FOREWORD

This report was prepared by the Physiology Division, Biomedical Laboratory of the 6570th Aerospace Medical Research Laboratories, Aerospace Medical Division, Wright-Patterson Air Force Base, Ohio. The work reported herein represents one phase of the research program being conducted by the Altitude Protection Branch under Project No. 6301, "Aerospace Systems Personnel Protection," Task No. 630104, "Space Protective Garments." The author wishes to express his sincere appreciation to the following personnel who contributed their ideas and efforts to the studies covered in this report:

Fritz K. Klemm
Milton Alexander
Dieter E. Walk
Major Paul W. Lappin
Henry C. Sommer
Willi J. Buehring
2d Lt Darrel L. Haub
Mrs. Lee C. Rock
Charles R. Kimball
Harold S. Pryor
Oswald Rogers
Harald K. Hille
Walter J. Downs
James S. Ater
Warren G. Miller
Paul W. Rinehart

and to Captain Carlton J. Peterson, MC, of the Air Force Logistics Command, Captain Richard A. Davidson, MC, of the Air Force Missile Test Center, and Dr. Cletus J. Muick, of the Research and Technology Division, for their significant contributions to the overall program.

The pressure suits employed were manufactured by the David Clark Company, Worcester, Mass., under the technical direction of Dr. E. G. Vail of the X-20 Engineering Office, Research and Technology Division. These suits were known as "training" rather than "flight ready" garments. The tests were planned to produce specific design and performance information for the X-20 Engineering Office, which provided the cabin environment design values and approved the plan prior to the experiments.

ABSTRACT

A series of experimental procedures was accomplished to demonstrate and measure the protection X-20A (Dyna-Soar) pilots obtain by wearing their custom fitted pressure garments while exposed to simulated mission conditions. Mission conditions were simulated to the extent possible with available altitude and temperature test facilities. Physical characteristics of the garments were determined such as weight, pressure drop with flow, dimensional stability, visual fields, and acoustical attenuation.

PUBLICATION REVIEW

This technical documentary report is approved.

W.H. McCandless
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Technical Director
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TABLE OF CONTENTS

TABLE OF CONTENTS (Cont'd)

Page

LIST OF ILLUSTRATIONS

Page

LIST OF TABLES

X-20A FULL-PRESSURE SUIT QUANTITATIVE PERFORMANCE

J.D. Bowen

INTRODUCTION

In September 1963 the X-20A engineering office at Wright-Patterson Air Force Base, Ohio requested that a program be planned and accomplished to demonstrate the adequacy of pilot protection from the environment to be encountered in the glider's pilot compartment. Secondary purposes of the program were:

(1) to determine and compare physical characteristics of the pressure suits,

(2) to measure the quantity of water exhausted from the suit into the pilot's compartment to provide data for the design of dessicaters, and

(3) to familiarize the pilots with use of their suits under conditions established by cabin environment equipment and the mission conditions.

Background

Previous experience with this type of suit had been gained through evaluation of a prototype suit of medium-regular size about one year earlier. The suits used in this evaluation were custom fitted to each of the pilots selected for the X-20A program. Pilot A and Pilot B accomplished their part of the program in the first week of December 1963. Pilot C and Pilot D completed the evaluation with their participation the following week. The cancellation of the X-20A program terminated the studies during the second week of testing; therefore, Pilot E and Pilot F did not participate.

X–20A PILOT COMPARTMENT ENVIRONMENT

The X-20A engineering office furnished the following pilot compartment environmental information for use in design of this program:

Cabin Temperature (On the Pad)

Random between 74° and 80° F

Cabin Temperature (After Launch)

91° F, rising rapidly to 120° F during descent and landing

Cabin Pressure (In Flight)

7.35 psia, equivalent to an altitude of 18,000 feet.

Suit Ventilation Gas Temperature (On the Pad)

Selectable, 45° to 105° F

Suit Ventilation Gas Temperaturature (In Flight)

Selectable, 45° F minimum

Mass Flow Conditions

In this garment there is no separation of gas for breathing and ventilation. The X-20A design provides the pilot with three mass-flow conditions:

Normal: O_2 at 0.09 to 0.11 lb/min and N_2 at 0.12 to 0.14 lb/min

Emergency: O_2 at 0.18 to 0.22 lb/min

Ground: O_2 at 0.18 to 0.22 lb/min and N_2, 0.42 to 0.50 lb/min

Maximum and minimum values were selected to impose the greatest stress. For example, oxygen at the minimum value of 0.09 lb/min and nitrogen at the maximum value of 0.14 lb/min provided the lowest concentration of oxygen in the Normal setting. For Emergency, 0.18 lb/min of pure oxygen was used. For Ground, the flow was 0.18 lb/min of oxygen plus 0.50 lb/min of nitrogen. The volume flow in the X-20A with the selection of Normal or Ground could have been slightly less than those used if the nitrogen flow was below the maximum tolerance value.

