of 0.53 SCFM at 2.5 G to a minimum of 0.38 SCFM at 3.5 G, averaging 0.44 SCFM.

4.4.3 P-G Profile End Points of the Bendix Valve

The end points of the P-G profile define the useful range of acceleration over which the valve may be used. The low-pressure end of the P-G profile is defined as the "cut-in" point (i.e., that value of G at which the valve starts to apply pressure to the suit). The high-pressure end is defined by the relief valve actuation. It should be understood that the relief valve, the function of which is to protect the subject in case of valve failure, is not normally operational.

The Bendix cut-in point varied between 1.87 G and 2.37 G during these tests, with the majority of values occurring at slightly over 2 G. As might be expected, no reliable relationship was found between cut-in point and the volume of the suit being inflated. Also, no definable relationship existed between source pressure and cut-in point. There was a definable difference in cut-in point, with respect to the onset rate of the test. Using 0.5 G/sec onset rates, pressure was applied at 1.95 G--compared to an average of 2.1 G for 1 G/sec, and 2.30 G for 1.5 G/sec. As already noted, the Bendix was designed to cut in at 2 G; and 1.9 G is probably a reasonable deviation. However, the 2.3 G point suggests that the valve was not capable of filling the dead space in the anti-G suit at high onset rates.

A review of the Bendix design suggests that no change in relief valve operation is normally expected with respect to source pressure, suit volume, or onset rate. Because of the valve's limited flow capability, the suit pressure never reached the relief valve cracking pressure at 1 G/sec or 1.5 G/sec onset rates. At the 0.5 G/sec onset rate, the relationship was almost random between the cracking pressure and the acceleratior at which that pressure was reached. Using only the 0.1 G/sec onset-rate data, it appears that the relief valve opened at approximatley 7.33 psig (6.75 G) for the minimum source pressure, and at 9.6 psig (8 G) for the 80-psig and 120-psig runs. No explanation was derived for any variation related to source pressure.

4.4.4 Compliance of the Bendix Valve with MIL-V-9370D

The Bendix valve was evaluated between 2-1/2 G and 8-1/2 G (the linear region) for compliance with MIL-V-9370D. Data graphically representing the valve's response are recorded in Appendix E (pp. 10-22). Contained in Table 8 are the results of the comparisons.

TABLE 8. COMPLIANCE OF THE BENDIX ANTI-G VALVE WITH MIL-V-9370D

G Onset	Source Pressure (psig)		
	40	170	120
0.1	X	Out at low G	Out at low G
0.5	X	X	X
1.0	X	X	X
1.5	X	X	X
1 at 10°		X	
1 at 20°		X	

X = the valve response was out of the Mil. Spec. requirements over 50% of the study range, and by a significant amount.

The valve's performance did not meet the requirements of MIL-V-9370D. The valve's best performance was a minimal onset rate with maximum source pressure, where it was only out at low G. The Bendix valve is subject to a pronounced drooping effect over the entire G scale. This effect increases with increasing G onset. As a result, the linear region of the Bendix is distinctly nonlinear. The pressure profile more closely approximates:

$$P = k_1/(k_2 - G)$$

where $k_2 \geq 10$.

4.4.5 Sigma Analysis of the Bendix Valve

Using the sigma evaluation techniques (of Vol. I, section 3.9), the following quantities have been calculated for the Bendix anti-G valve:

(1) $\bar{\sigma}_p(V_t)$ = the deviation in the valve data due to pressure dead band.

(2) $\bar{\sigma}_g(\frac{dG}{dt}, \emptyset_z, V_s, P_s, V_t)$ = the net deviation in the valve data.

$\bar{\sigma}_g$ is a function of onset rate, angle, source pressure, suit size, and valve type.

(3) $\bar{\bar{\sigma}}_g^{\,2}$= the average variance in the valve data as a function of a limited number of variables.

All values in Tables 9 and 10 are expressed in psi and psi^2, respectively. (For the Bendix anti-G valve, $\bar{\sigma}_p$ = 0.072498 psi. The $\bar{\sigma}_g$ values are listed in Table 9.)

Several conclusions may be drawn from the data in Tables 9 and 10:

(1) The Bendix is NOT a "tight" valve. Values of $\bar{\sigma}_g$ approaching 0.5 psig are found at all source pressures. Values of $\bar{\sigma}_g$ in excess of 0.5 psig were obtained from the minimum source pressure and "off-axis" (angle) alinement tests.

(2) With the exception of a 40-psig source pressure, the valve's sensitivity is fairly constant over decreasing onset rates, suit sizes, and the higher source pressures. The sensitivity at increasing onset rates (as shown in Table 10) is not conclusive except to evidence <u>extreme</u> run-to-run variation in the output.

TABLE 9. NET STANDARD DEVIATION OF THE BENDIX ANTI-G VALVE DATA
(Values are expressed in psi)

INCREASING ACCELERATION

$\frac{dG}{dt}$ \ V_s	M_1 P_s=40	M_1 P_s=120	M_2 P_s=70	M_3 P_s=120	M_3 P_s=40
0.5	0.104736	0.167475	0.246957	0.199423	0.810274
1.0	0.312175	0.196183	0.465700	0.280682	0.982130
1.5	0.282723	0.201710	0.155461	0.420970	0.138081
$\emptyset_1$			0.647620		
$\emptyset_2$			0.506664		

DECREASING ACCELERATION

$\frac{dG}{dt}$ \ V_s	M_1 P_s=40	M_1 P_s=120	M_2 P_s=70	M_3 P_s=120	M_3 P_s=40
0.5	0.102932	0.099250	0.145979	0.079150	0.144622
1.0	0.164347	0.166113	0.180350	0.176566	0.164948
1.5	0.141552	0.135863	0.137981	0.112316	0.174344
$\emptyset_1$			0.139093		
$\emptyset_2$			0.148928		

The variable notation is defined as follows:

VARIABLES

V_t = Bendix

P_s = 40, 70, or 120 psig

V_s = M_1, M_2, M_3 —

- M_1 = small suit volume = 6 liters
- M_2 = medium suit volume = 9 liters
- M_3 = large suit volume = 12 liters

VARIABLES (Cont'd.)

$\emptyset_z = 0^\circ, 10^\circ, \text{ or } 20^\circ$ —— $\begin{cases} \emptyset_1 = 10^\circ, \text{ with } \frac{dG}{dt} = \pm 1 \\ \emptyset_2 = 20^\circ, \text{ with } \frac{dG}{dt} = \pm 1 \end{cases}$

$\frac{dG}{dt} = \pm 0.5, \pm 1.0, \text{ or } \pm 1.5$ G/sec

Pressure variance as a function of a limited number of variables, $\bar{\bar{\sigma}}^2(\frac{dG}{dt})$ and $\bar{\bar{\sigma}}^2(V_s, P_s, S)$, is presented in Table 10. The values calculated provide a simple comparison of the variance in the valve data as a function of an isolated variable.

TABLE 10. PRESSURE VARIANCE OF THE BENDIX ANTI-G VALVE DATA
(Values expressed in psi^2)

$\bar{\bar{\sigma}}_g^2$ (0.5) = 0.1593	$\bar{\bar{\sigma}}_g^2$ (-0.5) = 0.0138
$\bar{\bar{\sigma}}_g^2$ (1.0) = 0.2792	$\bar{\bar{\sigma}}_g^2$ (-1.0) = 0.0294
$\bar{\bar{\sigma}}_g^2$ (1.5) = 0.0682	$\bar{\bar{\sigma}}_g^2$ (-1.5) = 0.0201
$\bar{\bar{\sigma}}_g^2$ (M_1, 40, +) = 0.0628	$\bar{\bar{\sigma}}_g^2$ (M_1, 40, -) = 0.0192
$\bar{\bar{\sigma}}_g^2$ (M_1, 170, +) = 0.0273	$\bar{\bar{\sigma}}_g^2$ (M_1, 120, -) = 0.0186
$\bar{\bar{\sigma}}_g^2$ (M_2, 70, +) = 0.1007	$\bar{\bar{\sigma}}_g^2$ (M_2, 70, -) = 0.0243
$\bar{\bar{\sigma}}_g^2$ (M_3, 120, +) = 0.0986	$\bar{\bar{\sigma}}_g^2$ (M_3, 120, -) = 0.0167
$\bar{\bar{\sigma}}_g^2$ (M_3, 40, +) = 0.5467	$\bar{\bar{\sigma}}_g^2$ (M_3, 40, -) = 0.0262

4.4.6 Response Hysteresis of the Bendix Valve

Hysteresis is a classic measurement of the quality of regulation in any system. In the case of anti-G valves, hysteresis is determined by subtracting the pressure at a point in G during a decreasing acceleration profile from the pressure at the same G value in an increasing profile. (The data reported here were derived from Appendix E, pp. 17-220.)

The hysteresis of the Bendix was massive. The onset rate had the greatest effect, as might be expected, while the suit volume had questionable effect, which was not expected. The hysteresis that was measured tended to center between 4 G and 5 G.

Hysteresis from Phase II(IV) data (where the onset rate was approximately 0.1 G/sec) was respectable, averaging less than 0.28 psig--essentially a measure of the steady-state response of the Bendix. As the onset rate increased, the hysteresis increased rapidly, yielding average values for all conditions and experiments of approximately 2.16 psig for 0.5 G/sec onset rate, 3.84 psig for 1 G/sec, and 4.86 psig for 1.5 G/sec.

Variations in hysteresis with respect to the suit volume were mixed. The average value for all conditions and experiments at minimum volume was 3.25 psig; at median volume, 4.2 psig; and at maximum volume, 3.75 psig.

The angle of alinement of the valve with respect to the G vector had a slightly less than expected effect. However, when one considers the magnitude of the average hysteresis, the differences at angles are insignificant.

The Bendix hysteresis variation with respect to source pressure was less than expected, and it did vary proportionally to the flow capacity of the valve. For a source pressure of 40 psig, the average hysteresis for all conditions and experiments was 3.67 psig; for 70-psig source pressure, 3.23 psig; and for 120 psig, 3.10 psig.

4.4.7 ACM Response of the Bendix Valve

The best overall comparative measurement of valve performance was derived from the SACM test. The best measure of error from these tests came from the difference in pressure between the actual suit-pressure results and the ideal suit pressure (refer to section 3). Of the two curves of this type, the more valuable was that plotted with respect to the integral of G with respect to t. By using this value as the abscissa, the area under the curve was weighted in direct proportion to the instantaneous magnitude of G stimulus. The integral of the differential pressure values on this curve is a relative measure of the suit-pressure error during the run.

It must be emphasized that this value is not an absolute measure of error, but a relative measure. When scales are compatible, however, this integral provides a direct comparison of the magnitude of errors between runs and between valves. In the case of the Bendix anti-G valve, SACM errors were very large--but not as large as might have been predicted from the trapezoidal runs. The reason for the smaller than expected errors was the initial 3-G step in the SACM. This period allowed the Bendix to fill the dead space in the suit before the high-G levels occurred. The following SACM peak brought the suit pressure up with a relatively small additional volume. As a result, most of the SACM error appears as overpressure error.

The integral of SACM error for the Bendix, operating at the design nominal source pressure and a median suit volume, was -361 (i.e., approximately 69 times the error for the VAG 110-007); and the absolute error was 387 (i.e., only 4.6 times the VAG error).

4.5 Performance of the Electronic Anti-G Valve

The USAFSAM Electronic Anti-G Valve (E-valve), the result of an inhouse project, was designed and built by personnel assigned to the USAFSAM Human Centrifuge Facility. The E-valve represents an "electronics controls" approach to the design and construction of a programmable anti-G valve suitable for research use on the human centrifuge at Brooks AFB.

The E-valve offers considerable flexibility in programmable suit-inflation schedules. Suit pressure per G_Z is variable over the range 0 to 2 psi/G; and the "START LEVEL" control may be set to initiate suit inflation at any level between 1 G and 5 G. Two step functions are available. One is the "STEP PSI" which will, when a selected start level is reached, immediately inflate the suit to a preselected pressure within the range of 0 - 5 psig. The remaining step function--the "STEP DELAY"--is used to allow the valve to initiate suit inflation smoothly at the chosen start level, and to continue inflating at the rate determined by the setting of the "PSI/G" control until reaching the preselected G level chosen by the "STEP DELAY" control. At this level the suit immediately inflates to the pressure that has been preselected by the "STEP PSI" setting.

The four main systems comprising the E-valve are the G-sensing transducer, the pressure-sensing transducer, the electronics package, and the direct current motor-driven modified ALAR anti-G valve. The G-sensing transducer is the accelerometer permanently installed in the gondola, while the suit-pressure-sensing transducer is a strain-gage type Statham P23De. The electronics package was constructed inhouse and functions to provide the driving signal which controls the modified ALAR anti-G valve.

In brief, the valve functions as follows: An increase in G_Z (corresponding to acceleration in the gondola) will cause an increased output signal, from the accelerometer, which is input into the signal conditioning stage of the electronics package. When the G_Z is such that the accelerometer signal exceeds a threshold set by the "START LEVEL" control, a motor-driving signal proportional to the setting of the "PSI/G" control is produced. The driving of the valve motor actuates the modified ALAR anti-G valve and allows air to flow into the suit. As the suit pressure increases, it is sensed by the P23De transducer, thus producing a signal which is opposite in polarity to the accelerometer signal and proportional to the suit pressure. The conditioned signals of the accelerometer and the pressure transducer are summed in a circuit that produces a motor-driving signal.

When the suit pressure reaches a level such that the summation of the pressure transducer signal and the accelerometer signal equals zero, the motor-driving signal is zero. Should the G level remain steady, the steady suit pressure at that G level will be proportional to the setting of the "PSI/G" control. Other stages of electronic circuitry (such as zero crossover detectors and comparators) are used to effect the programming of the step functions; however, their complexity precludes their inclusion in this brief discussion. Electric power is afforded by power supplies mounted in the gondola.

The modified ALAR anti-G valve has had the mass spring mechanism removed and replaced by a spring-loaded plunger which is driven by a geared down DC motor. The spring loading serves to return the plunger and remove suit pressure should the motor or drive fail. The original relief valve is retained intact.

The dimensions of the electronics package are 10" wide x 14" long x 3" deep (25.4 cm x 35.6 cm x 7.6 cm); and those of the valve are 6" high x 3½" wide x 4½" deep (15.2 cm x 8.9 cm x 11.4 cm).

4.5.1 Test Summary of the E-valve

The E-valve was tested using the three-phase protocol. (The data resulting from these tests are available in Appendix F: Phase I data, pp. 1-9; Phase II(IV), pp. 10-33; and Phase III(V), pp. 34-304.)

The E-valve design minimum and maximum source pressures--30 psig and 170 psig, respectively--were the determining factors in setting the span of pressures used during testing. Median source pressure was 125 psig. Suit volumes of 6 liters (minimum), 9 liters (median), and 12 liters (maximum) were used in Phase III(V) testing; and the median volume was used for Phase II(IV). Since the E-valve was a prototype valve and used the main gondola accelerometer as one of the driving signals, it was decided that tests with some or all portions of the valve subsystems alined at an angle to the G vector would be of minimal value, and the angle tests were deleted. All test phases were run with the following control settings on the E-valve electronics package:

INFLATION RATE	750 divisions	1.5 psig/G
START LEVEL	250 divisions	2 G
STEP PSI	0 divisions	0 psig
STEP DELAY	0 divisions	0 G

Great care was taken to assure all four controls were set as accurately as possible before each set of tests. However, these settings were accomplished via the front panel dial. No measurements were made to compensate for control backlash, or internal electronic variations. In addition, the power supplies for the E-valve were set using a calibrated digital voltmeter as an independent standard.

4.5.2 Open-Flow Capacity of the E-valve

Phase I open-flow tests of the E-valve (the results of which are in Appendix F, pp. 1-9) were conducted with a normal length of hose, attached downstream from the flow meter, and terminated by female connectors matching those used for CSU series Air Force anti-G suits. The tests were conducted using three source pressures including the design minimum of 30 psig, the design maximum of 170 psig, and a median pressure selected at 125 psig.

With a source pressure of 30 psig, the curve exhibited relatively linear characteristics up to 5.5 G (Appendix F, pp. 1-3). Flow began at approximately 2 G and increased linearly to 19.3 SCFM at 5.5 G. Between 5.5 G and 10 G, the flow remained reasonably constant, with a peak of 20.8 SCFM at about 7.25 G. The difference between minimum and maximum flow values (ΔF) suggests (Appendix F, p.3) that these data are real and reasonably repeatable. The maximum ΔF recorded was 2.3 SCFM at 7.6 G, and averaged approximately 1.15 SCFM.

The flow curve resulting from the 125-psig tests exhibited very similar characteristics. Flow started at approximately 1.85 G and rose to 22.5 SCFM at 6 G. Flow then increased very slowly to approximately 26.3 SCFM at 7.75 G. The output then dipped to 24.3 SCFM at 9.8 G. A review of the ΔF values (Appendix F, p. 6) suggests a tighter data set than the 30-psig set. The maximum ΔF recorded was 1.1 SCFM at 4.9 G, and averaged approximately 0.75. The sharp increase in ΔF at the 10-G end of the curve is the result of "end off" data resulting from varying flow values recorded at the end of a data run. This rise is probably not real and should be considered a characteristic of the analysis technique, not of the E-valve.

The 170-psig source-pressure data again exhibit the same characteristics as the 30-psig and 125-psig source-pressure data. Flow began at approximately 2.0 G and increased to 21.7 SCFM at 6.25 G. This flow rate was maintained through 8.0 G, and then drooped slightly to 21.25 SCFM at 9.9 G. The ΔF values ranged from a maximum of 0.9 SCFM at 9.0 G to a minimum of 0.5 SCFM at 3.3 G, thus averaging 0.76 SCFM.

4.5.3 P-G Profile End Points of the E-valve

The end points of the P-G profile define the useful range of acceleration over which the valve may be used. The low-pressure end of the P-G profile is defined as the "cut-in" point (i.e., that value of G at which the valve starts to apply pressure to the suit). The high-pressure end is defined by the relief valve actuation. It should be understood that the relief valve, the function of which is to protect the subject in case of valve failure, is not normally operational.

The E-valve cut-in pressure varied between 1.7 G and 2.0 G during these tests, with an average value of 1.85 G. As might be expected, no definable relationship was found between cut-in points with respect to the volume of the suit being inflated, although the median volume runs consistently cut in at higher G values. There was a definable (but slight) difference in cut-in point with respect to the onset rate of the test. With 0.5 G/sec onset rates being used, pressure was applied at 1.88 G--as compared with an average of approximately 1.83 G for

1 G/sec and 1.80 G for 1.5 G/sec onset rates. Correlation between source pressure and the application of pressure to the suit is similar to the suit-volume variations.

A review of the E-valve design suggests the relief valve operation should be very similar to that of the ALAR anti-G valve tested. There was a slight proportional relationship between suit volume and the cracking pressure (i.e., 10.95 psig, 11.06 psig, and 11.20 psig average for min, mid, and max volumes respectively). On the other hand, the source pressure showed an inverse relationship (i.e., 11.39 psig, 11.06 psig, and 10.76 psig averages for min, mid, and max source pressures, respectively). In neither case did the G level associated with the cracking pressure have the same relationship with the variable. This finding suggests that these relationships may be accidents of probability. The E-valve exhibited a relatively small dispersion of relief valve operating pressures. The maximum three-run average of operating pressures was 11.59 psig, and the minimum was 10.46 psig.

4.5.4 Compliance of the E-valve with MIL-V-9370D

The E-valve was evaluated between 2-1/2 G and 8-1/2 G (the linear region) for compliance with MIL-V-9370D. Data graphically representing the valve's response are recorded in Appendix F (pp. 16-177). Contained in Table 11 are the results of the comparisons.

TABLE 11. COMPLIANCE OF THE ELECTRONIC ANTI-G VALVE WITH MIL-V-9370D

G Onset	Source Pressure (psig)		
	30	120	170
0.1	OK	OK	OK
0.5	OK	OK	OK
1.0	OK	OK	OK
1.5	Slightly out at 8 G	Slightly out at all G	Slightly out at all G

The valve's performance is within the requirements of MIL-V-9370D for G-onset rates up to 1 G/sec, with all source pressures. In terms of Mil. Spec. performance, the E-valve was one of the best valves tested on the TEHG program.

4.5.5 Sigma Analysis of the E-valve

Using the sigma evaluation techniques (Vol. I, section 3.9), the following quantities have been calculated for the electronic anti-G valve:

(1) $\bar{\sigma}_p(V_t)$ = the deviation in the valve data due to pressure dead band.

(2) $\bar{\sigma}_g(\frac{dG}{dt}, \emptyset_z, V_s, P_s, V_t)$ = the net deviation in the valve data.

$\bar{\sigma}_g$ is a function of onset rate, angle, source pressure, suit size, and valve type.

(3) $\bar{\bar{\sigma}}_g{}^2$ = the average variance in the valve data as a function of a limited number of variables.

All values in Tables 12 and 13 are expressed in psi and psi^2, respectively. (For the E-valve, $\bar{\sigma}_p$ = 0.040146 psi. The $\bar{\sigma}_g$ values are listed in Table 12.)

The data in Tables 12 and 13 suggest that the E-valve is a very "tight" valve. In the worst case, $\bar{\sigma}_g$ = 0.139196, which--in the case of a normal distribution of errors--would predict that 99% of all data would fall within 0.4 psig of the median values. Ironically, this "worst case" occurred on a set of 1.5 G/sec trapezoidal runs under "best case" conditions (i.e., maximum source pressure, minimum suit volume).

4.5.6 Response Hysteresis of the E-valve

Hysteresis is a classic measurement of the quality of regulation in any system. In the case of anti-G valves, hysteresis is determined by subtracting the pressure at a point in G during a decreasing acceleration profile from the pressure at the same G value in an increasing profile. (The data reported here were derived from Appendix F, pp. 16-177.)

The hysteresis of the E-valve varied as a function of onset rate, as might be expected, while the suit volume and source pressure had questionable effects. Most of the hysteresis that was measured occurred between 7.5 G and 8.5 G.