Cabin Decompression

Suit pressure in any decompression of the cabin is limited to 5 psia by the automatic exhaust gas controller on the suit, providing there is a sufficient flow of ventilation gas to the garment. Simulation of decompression was limited by vacuum pump capacity to approximately 1 psia in the test chamber.

SIMULATION OF X–20A MISSION

Simulation of missions required the control of ambient temperature, altitude, and ventilation, with particular attention to the constituents of the ventilation gas, its humidity and temperature. The Aerospace Medical Research Laboratories Environmental Test Facility was used as the test chamber. The automatic chamber control system was set up with control instrument charts designed for the altitude and temperature values needed in the visor fogging test. A separate set of charts simulated the mission.

An air-source apparatus provided means of pumping, dehumidifying and establishing the proper temperature of clean air. This apparatus was modified by incorporating an oxygen-metering system and supplemental flow-measuring instrumentation so that each vent condition could be readily established. It was much more economical and expeditious to use air and add sufficient oxygen to obtain the proper oxygen concentrations than to obtain both oxygen and nitrogen from commercial stored-gas cylinders. The dewpoint of vent gas from the air source was held well below +32° F. Although this is not as dry as the cryogenic stores in the X-20A, it is adequate for test purposes.

THE X–20A FULL–PRESSURE SUIT

Five custom-fitted suits were utilized in this evaluation. These suits contain a restraint layer of "link net" and a torso-circling entrance closure. The glove disconnects provide wrist rotation through the use of sealed bearings. The pressure-sealing closure has a common slide fastener placed over it which carries a portion of the force. Sizing lacings are included for adjusting arm and leg lengths.

The helmet is not a final "flight" configuration model but a "training" model of the dome type. A head protector that contains the communication headset is worn with the helmet. Space is provided for head turning and limited nodding. The visor pivots vertically inside the helmet shell, and seals against a rubber gasket by moving forward when in the "down" position.

The visor is opened by pressing down on the lever located at the left-front area below the visor and lifting the visor against slight spring pressure until it latches at the top. Depressing the lever moves the visor back into the helmet until it is free to rotate upward. The visor can also be opened by pushing inward and then upward with the hands. An altitude-controlled, visor-release latch was planned for the "flight" configuration but was not incorporated into the "training" models. The helmet attaches to the suit with a disconnect ring identical to that on the AF Type A/P22S-2 outfit but with no rotation bearing. The bottom half of the ring is anchored to the restraint layer.

A helmet tiedown device is not provided nor needed with the X-20A pressure suit. A thin layer of insulation is provided on the outside of the restraint layer as well as on the leather boots.

The exterior of the integrated coveralls is completed by a layer of thin cloth, international orange in color. The coveralls include a port in the right-thigh area for passage of instrument wiring which in these evaluations consisted of ECG leads, thermistor leads, and the oxygen partial-pressure-sensor leads. For sound attenuation tests, a special microphone was placed in the helmet with leads sealed through this port. The left-thigh area contains an absolute pressure gauge calibrated in thousands of feet, starting at 30,000 feet. This is the standard gauge used in the A/P22S-2 outfit and shows no deflection as long as the X-20A suit maintains a pressure equivalent below 30,000 feet.

An exterior garment fabricated of sturdy aluminized fabric contains the parachute harness and the flotation vest. Ventilation gas used with this garment must be of breathable quality and must provide adequate oxygen partial pressure. The gas enters the lower opening on the pressure controller located on the lower-right side of the chest and is distributed over the body and into the helmet. Exhaust ducts collect the gas and discharge it through the upper opening on the controller.

A hose equipped with a manual-disconnect conveys the ventilation gas overboard in the X-20A during launch pad "countdown" as a means of minimizing moisture content in the glider. Minor design variations were noted in the suit exhaust ducting, eg, Pilot D's suit did not route all the flow up to the neck area to enter the exhaust ducts, but instead utilized an opening located near the midline at the front of the torso.