Hysteresis from Phase II data varied between 0.2 psig and 0.56 psig for three-run averages, and showed a strong correlation to source pressure--essentially a measure of the steady-state response of the E-valve. As the onset rate increased, the hysteresis increased proportionally, yielding average values for all conditions and experiments of approximately 0.38 psig for the 0.5 G/sec onset rate, 0.63 psig for the 1 G/sec, and 0.84 psig for the 1.5 G/sec.

At higher onset rates, the mid-suit volume, mid-source pressure runs exhibited higher hysteresis than any other case without exception. A review of the design, test protocol, and test equipment configurations failed to suggest an explanation for this phenomenon.

TABLE 12. NET STANDARD DEVIATION OF THE ELECTRONIC ANTI-G VALVE DATA (Values are expressed in psi)

INCREASING ACCELERATION

$\frac{dG}{dt}$ \ V_s	M_1		M_2	M_3	
	P_s=32	P_s=170	P_s=80	P_s=170	P_s=32
0.5	0.022694	0.107288	0.051222	0.078526	0.077623
1.0	0.061488	0.085075	0.061036	0.033862	0.054364
1.5	0.058339	0.067242	0.108519	0.131157	0.134748

DECREASING ACCELERATION

$\frac{dG}{dt}$ \ V_s	M_1		M_2	M_3	
	P_s=32	P_s=170	P_s=80	P_s=170	P_s=32
0.5	0.020989	0.042151	0.093401	0.086863	0.082412
1.0	0.096007	0.106105	0.110743	0.092514	0.114727
1.5	0.110071	0.139196	0.129453	0.125757	0.126163

The variable notation is defined as follows:

VARIABLES

V_t = Electronic

P_s = 30, 80, or 170 psig

V_s = M_1, M_2, M_3 —
- M_1 = small suit volume = 6 liters
- M_2 = medium suit volume = 9 liters
- M_3 = large suit volume = 12 liters

$\emptyset_z$ = 0

$\frac{dG}{dt}$ = ±0.5, ±1.0 or ±1.5 G/sec

Pressure variance as a function of a limited number of variables, $\bar{\bar{\sigma}}^2(\frac{dG}{dt})$ and $\bar{\bar{\sigma}}^2(V_s, P_s, S)$, is presented in Table 13. The values calculated provide a simple comparison of the variance in the valve data as a function of an isolated variable.

TABLE 13. PRESSURE VARIANCE OF THE ELECTRONIC ANTI-G VALVE DATA
(Values are expressed in psi^2)

$\bar{\bar{\sigma}}_g^2$ (0.5) = 0.0054	$\bar{\bar{\sigma}}_g^2$ (-0.5) = 0.0051
$\bar{\bar{\sigma}}_g^2$ (1.0) = 0.0038	$\bar{\bar{\sigma}}_g^2$ (-1.0) = 0.0109
$\bar{\bar{\sigma}}_g^2$ (1.5) = 0.0110	$\bar{\bar{\sigma}}_g^2$ (-1.5) = 0.0160
$\bar{\bar{\sigma}}_g^2$ (M_1, 30, +) = 0.0024	$\bar{\bar{\sigma}}_g^2$ (M_1, 32, -) = 0.0073
$\bar{\bar{\sigma}}_g^2$ (M_1, 170, +) = 0.0078	$\bar{\bar{\sigma}}_g^2$ (M_1, 170, -) = 0.0099
$\bar{\bar{\sigma}}_g^2$ (M_2, 80, +) = 0.0060	$\bar{\bar{\sigma}}_g^2$ (M_2, 80, -) = 0.0126
$\bar{\bar{\sigma}}_g^2$ (M_3, 170, +) = 0.0082	$\bar{\bar{\sigma}}_g^2$ (M_3, 170, -) = 0.0106
$\bar{\bar{\sigma}}_g^2$ (M_3, 32, +) = 0.0090	$\bar{\bar{\sigma}}_g^2$ (M_3, 32, -) = 0.0120

4.5.7 ACM Response of the E-valve

The best overall comparative measurement of valve performance was derived from the SACM test. These tests were designed to simulate assumed best case, worst case, and median case conditions in an aircraft (i.e., maximum source pressure with minimum suit volume, minimum source pressure with maximum suit volume, and median source pressure with median suit volume). The best measure of error from these tests came from the difference in pressure between the actual suit-pressure results and the ideal suit pressure (refer to section 3). Of the two curves of this type, the more valuable was that plotted with respect to the integral of G with respect to t. By using this value as the abscissa, the area under the curve was weighted in direct proportion to the instantaneous magnitude of G stimulus. The integral of the differential pressure values on this curve is a relative measure of the suit-pressure error during the run.

It must be emphasized that this value is not an absolute measure of error, but a relative measure. However, when scales are compatible, this integral provides a direct comparison of the magnitude of errors between runs and between valves. In the case of the E-valve, the 30-psi source-pressure (i.e., worst case) SACM's yielded a net value of 64.13 and an absolute value of 77.43. These values indicate that 91% of the error resulted from the actual pressure being less than the ideal pressure. The 80-psig data yielded values of 48.68 and 89.58. The best case ACM (i.e., source pressure = 170 psig, and suit volume = 6 liters) yielded the best ACM response data with a net integral value of -1.05 and an absolute integral value of 42.1. These values indicate the error was almost evenly distributed, the slightly larger error being caused by excess pressure.

4.6 Description of the Honeywell Fluidic Anti-G Valve

The Fluidic Anti-G Valve (F-valve) was designed and built (by the Honeywell Systems and Research Center, Minneapolis, Minn.), under contract to USAFSAM to fill the need for a programmable (suit pressure vs. G_Z) anti-G valve for use in human centrifuge research at Brooks AFB.

The F-valve is basically a hybrid system, utilizing both electronic and fluidic components. The output from a gondola-mounted accelerometer is used to drive the X-axis (drum rotational position) of a modified Model 5110 X-Y Data Trak (Research Inc., Minneapolis, Minn.). This Data Trak provides the programmable feature of the F-valve. Because the suit pressure is controlled by the Y-axis (horizontal probe position), and the X-axis (drum rotational position) is controlled by acceleration (G_Z), any desired suit pressure per G_Z schedule can be attained by scribing the Data Trak chart with the proper curve. The Y-axis stylus is an electrostatic probe which is servo driven to seek continually the zero potential at the center of the curve scribed on the Data Trak chart. The output from the Y stylus is fed through a linear amplifier into the torque motor of an electronic-to-fluidic signal converter (E to F valve). This torque motor changes the position of a flapper which, when not in the center position, creates a differential pressure at the nozzles. The pressure signal from the E to F valve is connected, via a series of fluidic amplifiers, to a spring-centered spool. This spool acts as a shuttle-valve which, depending on position, allows pressure to be applied to the suit outlet-- or suit pressure to be vented to atmosphere. This shuttle valve, as used in the F-valve, does not linearly modulate pressure, but operates as a binary system (viz., a "bang-bang" system). The output control valve is either "full on" or "full off". When the suit pressure drops below the limits dictated by the E to F valve position, the shuttle valve opens and pressure is applied to the suit at a fixed rate until the suit pressure is within the limits; and then the valve shuts off. The rapid operation of the shuttle valve accounts for the characteristic "popping" sound emitted by the F-valve while in operation.

The flow through the F-valve is limited by the spool. The design flow through the spool is specified to be 20.2 SCFM with a source pressure of 80 psig venting to ambient. This flow rate would theoretically pressurize an 11-liter suit at 12.8 psig/sec with a source pressure of 80 psig.

Suit overpressure protection is provided by a pressure switch connected to a solenoid valve. Two pressure switches are provided with the valve: one for use in the 10-psig suit-pressure mode, and one for use with the 50-psig suit-pressure mode. These switches are designed such that, when the pressure drops below the actuation pressure of the switch, it will close the solenoid and suit pressure will rise until the switch opens again. The 10-psig switch allows suit pressure to fluctuate between 11.2 psig and 12.0 psig at about 2 Hz. The 50-psig switch allows suit pressure to fluctuate between 57.0 psig and 58.0 psig at about 1.3 Hz.

The F-valve is designed to operate with a nominal source pressure of 80 psig. The F-valve was tested with a source pressure of 160 psig on the spool, but the fluidics supply pressure was held at 80 psig.

The F-valve has a remote emergency abort feature which closes a solenoid valve on the supply pressure and vents the suit pressure. A functional test of the valve is accomplished by using a direct current power supply to simulate accelerometer input to the Data Trak. The physical dimensions of the gondola-mounted portion of the F-valve system are 6 x 19 x 7 in. (15.24 x 48.26 x 17.78 cm).

4.6.1 Test Summary of the F-valve

The F-valve was tested using the three-phase protocol, with additions to examine the 50-G mode of operation. (The data from these tests are available in Appendix G: Part 1, and Part 2--supplemental data, also; Phase I data, on pp. 1-9; Phase II, on pp. 10-49; and Phase III, on pp. 50-etc.).

The F-valve design minimum and maximum source pressures--30 psig and 160 psig, respectively--were the determining factors for setting the span of pressures used during testing. Median source pressure was 80 psig. Suit volumes of 6 liters (minimum), 9 liters (median), and 12 liters (maximum) were used in Phase III testing, while the median volume was used for Phase II. Only one suit volume was used for the supplemental data on the 50-G mode of operation of the F-valve.

4.6.2 Open-Flow Capacity of the F-valve

Phase I open-flow tests of the F-valve (the results of which are available in Appendix G: Part 1, pp. 1-9; and Part 2, pp. 1-3) were conducted with a normal length of hose, attached downstream from the flow meter and terminated by female connectors matching those used for CSU series Air Force anti-G suits. The tests were conducted using three source pressures, including the design minimum of 30 psig, the design maximum of 160 psig, and a median pressure selected at 80 psig.

The F-valve, operating in either mode, demonstrated the same general flow curve, irrespective of source pressure. Generally, the flow rises linearly to a maximum flow, reached between 2 G and 4 G, and then abruptly levels off. The flow maintained at the maximum through the remainder of the G range. Listed in Table 14 is the flow over all source pressures, and in both modes of operation.

TABLE 14. FLOW CHARACTERISTICS OF THE FLUIDIC ANTI-G VALVE
(All flows are expressed in SCFM)

10-G Mode	F_1	G_o	F_M
30 psi	0	2.7	12.5
80 psi	0	3.5	26
160 psi	1	4.2	32
50-G Mode			
105 psi	11	2.0	34

F_1 = the flow at 2 G (operating in the 10-G mode) or 1.5 G (operating in the 50-G mode)

G_α = the approximate value of G where maximum flow is obtained

F_M = the maximum flow delivered.

In the 10-G mode, flow generally started at or near 2 G, and peaked at a G value which was proportional to the source pressure. The peak value of the flow was also proportional to the source pressure.

Operating in the 50-G mode, flow generally started at (or just prior to) obtaining 1.5 G. A maximum flow of 34 SCFM was reached at 2 G.

4.6.3 P-G Profile End Points of the F-valve

The end points of the P-G profile define the useful range of acceleration over which the valve may be used. The low-pressure end of the P-G profile is defined as the "cut-in" point (i.e., that value of G at which the valve starts to apply pressure to the suit). The high-pressure end is defined by the relief valve actuation. It should be understood that the relief valve, the function of which is to protect the subject in case of valve failure, is not normally operational.

The F-valve cut-in pressure varied between 1.75 G and 2.5 G during these tests, with the majority of values occurring at approximately 1.973 G. As might be expected, no change was found in cut-in point with respect to the volume of the suit being inflated. Operating in the 50-G mode, the valve cut-in point varied between 1.37 G and 1.5 G, with an average cut in of 1.435 G. There was a negligible but definable difference in cut-in point with respect to the onset rate of the test. With 0.5 G/sec onset rates being used, pressure was applied at 2.05 G, as compared to an average of approximately 1.95 G for both 1 G/sec and 1.5 G/sec onset rates. Operating in the 50-G mode, the F-valve did not vary more than 0.15 G from the average cut-in value for any run. Therefore, the only significant variation in cut-in points was between modes of operation. The average cut in using 30-psig source pressure is 2 G, while averages for 80-psig and 160-psig source pressure are 2.1 G and 1.9 G, respectively--which is not a very significant variation. Therefore, variation with source pressure does not appear to be important. The F-valve, which is designed to cut in around 2 G, does so with little variation while operating in the 10-G mode. The valve opens earlier in the 50-G mode (around 1.5 G)

A review of the F-valve design suggests that no change in relief valve operation is normally expected with respect to source pressure, suit volume, or onset rate. The relief valve (operating in the 10-G mode) generally opened between 8.5 G and 9 G, with an average of approximately 8.75 G. The suit pressure was usually 9.2 psig when the relief valve opened, with little variation. When operating in the 50-G mode, the relief valve opened at 10 G, with almost no variation. The suit pressure varied between 46 psig and 47.5 psig at the time the relief valve opened. The most likely suit pressure was 47 psig at relief valve opening. When operating at $+90^{\circ}$, the relief valve opened at 7.6 G, with a suit pressure of 10.2 psig. This finding suggests failure of the valve to operate properly with a $+90^{\circ}$ orientation to the G-vector.

4.6.4 Compliance of the F-valve with MIL-V-9370D

The 10-G mode operation of the F-valve was evaluated between 2-1/2 G and 8-1/2 G (the linear region) for compliance with MIL-V-9370D. Data graphically representing the valve's response are recorded in Appendix G (part 1, p. 10). Contained in Table 15 are the results of the comparisons.

The valve's performance meets the requirements of MIL-V-9370D for most test conditions. The valve did not meet the Mil. Spec. standards at high onset rates with a minimal source pressure, nor under a -90° angular influence.

Several observations can be made regarding the performance of the Fluidic anti-G valve:

(1) The F-valve is strongly linear under all test conditions, with a reduced slope when operating with a minimal source pressure.

(2) The valve's basic response function (linear region) is of the form:

$$P = k_1G + k_2\sin(k_3G = \emptyset_0) + k_4.$$

TABLE 15. COMPLIANCE OF THE FLUIDIC ANTI-G VALVE WITH MIL-V-9370D

G Onset	Source Pressure (psig)		
	30	80	160
0.1	OK	OK	OK
0.5	OK	OK	OK
1.0	Slightly off at 8 G	OK	OK
1.5	X	OK	OK
1 at -90°		X	
1 at $+90^{\circ}$		OK	

X = the valve response was out of the Mil. Spec. requirements over 50% of the study range, and by a significant amount.

4.6.5 Sigma Analysis of the F-valve

Using the sigma evaluation techniques (Vol. I, section 3.9), the following quantities have been calculated for the F-valve operating in the 10-G mode:

(1) $\bar{\sigma}_p(V_t)$ = the deviation in the valve data due to pressure dead band.

(2) $\bar{\sigma}_g(\frac{dG}{dt}, \emptyset_z, V_s, P_s, V_t)$ = the net deviation in the valve data. $\bar{\sigma}_g$ is a function of onset rate, angle, source pressure, suit size and valve type.

(3) $\bar{\bar{\sigma}}_g^{\,2}$ = the average variance in the valve data as a function of a limited number of variables.

All values in Tables 16 and 17 are expressed in psi and psi^2, respectively. (For the F-valve, $\bar{\sigma}_p$ = 0.284755 psi. The $\bar{\sigma}_g$ values are listed in Table 16.)

Several conclusions may be drawn from the data in Tables 16 and 17:

(1) The F-valve is not a "tight" valve at any source pressure, but does show a definite trend for increasing $\bar{\sigma}_g$ with increasing P_s. Under minimum source pressure conditions, σ_g never exceeds 0.5 psig, but does exceed 1.0 psig when operating with maximum source pressure.

(2) The F-valve exhibits a tendency toward increasing variance as the onset rate increases (i.e., minimum $\bar{\sigma}_g$ occurs at -1.5 G/sec and maximum occurs at +1.5 G/sec.

(3) The valve's variance shows a sharp variation with source pressure, and with the direction of G-onset (i.e., increasing or decreasing). Other variations in $\bar{\sigma}_g$ are not noticeable.

4.6.6 Response Hysteresis of the F-valve

Hysteresis is a classic measurement of the quality of regulation in any system. In the case of anti-G valves, hysteresis is determined by subtracting the pressure at a point in G during a decreasing acceleration profile from the pressure at the same G value in an increasing profile. (The data reported here were derived from Appendix G, Parts 1 and 2.)

The hysteresis of the F-valve varied strongest as a function of G-onset rate, but also varied with respect to source pressure. Oddly enough, the F-valve's hysteresis did not vary much between the 10-G and 50-G operating modes. The onset rate had the greatest effect, as might have been expected; and the suit volume had little, if any, effect. Hysteresis that was observed occurred fairly constantly over the whole G range. The only exception was at low onset rates, where the hysteresis curve appeared as a wave through the X axis.

Hysteresis from Phase II data (where the onset rate was 0.1 G/sec) averaged less than ±0.2 psi, being essentially a measure of the steady-state response of the F-valve. As the onset rate increased, the hysteresis increased proportionally--yielding, for all conditions and experiments, average values of approximatley ±0.2 psig for 0.1 G/sec onset, 0.4 psig for 0.5 G/sec, 0.8 psig for 1 G/sec, and 1.4 psig for a 1.5 G/sec onset rate.

Variations in hysteresis with respect to the suit volume were not discernible. The average value for all conditions and experiments at minimum volume was 1.08 psig; at mid-volume, 0.7 psig; and at maximum, 0.8 psig.

The angle of alinement of the valve with respect to the G vector did not have a noticeable effect, with the hysteresis being comparable to that of other runs at the same onset rate.

TABLE 16. NET STANDARD DEVIATION OF THE FLUIDIC ANTI-G VALVE DATA
(Values are expressed in psi)

INCREASING ACCELERATION

dG/dt \ V_s	M_1		M_2	M_3	
	P_s=30	P_s=160	P_s=80	P_s=160	P_s=30
0.5	0.218815	0.948975	0.492534	0.938981	0.406586
1.0	0.222768	1.04443	0.570983	1.190252	0.436538
1.5	0.305638	1.26986	0.493045	1.49250	0.418904
$\emptyset_1$			0.517501		
$\emptyset_2$			0.330588		

DECREASING ACCELERATION

dG/dt \ V_s	M_1		M_2	M_3	
	P_s=30	P_s=160	P_s=80	P_s=160	P_s=30
0.5	0.153822	0.826571	0.252682	0.715334	0.344143
1.0	0.486868	0.703113	0.169865	0.563427	0.314523
1.5	0.117013	0.619674	0.163452	0.559153	0.236217
$\emptyset_1$			0.133159		
$\emptyset_2$			0.028705		

The variable notation is defined as follows:

VARIABLES

V_t = Fluidic

P_s = 30, 80, or 160 psig

V_s = M_1, M_2, M_3 — { M_1 = small suit volume = 6 liters; M_2 = medium suit volume = 9 liters; M_3 = large suit volume = 12 liters }

$\emptyset_z$ = 0°, -90°, or $+90^\circ$ — { $\emptyset_1 = -90^\circ$, with $\frac{dG}{dt} = \pm 1$; $\emptyset_2 = +90^\circ$, with $\frac{dG}{dt} = \pm 1$ }

$\frac{dG}{dt}$ = ±0.5, ±1.0, or ±1.5 G/sec

Pressure variance as a function of a limited number of variables, $\bar{\bar{\sigma}}^2(\frac{dG}{dt})$ and $\bar{\bar{\sigma}}^2(V_s, P_s, S)$, is presented in Table 17. The values calculated provide a simple comparison of the variance in the valve data as a function of an isolated variable.

TABLE 17. PRESSURE VARIANCE OF THE FLUIDIC ANTI-G VALVE DATA (Values are expressed in psi^2)

$\bar{\bar{\sigma}}_g^{\,2}$ (0.5) = 0.4476	$\bar{\bar{\sigma}}_g^{\,2}$ (-0.5) = 0.2802
$\bar{\bar{\sigma}}_g^{\,2}$ (1.0) = 0.6147	$\bar{\bar{\sigma}}_g^{\,2}$ (-1.0) = 0.2353
$\bar{\bar{\sigma}}_g^{\,2}$ (1.5) = 0.8704	$\bar{\bar{\sigma}}_g^{\,2}$ (-1.5) = 0.1586
$\bar{\bar{\sigma}}_g^{\,2}$ (M_1, 30, +) = 0.0636	$\bar{\bar{\sigma}}_g^{\,2}$ (M_1, 30, -) = 0.0915
$\bar{\bar{\sigma}}_g^{\,2}$ (M_1, 160, +) = 1.2013	$\bar{\bar{\sigma}}_g^{\,2}$ (M_1, 160, -) = 0.5205
$\bar{\bar{\sigma}}_g^{\,2}$ (M_2, 80, +) = 0.2705	$\bar{\bar{\sigma}}_g^{\,2}$ (M_2, 80, -) = 0.0398
$\bar{\bar{\sigma}}_g^{\,2}$ (M_3, 160, +) = 1.5086	$\bar{\bar{\sigma}}_g^{\,2}$ (M_3, 160, -) = 0.3806
$\bar{\bar{\sigma}}_g^{\,2}$ (M_3, 30, +) = 0.1771	$\bar{\bar{\sigma}}_g^{\,2}$ (M_3, 30, -) = 0.0911

The real surprise in the F-valve's hysteresis was its variation with respect to source pressure. While the magnitude of hysteresis was about the same at all source pressures, for a given onset rate, the sign of the hysteresis varied. With low source pressures (30 psig), the decreasing runs led the increasing runs, yielding negative hysteresis (averaging -0.8 psi), which is common. With high source pressures (160 psig), the increasing runs led the decreasing runs, yielding positive hysteresis (averaging +0.8 psi), which is unusual.

4.6.7 ACM Response of the F-valve

The best overall comparative measurement of valve performance was derived from the SACM tests. These tests were designed to simulate assumed best, worst, and median case conditions in an aircraft (i.e., maximum source pressure with minimum suit volume, minimum source pressure with maximum suit volume, and median source pressure with median suit volume). In addition, one set of SACM's was run at the median angle tested. The best measure of error from these tests came from the difference in pressure between the actual suit pressure results and the ideal suit pressure (refer to section 3). Of the two curves of this type, the more valuable was the curve that was plotted with respect to the integral of G with respect to t. By using this value as the abscissa, the area under the curve was weighted in direct proportion to the instantaneous magnitude of G stimulus. The integral of the differential pressure values on this curve is a relative measure of the suit-pressure error during the run.

It must be emphasized that this value is <u>not</u> an absolute measure of error, but a relative measure. When scales are compatible, however, this integral provides a direct comparison of the magnitude of errors between runs and between valves. In the case of the F-valve, the 30-psi source pressure (i.e., worst case) SACM's yielded a net value of 11.5 and an absolute value of 124.6. These values indicate that the error resulted almost equally from the actual pressure being less than the ideal pressure, and vice versa. The 80-psig data yielded net values of -119.8 for the 0° case, 251.5 for the -90° case, and -487.5 for the $+90^{\circ}$ case, as well as absolute values within 2% of the net integral in each case. These values indicate that the ideal pressure either led or followed the real pressure over most of the ACM. The ACM's at $\pm 90^{\circ}$ had greater error than at no angle, indicating increasing deviation from the ideal. The last ACM (i.e., source pressure equal to 160 psig, suit pressure equal to 6 liters) yielded integral values of -192.5, with an absolute integral value of approximately +192.5. This finding indicates that the real pressure led the ideal pressure throughout the ACM.

5. STANDARDIZED ANTI-G VALVE TEST PROTOCOL

5.1 Introduction

The purpose of the Standardized Anti-G Valve Test Protocol (SVTP) is to describe a uniform test procedure for evaluating the relative performance characteristics of anti-G valves. The data resulting from this protocol should provide a standard of performance.

The SVTP--designed to augment, not replace, MIL-V-9370D--deals only with the active or dynamic elements of anti-G valve testing. (It does not deal with physical dimensional specifications, material specifications, environmental specifications, or static performance specifications.) The dynamic tests described are intended to be performed on the USAFSAM/VNB human centrifuge at Brooks AFB.

One of the projected uses of the SVTP is to develop a data base for design selection of anti-G protective subsystem components for existing and proposed weapon system-mission combinations at the earliest feasible time. Because of the almost infinite variety of conditions and requirements of such subsystems, this protocol does not propose to simulate all possible combinations. Rather, the intention is that limits of conditions be set, allowing an indication of acceptability of a particular valve for a particular mission. This procedure will allow selection of existing anti-G valves for more explicit testing before their application to a specific weapon system-mission combination.

5.2 Test Configuration

Two basic test configurations will be used for evaluating anti-G valves. The first (Fig. 3) will be used only for the flow tests (refer to section 5.4.1). The second test configuration (Fig. 4) is identical to the first except for the addition of the sink volume. (All transducers and data-handling equipment are discussed in section 5.3.)

The pressure-source configuration will involve the installation, in the gondola, of standard "K bottles" containing 220 SCF air at 2200 psig. A remotely controlled solenoid valve will be installed in the system. The valve will be used to conserve air. This unit will be capable of switching up to 300 psig. The valve will be controlled by a relay--mounted in the gondola--which will, in turn, be controlled by low-current lines through the slip rings to control console-mounted switches.

Regulation of the source pressure to the anti-G valve under test is an especially critical system requirement. The regulation system must be capable of maintaining the source pressure, plus or minus 10% (preferably ±5%), through a wide range of flow rates (i.e., 0 - 30 SCFM). It may prove most practical to use two regulation systems. Because the open-flow tests (i.e., open-flow test configuration) will contain all of the higher flow rates, a wide dynamic range regulation system may be used

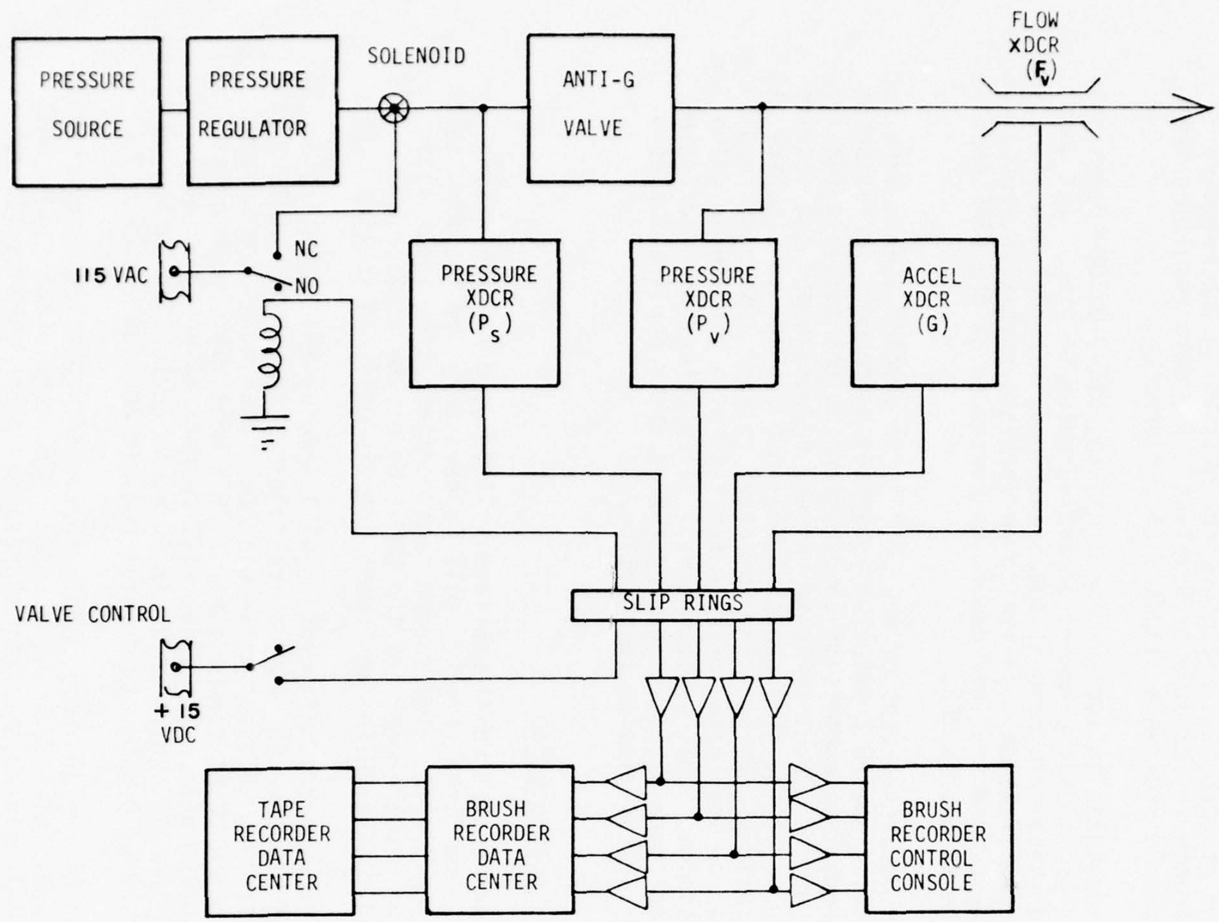

Figure 3. Open-flow test configuration established by the Standardized Anti-G Valve Test Protocol. [F_V = air flow; NC = normally closed; NO = normally open; P_S = source pressure; P_V = suit pressure; XDCR = transducer; and VAC = volts alternating current]

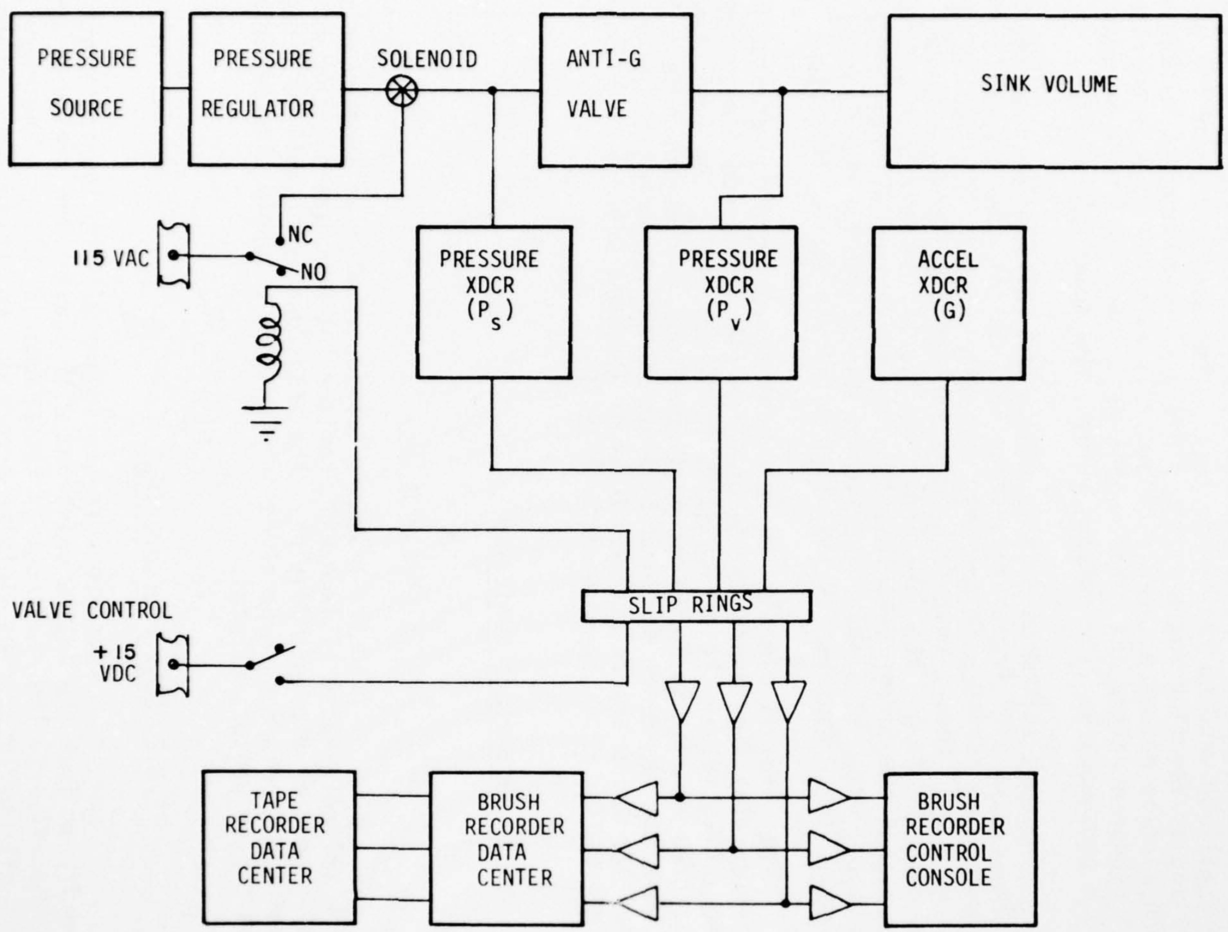

Figure 4. Dynamic test configuration established by the Standardized Anti-G Valve Test Protocol. [For abbreviations, see legend for Fig. 3.]

exclusively for these tests. A less bulky standard regulator mounted directly on the K bottle pressure source will probably be sufficient for dynamic test configurations.

The anti-G valve will be mounted on a plate which is indexed and scaled in degrees. This plate may be locked in any angular position, and will be used to facilitate testing the sensitivity of the anti-G valves to mounting angle. This plate will be mounted on a test stand and will be alined as nearly as possible with the gondola accelerometer to reduce acceleration error. This test stand will also be used to mount such equipment as flow meters, relays, and solenoid valves.

The sink volume used to terminate the valve under test should be a "flexible volume" (refer to section 5.6) at the volume specified to simulate an anti-G suit properly. "Rigid volumes" will not be acceptable. If an actual anti-G suit is used, a minimum flow impedance model should be selected (e.g., the CSU-15/P). The specified volume is intended to represent the incompressible volume, or the volume of water required to fill the suit, at 5 psig. Stretch in the flexible volume should be limited to an increase of 10% at 10 psig over the 5 psig volume.

The terminal plumbing in both test systems configurations should be very carefully designed to minimize the flow impedance downstream from the anti-G valve. It is suggested that essentially the same plumbing fixtures be used in both test configurations. An adequate test for downstream impedance may be determined during the open-flow tests by limiting the pressure at the output of the anti-G valve to 1 psig at the maximum flow rate (approximately 30 SCFM).

5.3 Parameters Monitored

5.3.1 Source Pressure (P_S)

A source-pressure transducer will be located downstream from solenoid valve #1, and will monitor the pressure supplied to the inlet port of the anti-G valve. The transducer port will be located to minimize errors due to pressure drop caused by supply line restrictions and due to venturi effects.

5.3.2 Suit Pressure (P_V)

A suit-pressure transducer will be located immediately downstream from the anti-G valve and will monitor the pressure supplied by the valve to the remainder of the pneumatic system. The transducer port will be located to minimize errors due to pressure drop through the interconnecting tubing and due to venturi effects.

5.3.3 Air Flow (F_v)

The flow measurement transducer should have a dynamic range of at least 1.0 - 30 SCFM, with additional high-range capability being desirable. It is suggested that a hot-wire type of sensor would be most advantageous to improve the response of the monitoring system and to detect high-frequency fluctuations in the valve's operation. (NOTE: Not all hot-wire sensors have good high-frequency response.) The flow sensor should be installed immediately downstream from the suit-pressure transducer and must be selected to avoid excess flow impedance.

5.3.4 Acceleration (G_z)

Acceleration will be measured only in the +Z axis (i.e., in this case, parallel to the sensitive axis marked on the anti-G valve). The sensor should have a dynamic range of from 1 to 11 G, with additional high range capability being desirable. While the need for testing along other axes will be necessary in the foreseeable future, none of the valves or weapon systems in immediate prospect have this capability and testing for this variation would significantly increase the complexity of this protocol.

5.3.5 Valve Angle

The valve under test will be attached to a circular plate, indexed in degrees, and mounted in a position such that the centerline is parallel to a line through the center of the mounting plate and the zero degree index mark. The plate will be attached to a frame through a single point at its center such that it may be firmly set at any desired angle. The mounting plate will be referenced to the frame to assure alinement of the valve's acceleration sensor with the resultant G vector in the gondola.

5.3.6 Suit Volume

The sink volume (simulating anti-G suit volume) will be measured by evacuating the volume with a mild vacuum, then pressurizing to 5 psig from a known volume at known initial and final pressures. The sink volume will then be calculated from the pressure drop in the source bottle. Variations in barometric pressure will be included in volume calculations.

5.3.7 Signal Conditioning and Recording

The majority of the data recorded for these tests should utilize standard techniques similar to those presently being used for the majority of tests run on the USAFSAM human centrifuge. These techniques involve passing the electrical signals through slip rings to the control console where they are amplified or attenuated as necessary, recording the most important of the processed signals on the control console Brush recorder, filtering and rescaling the signals in the data center, recording the reprocessed signals on magnetic tape, and recording the output of the tape recorder playback electronics on one or two Brush recorders in the data center.

5.4 Test Description

The performance evaluation tests for anti-G valves will be conducted in three phases. It is essential that the test setup and instrumentation (described in sections 5.2 and 5.3) be carefully prepared. However, each phase need not be conducted independently or continuously, as long as sufficient documentation is maintained to assure that the proper data are used for each element of the data analysis.

The term "trapezoid run" should be defined for the purposes of this test description. The actual G profile of a trapezoidal run on a strip-chart recorder, with time recorded as one axis, will approximate a geometric trapezoid. The data of interest are contained in the increasing and decreasing slopes, and none are extracted from the flat top. The quality of the data will be significantly enhanced if trapezoids are run from 1 to 11 G, and from 11 to 1 G (instead of 1 to 10 G). Termination of the data in the computer at 10 G results in significant program economies. It is important that the operator allow enough time between the increasing and decreasing slopes of a trapezoidal to permit the data analyst to separate the data in the computer. The time required is approximately 2 min of analog tape time. It is also important to note that 2 min of actual run time are not required if the operator places the recording tape in high-speed forward for a short period of time.

5.4.1 Phase I--Maximum Flow Capacity

The purpose of this test is to determine the maximum flow capability of the anti-G valve under test. (The test setup already shown in Fig. 3 is used.) Three source pressures are selected for one major variable and include the design maximum, minimum, and optimum median value for the valve under test.

Three trapezoidal runs are made at each source pressure, using 0.1 G/sec onset and offset rates. During these runs, the operator must monitor the data very carefully to assure that the source pressure remains within ±10% of the desired value (preferably ±5%), and that the pressure at the valve output never exceeds 1 psig. The total recorded data for this phase are 9 trapezoidal runs.

5.4.2 Phase II--Dynamic Response Testing

The purpose of this test is to determine the dynamic response capability of the anti-G valve under test. (The test setup shown in Fig. 4 is used.) All tests are run with the valve terminated in a flexible sink volume of 10 liters (refer to sections 5.2 and 5.6).

Three 0.1 G/sec trapezoids are run at each source pressure (i.e., minimum, median, and maximum source pressure). A fourth set of three 0.1-G/sec trapezoids are run at a selected valve angle (i.e., 20°, or the maximum design capability of the valve) with a median source pressure. An identical set of data runs are recorded using 1.5 G/sec onset and offset rates. Additional sets of three trapezoids are run at the median source pressure using 0.5 G/sec and 1.0 G/sec onset and offset rates. The total recorded data for this phase consist of 30 trapezoidal runs.

5.4.3 Phase III--Complex Dynamic Response Testing

This phase of testing provides a measure of the relative capability of an anti-G valve to function under SACM conditions. The G profile used is the SACM shown in Figure 5. In order to compare the relative performance under varying conditions, four sets of 3 iterations of the SACM are run. If the G profile is manually controlled, the best example of the set is used for data analysis. Where the G profile is automatically controlled, data from all three iterations may be combined if the magnitude of sigma for the G profile approaches the 6 sigma magnitude resulting from instrument uncertainty.

The first set of SACM's utilizes a median flexible volume (10 liters) at the median source pressure. The second set is made under identical conditions, except that the anti-G valve is misalined to the vertical by the angle selected for Phase II. The third set of SACM's is run with a maximum suit volume (14 liters) and the minimum source pressure; the fourth set, with the minimum suit volume (6 liters) and the maximum source pressure.

5.5 Data Analysis

Data from the tests run in accordance with SVTP will be recorded on magnetic tape (as described in sections 5.2 and 5.3). The magnetic taped data will be converted to digital data at the appropriate sampling rates to support the frequency content of the data and subjected to analysis. The product of this analysis takes two forms: The graphic presentations, and the Relative Performance Evaluation Table (RPET).

The first product of data analysis, graphic forms, are used to display the absolute and relative results of the tests. The principal purpose of this presentation is to show the effects of the various variables (for example, source pressure, and suit volume, etc.) on the valve performance. In some cases, the graphic presentations serve to indicate the valve performance relative to MIL-V-9370D requirements. In addition, they aid in understanding the RPET.

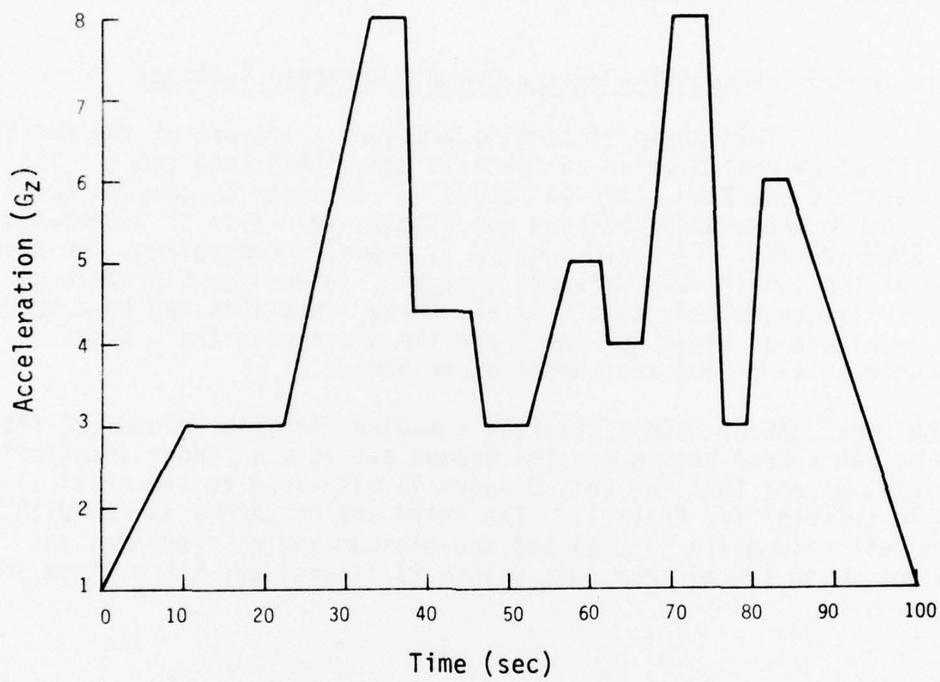

Figure 5. The G profile of a simulated aerial combat maneuver (SACM).

The purpose of the RPET is to provide a quantitative means of evaluating the relative quality of anti-G valves. Various measures, of those characteristics judged to be most important to the satisfactory performance of an anti-G valve under diverse conditions (environmental, mechanical, and tactical), have been selected for comparison. These measures, in accordance with the aim of subjecting all valves to the same tests, serve on a point-by-point basis as a quantitative measure of the quality of performance. With the addition of appropriate weighting factors, these quantitative measures may be added to represent the overall quality in each area of performance (i.e., flow capability, dynamic response, complex response) and overall quality.

The remainder of this section deals with the content and purpose of these two products of evaluation. Specific techniques have not been dictated unless that technique is unique (i.e., not the result of a standard statistical or analytical procedure). The weighting factors may be inserted on the basis of engineering judgment, but are inserted preferably as the result of comprehensive testing (using this protocol) and evaluation of several types of anti-G valves.

5.5.1 Graphic Results

The analyzed data of the Standardized Anti-G Valve Protocol are graphically displayed on 18 plots. The format and content of each of these graphs are described here. (The algorithms used to derive the quantities described are not defined. That effort is left to the discretion of the programmer, so that the standard software available at his facility may be optimally utilized.)

(1) FLOW vs. G (F-G): The horizontal axis (abscissa) represents the impressed G_Z while the vertical axis (ordinate) represents the standard cubic feet per minute (SCFM) of air flow. The data are derived from Phase I tests. Three curves are drawn on the same set of axes, representing the mean F-G profile resulting from maximum, median, and minimum source pressures.

(2) $3\sigma_F$ vs. G: The abscissa represents the impressed G_Z while the ordinate represents three times the standard deviation of the data (i.e., the magnitude of the span of flow values on each side of the mean that includes 99.7% of the probable data points, assuming normal distribution). The data are derived from Phase I tests. Three curves are drawn on the same set of axes, representing 3σ of the means displayed in the F-G profiles, already described in (1).

(3) P_V vs. G(dG): The abscissa represents the impressed G_Z while the ordinate represents the resulting suit pressure (P_V) in pounds per square inch gage (psig). The data are derived from Phase II tests. Four curves are drawn on the same set of axes, representing the mean P-G profile resulting from a median source

pressure, 10-liter suit volume, and G onset rates of 0.1, 0.5, 1.0, and 1.5 G/sec. In addition the limits of acceptable performance imposed by MIL-V-9370D are plotted on the same set of axes.

(4) P_V vs. G(0.1): The abscissa and ordinate are identical to the P_V vs. G(dg) curve, and the MIL-V-9370D limits are also plotted. These data also are derived from Phase II tests, using only the 0.1 G/sec onset/offset iterations. In this case, four curves are drawn, representing mean P-G profiles when the source pressure is set at minimum, median, and maximum values, and when the valve is set at an angle.

(5) P_V vs. G(1.5): This graph is identical to P_V vs. G(0.1), already described, except that the only data used are derived from Phase II tests using 1.5 G/sec onset/offset rates.

(6) $3\sigma_P$ vs. G(0.1): The abscissa and ordinate are identical to the $3\sigma_F$ vs. G curve. Four curves will be plotted, representing the 3σ's of the means plotted on the P_V vs. G(0.1) graph.

(7) $3\sigma_P$ vs. G(1.5): This graph is identical to $3\sigma_P$ vs. G(0.1), already described, except that the 3σ's of the P_V vs. G(1.5) means are used.

(8) ΔP vs. G(0.1): The abscissa represents the impressed G_Z, while the ordinate represents the difference (hysteresis) between the inflation and exhaust pressures at the same G_Z. The data are derived from Phase II tests, using only the 0.1 G/sec onset/offset iterations. Four curves are plotted representing the mean ΔP when the source pressure is set at minimum, median, and maximum values, and when the valve is set at the selected angle with respect to the G_Z vector.

(9) ΔP vs. G(1.5): This graph is identical to ΔP vs. G(0.1), already described, except that only data from the Phase II 1.5 G/sec onset/offset iterations are used.

(10) P_V vs. G(H): This graph is identical to P_V vs. G(dG), already described. In this case, two complete P-G profiles (inflation and exhaust) derived from Phase II tests are plotted using 0.1 G/sec onset/offset iterations data in one case, and 1.5 G/sec trapezoid data in the other.

(11) P vs. T(DD): The abscissa represents the elapsed time of an ACM, while the ordinate represents the suit pressure in pounds per square inch gage. The data are derived from Phase III ACM's, using the median source pressure and a median suit volume. Two curves are drawn representing the ideal suit pressure and the actual suit pressure. The ideal suit pressure is derived by matching the actual ACM G_Z profile to the suit pressure delivered

by that valve, using the median source pressure and cosine of the angle of the valve with respect to G_Z in the Phase II 0.1 G/sec trapezoid tests.

(12) P vs. T(Ø): This graph is identical to P vs. T(DD), already described in (11), except that the data are derived from Phase III ACM's where the valve is alined at the selected angle with respect to the G_Z vector.

(13) P vs. T(NX): This graph is identical to P vs. T(DD), already described, except that the data are derived from Phase III ACM's where the source pressure is set at the minimum value and the suit volume is set at the maximum.

(14) P vs. T(XN): This graph is identical to P vs. T(DD), already described, except that the data are derived from Phase III ACM's where the source pressure is set at the maximum value and the suit volume is set at the minimum.

(15) ΔP vs. IG(DD): The abscissa represents $\int_0^t G(t)dt$ of tne ACM G profile, while the ordinate represents the difference ($P_R - P_I$) between the actual suit pressure and the ideal suit pressure. The curve is derived from the same tests and data as P vs. T(DD), already described in (11).

(16) ΔP vs. IG(Ø): This graph is identical to ΔP vs. IG(DD), already described, except that the curve is derived from the same tests and data as P vs. T(Ø).

(17) ΔP vs. IG(NX): This graph is identical to ΔP vs. IG(DD), already described, except the curve is derived from the same tests and data as P vs. T(NX).

(18) ΔP vs. IG(XN): This graph is identical to ΔP vs. IG(DD), already described, except the curve is derived from the same tests and data as P vs. T(XN).

The purpose, implications, and expected results of these curves are presented in section 5.6.

5.5.2 Anti-G Valve Relative Performance Evaluation Table

The Anti-G Valve Relative Performance Evaluation Table (RPET) is intended to provide the investigator with a means of measuring the relative performance quality of anti-G valves. The primary advantage of RPET lies in its direct comparison of different valves performing identical tasks. The weighting functions have not been assigned, pending the availability of data from tests utilizing the SVTP.

Shown in Table 18 are the format and content of an RPET. The following report sections provide the function definitions and variable notations used in the RPET. (Additional discussion is included in section 5.6.)

TABLE 18. ANTI-G VALVE RELATIVE PERFORMANCE EVALUATION TABLE

TEST STANDARDS:

1.	SPMIN	=	psig
2.	SPMID	=	psig
3.	SPMAX	=	psig
4.	THETA	=	degrees
5.	SVMIN	=	6 liters
6.	SVMID	=	10 liters
7.	SVMAX	=	14 liters

CHARACTERISTIC NUMBERS:

8.	XSPMX	=	
9.	XSPMN	=	
10.	XTHTA	=	
11.			Design Total:____________
12.	XFLBR	=	
13.	XDELF	=	
14.	XDDLF	=	
15.	XSIGF	=	
16.			Flow Total:____________
17.	XCCP1	=	
18.	XDDP1	=	
19.	XSGP1	=	
20.	XDPP1	=	
21.			Low Onset Total:_________
22.	XCCP2	=	
23.	XDDP2	=	
24.	XSGP2	=	
25.	XDPP2	=	
26.	XTDP2	=	
27.			High Onset Total:________
28.	XIDPA	=	
29.	XIDPB	=	
30.	XIDPC	=	
31.	XIDPD	=	
32.			SACM Total:____________
33.			Valve Total:____________

DEFINITIONS:

1. SPMIN = Design Minimum Source Pressure
2. SPMID - Design Medium Source Pressure
3. SPMAX = Design Maximum Source Pressure
4. THETA = Design Maximum Angle WRT G-Vector

TABLE 18: DEFINITIONS (CONT'D.)

5. SVMIN = Minimum Test Suit Volume

6. SVMID = Medium Test Suit Volume

7. SVMAX = Maximum Test Suit Volume

8. XSPMX = $W_8 \cdot (300/SPMAX)$

9. XSPMN = $W_9 \cdot (SPMIN/30)$

10. XTHTA = $W_{10} \cdot (20/THETA)$

11. Design Total = <u>Sum of 8, 9 and 10.</u>

12. XFLBR = $\sum_{k=2}^{10} [\,\overline{F}_{MN_k} + \overline{F}_{MD_k} + \overline{F}_{MX_k}\,] \cdot W_{12}$

13. XDELF = $\sum_{k=2}^{10} W_{13} \cdot |\,\overline{F}_{MX_k} - \overline{F}_{MN_k}\,|$

14. XDDLF = $\sum_{k=2}^{10} W_{14} \cdot [\,|\overline{F}_{MN_k} - \overline{F}_{MD_k}| + |\overline{F}_{MX_k} - \overline{F}_{MD_k}|\,]$

15. XSIGF = $\int_1^{10} W_{15}(G) \cdot [\sigma_{F_{MN}} F_{MN} + \sigma_{F_{MD}} F_{MD} + \sigma_{F_{MX}} F_{MX}]\, dG$

16. Flow Total = <u>Sum of 12, 13, 14 and 15.</u>

17. XCCP1 = $W_{17} \cdot [1/R^L_{MN} + 1/R^L_{MD} + 1/R^L_{MX} + 1/R^L_X + 1/R^L_\emptyset]$ where dG/dt = 0.1 G/sec

18. XDDP1 = $\sum_{k=1}^{10} W_{18} \cdot [\,|\overline{P^L_{MD_k}} - \overline{P^L_{MN_k}}| + |\overline{P^L_{MX_k}} - \overline{P^L_{MD_k}}|\,]$ where $\frac{dG}{dt}$ = 0.1 G/sec

19. XSGP1 = $\int_1^{10} W_{19}(G) \cdot [\sigma^L_{P_{MN}} P^L_{MN} + \sigma^L_{P_{MD}} P^L_{MD} + \sigma^L_{P_{MX}} P^L_{MX} + \sigma^L_{P_X} P^L_X + \sigma^L_{P_\emptyset} P^L_\emptyset]\, dG$

where dG/dt = .1 G/sec

20. XDPP1 = $\int_1^{10} W_{20}(G) \cdot [\,|H^L_{MN}| + |H^L_{MD}| + |H^L_{MX}| + |H^L_\emptyset|\,]\, dG$ where $\frac{dG}{dt}$ = 0.1 G/sec

21. Low Onset Total = <u>Sum of 17, 18, 19 and 20.</u>

22. XCCP2 = $W_{22} \cdot [1/R^H_{MX} + 1/R^H_{MD} + 1/R^H_{MD} + 1/R^H_{MN} + 1/R^H_X + 1/R^H_\emptyset]$

where dG/dt = 1.5 G/sec

23. XDDP2 = $\sum_{k=1}^{10} W_{23} \cdot [\,|P^H_{MD_k} - P^H_{MN_k}| + |P^H_{MX_k} - P^H_{MD_k}|\,]$ where dG/dt = 1.5 G/sec

24. XSGP2 = $\int_1^{10} W_{24}(G) \cdot [\sigma^H_{P_{MN}} P^H_{MN} + \sigma^H_{P_{MD}} P^H_{MD} + \sigma^H_{P_{MX}} P^H_{MX} + \sigma^H_{P_X} P^H_X + \sigma^H_{P_\emptyset} P^H_\emptyset]\, dG$

where dG/dt = 1.5 G/sec

25. XDPP2 = $\int_1^{10} W_{25}(G) \cdot [\,|H^H_{MN}| + |H^H_{MD}| + |H^H_{MX}| + |H^H_\emptyset|\,]\, dG$ where $\frac{dG}{dt}$ = 1.5 G/sec

26. XTDP2 = $\sum_{k=1}^{10} W_{26} \cdot [\,|P^L_{MD_k} - P^H_{MD_k}| + |P^L_{MN_k} - P^H_{MN_k}| + |P^L_{MX_k} - P^H_{MX_k}| + |P^L_{X_k} - P^H_{X_k}| + |P^L_{\emptyset_k} - P^H_{\emptyset_k}|\,]$

27. High Onset Total = <u>Sum of 22, 23, 24, 25 and 26.</u>

(CONT'D. ON NEXT PAGE)

TABLE 18. DEFINITIONS (CONT'D.)

28. $XIDPA = \int_0^{\tau_{MX}} |\Delta P_1(\tau)| \, d\tau$

29. $XIDPB = \int_0^{\tau_{MX}} |\Delta P_2(\tau)| \, d\tau$

30. $XIDPC = \int_0^{\tau_{MX}} |\Delta P_3(\tau)| \, d\tau$

31. $XIDPD = \int_0^{\tau_{MX}} |\Delta P_4(\tau)| \, d\tau$

32. SACM Total = Sum of 28, 29, 30 and 31.

33. Valve Total = Sum of 11, 16, 21, 27 and 32.

VARIABLE NOTATION:

W = Weighting function.

F = Flow in SCFM.

G = G-force in the Z-direction.

σ = Standard deviation.

R = A coefficient of linear correlation between 3G and 8G for a given G-P profile.

P = Suit pressure delivered by the valve.

H = The difference between the increasing pressure and decreasing pressure for a given suit size, onset rate, source pressure and angle. NOTE: H is also a function of G.

$\tau = \int_0^t G(t)dt$ (NOTE: τ_{MX} = maximum value of τ.)

t = Time in seconds.

ΔP = The difference between P-real and P-ideal during an SACM. P-ideal is defined by the Mid/Mid slow onset trapezoidal runs.

ΔP_1 = Refers to the Mid/Mid, no angle, SACM.

ΔP_2 = Refers to the Min Vol/Max source pressure, SACM.

ΔP_3 = Refers to the Max Vol/Min source pressure, SACM

ΔP_4 = Refers to the Mid/Mid, maximum angle, SACM.

SUBSCRIPTS:

MN = Minimum Source Pressure

MD = Medium Source Pressure

MX = Maximum Source Pressure

F = Flow

X = Exhaust

Ø = Maximum angle WRT the Z-axis

P = Pressure

SUPERSCRIPTS:

L = Low onset rate (dG/dt =0.1 G/sec)

H = High onset rate (dG/dt = 1.5 G/sec)

5.6 Discussion

The Standard Anti-G Valve Protocol provides a common denominator which an investigator may use to study anti-G valves. By subjecting all valves to the same test conditions and processing the results through identical (or at least similar) algorithms, the investigator may make valid direct performance comparisons. This technique is the most direct available to circumvent the "spec-man-ship" practiced by most manufacturers in describing their products.

For direct comparison, the RPET is the most valuable tool; but it should not be expected to stand alone as evidence for designating the best valve for a particular aircraft-mission requirement. The conditions under which the valve is to be used will have a definite bearing on the suitability of a particular end-item in a particular situation. In order to evaluate properly the effects of various conditions on a valve's performance, the graphic performance results are essential; for they permit the investigator to evaluate which input parameters (i.e., factors influencing the valve's performance) are most critical to the degradation of the output.

This protocol may also be used for specific performance evaluations when the designer wishes to choose among several candidates for a specific aircraft-mission situation. The input parameters (e.g., source pressures, suit volumes, valve angles, and onset rates) may thus be tailored to the specific requirements of the problem, so that a precise performance evaluation may be made. After all, the aim of this protocol is to provide the investigator with background data to determine not only the most likely set of candidates for these specific tests but also the guidelines for those tests.

Our recommendation is that the sink volume, used in the dynamic test configuration (refer to section 5.2) to terminate the anti-G valve, be a "flexible" rather than a rigid volume. This concept constitutes one of the major weaknesses of the MIL-V-9370D test procedure. While that specification does not require a rigid volume, the wording (i.e., "a tank having a volume of approximately 10 liters....") strongly suggests a metal-walled vessel of fixed volume. The difference between rigid and flexible volumes is most obvious in response testing.

When a valve is required to deliver enough air to raise the pressure to a 6-G equivalent level (i.e., 5.8 to 7.25 psig) in 3 sec (refer to par. 4.8.6 of MIL-V-9370D), that valve must deliver between 3.95 liters and 4.93 liters (when the barometric pressure is 14.7 psia) to a 10-liter rigid volume to effect this rise in pressure. In order to satisfy this requirement on a flexible volume (such as an actual anti-G suit with a 10-liter "incompressible" volume at the specified pressure), the valve must deliver between 13.95 liters and 14.93 liters.

The differential in flow required for the 10-G test (5 sec) is not as great as for the 6-G. Between 5.88 liters and 7.48 liters are required for a rigid volume, while between 15.88 and 17.48 liters are required for a flexible volume.

Obviously, the difference between the two test cases is the 10 liters of resident air at ambient pressure in the rigid volume. A reasonable assumption is that an anti-G suit, worn by aircrew personnel for any significant period, will be essentially void of resident air; and use of a flexible volume is a much more realistic test for performance under flight conditions. It is respectfully suggested that the continued use of a 10-liter rigid volume will result in the acceptance of anti-G valves which will not perform adequately under flight conditions.

Neither the specific computer algorithm for calculating the valves used in the graphic results nor the RPET are included in this protocol. Vast differences between computer facilities result in vast differences in the "economics" of various algorithms. Factors sucn as computer architecture, peripheral support, software languages, standard support software packages, and resident operator-programmer expertise have significant bearing on the specific cost of running a specific algorithm. On the other hand, the difference in accuracy between algorithms is generally (but certainly not universally) insignificant when compared with the standard deviations in the raw data. Should it be necessary or desirable to compare results from different test-computational facilities, a very careful evaluation must be made of the errors and biases inserted at all stages of data collection, transcription, and analysis.

One of the objectives of this protocol was to accommodate either single or multiple valve tests. Because considerable item-to-item variation occurs in most of the mass-produced anti-G valves, using multiple valve tests for baseline data will result in a more accurate performance profile. The general characteristics of performance variation suggest two important guidelines to the use of RPET:

First, a complete protocol must be performed on each item (i.e., a complete set of iterations on each test item, rather than using a different valve for each iteration)--and all of the data from each test should be used. Second, when the results are being used for performance comparison, single item tests must be compared only with other single item tests. Similarly, comparisons of multiple item tests should involve compatible numbers of test items in each set.

Two components of performance variation are present in multivalve tests (i.e., intra-valve variation and inter-valve variation). The inter-valve variations are item-to-item differences in performance; but the intra-valve variations result from dead band, hysteresis, and similar error sources.

The RPET does not distinguish between these two sources of performance variation. Consequently, the comparison of single and multiple item tests would probably be biased in favor of the former. The significance of this bias tends to decrease as the number of best valves increases (i.e., the comparison of 8- and 10-item tests is probably valid, while the comparison of 1- and 3-item tests certainly is not valid).

It is not practical to display graphically the mean pressure profile or pressure errors of multiple SACM runs. Because the G_Z profile will be (in most cases) manually controlled, too much run-to-run inconsistency will occur to make a mean presentation meaningful. The purpose of multiple iterations of SACM's is to allow the investigator the opportunity of choosing the "most typical" for analysis.

One of the variables used in this protocol deserves special attention. Using the function, $\int_0^t G(t)dt$, in the graphs and RPET serves to weight suit pressure errors proportionally to the G_Z level at which they occur. In other words, in the graphic presentation, the abscissa increases in value (with respect to elapsed time) at a rate proportional to the G_Z magnitude. As a result, the area under the error curve is proportional to the importance of the error. The resulting influence on the RPET evaluation figures--XIDPA, XIDPB, XIDPC, and XIDPD--is obvious.

6. CONCLUSION

In fulfillment of the research plans outlined at the beginning of this volume, a comprehensive overview of the respective characteristics and performance of six anti-G valves has now been accomplished. The significance of the anti-G valve cannot be overemphasized; for it remains a major component in a system designed to assist in the anti-blackout protection procedures necessary for crewmen under sustained high-G conditions. Hence, a section devoted to the Standardized Anti-G Valve Test Protocol has also been included in this volume.

Related material is available in Volume I (SAM-TR-78-10), which includes descriptions of the elements of data measurement and handling common to the majority of the tests, as well as detailed information on the miscellaneous tests and their results; and Volume III (SAM-TR-78-12), which contains test reports on the Anti-G suit tests, the field-test protocols developed, and the supplemental investigations of the Pneumatic Lever Anti-G Suit.

ABBREVIATIONS, ACRONYMS, AND SYMBOLS

ac	alternating current (In some figures: AC)
ACM	Aerial Combat Maneuver
dc	direct current [also, 0 kHz (or Hz)]
ΔF	difference in flow values
F_V	air flow
G_Z	acceleration along the Z axis (head to foot)
Hz	Hertz (cycles per sec)
kg	kilogram(s)
MD	median
MN	minimum
MX	maximum
NC	normally closed
NO	normally open
P - G	pressure per acceleration
P_S	source pressure
psia	pounds per square inch absolute
psid	pounds per square inch differential
psig	pounds per square inch gage
P_V	suit pressure
RAF/IAM	Royal Air Force Institute of Aviation Medicine (Farnborough, Hants, England)
RPET	Relative Performance Evaluation Table
SACM	Simulated Aerial Combat Maneuver
SAM	School of Aerospace Medicine (Brooks AFB, Tex.)
SCF	standard cubic foot
SCFM	standard cubic feet per minute
SVTP	Standardized Anti-G Valve Test Protocol
v	volt
VAC	volts (alternating current)
VDC	volts (direct current)
VNB	Biodynamics Branch, of the Crew Technology Division, USAFSAM
V_S	suit volume
WRT	with respect to

LIST OF APPENDIXES FOR THE TEHG SERIES: VOLUMES I, II, and III

(Although the information in these Appendixes pertains to all three volumes, most of the data in A - B apply especially to Vol. I; in C - G.2, to Vol. II; and, in H - M.2, to Vol. III.)

A. Mass spectrometer data curves

B. Pressure transducers data curves

C. Hymatic VAG 110-007 anti-G valve data curves

D. ALAR 88535-8400A anti-G valve data curves

E. Bendix FR-139-A2 anti-G valve data curves

F. USAFSAM electronic anti-G valve data curves

G.1. The 10-G mode Honeywell fluidic anti-G valve data curves

G.2. The 50-G mode Honeywell fluidic anti-G valve data curves

H. CSU 12/P anti-G suit data curves

I. CSU 13/P anti-G suit data curves

J. CSU 15/P anti-G suit data curves

K. RAF mini anti-G suit data curves

L. Lower body full pressure anti-G suit data curves

M.1. Bladder USAF pneumatic lever anti-G suit data curves

M.2. Legs USAF pneumatic lever anti-G suit data curves

N. Mass spectrometer data analysis program listing

O. Pressure transducer data analysis program listing

P. Anti-G valve data analysis program listing

Q. Anti-G suit data analysis program listing

R. Supplemental pneumatic lever evaluation program listing

[How to order Appendixes A - R]

RE: The USAF School of Aerospace Medicine's Technical Report Series on Engineering Test and Evaluation During High G--Volume I (SAM-TR-78-10), Volume II (SAM-TR-78-11), and Volume III (SAM-TR-78-12)

APPENDIXES A - R:

In order for comprehensive information on this research to be readily accessible, microfiche have been made of these Appendixes. The microfiche are available, individually or collectively, through:

The Strughold Aeromedical Library
Documentation Section (SAM/TSK)
USAF School of Aerospace Medicine
Brooks AFB, Texas 78235