The arms of the suits are designed to be nonsymmetrical since the pilot work space requires the right hand and arm to be "down" operating a sidestick controller while the left arm is "up" operating a variety of controls. For this reason and because numerous workplace tests had been accomplished previously in pilot compartment mockups, no workspace evaluation or arm-reach measurements were made.

PROCEDURES AND RESULTS

Weight

The weight of each part of the assemblies and the total was determined to the nearest 4 grams using a precision balance. The values are presented in table 1.

TABLE 1

WEIGHT OF COMPONENT PARTS
(pounds)

Component Parts	Pilot A	Pilot B	Pilot C	Pilot D
Helmet (dome)	4.95	5.29	5.11	5.10
Buffet Hel.	1.04	1.04	1.02	1.06
R. Glove	0.46	0.45	0.38	0.38
L. Glove	0.46	0.46	0.38	0.38
Torso	12.61	13.27	12.26	12.52
R. Bootie	0.13	0.14	0.14	0.10
L. Bootie	0.14	0.14	0.14	0.10
R. Shoe	1.50	1.70	1.56	1.65
L. Shoe	1.54	1.71	1.58	1.65
Coverall	5.24	5.42	5.20	5.44
Neck Ring Pad	-	0.12	-	-
Assembly Total	28.07	29.74	27.77	28.38

Leak Rate

Pressure suit leakage was measured by using oxygen flowing through a rotometer to maintain a constant pressure. Readings were made after values held essentially unchanged for one minute. Determinations were made by increasing and decreasing the suit pressure in steps. Initially the visor seal is improved by the rising suit pressure. Pilot B's suit had a high leak rate but this did not hinder completion of the planned program. Results are presented in figure 1. One helmet leaked excessively around the visor opening lever, but minor servicing stopped the leak.

Stretch

Measurements of the empty suit, pressurized to 5 psig, made before and after the validation indicated no significant change except for axillary chest circumference. The data are presented in table 2. The procedure is depicted in figure 2

Pressure Loss with Flow (Suit Only)

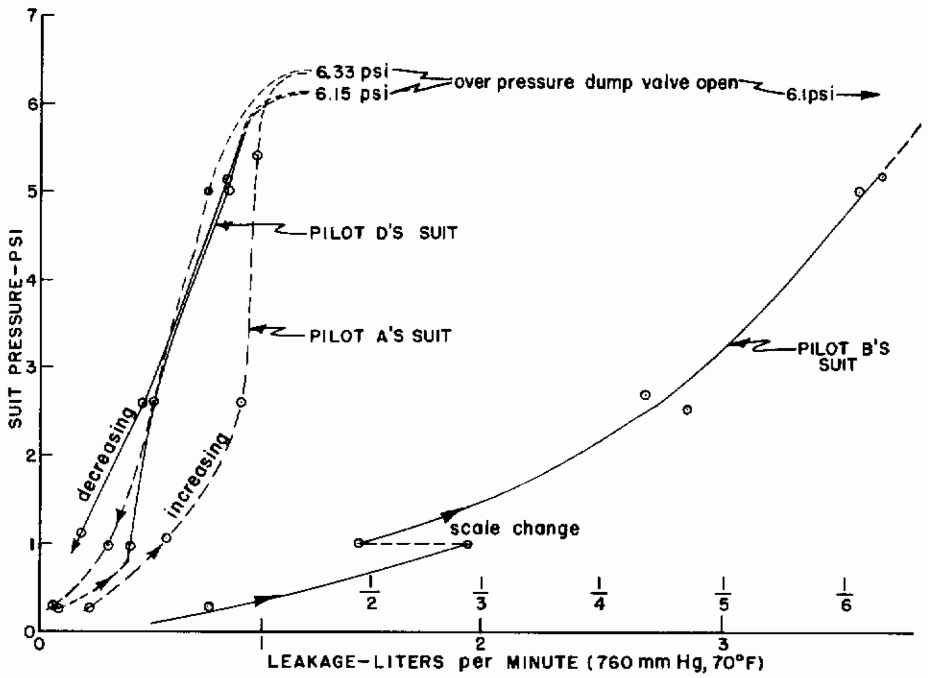
Flow-pressure drop characteristics were determined using air flowing through the suit in three different situations. First, with the visor open the air exhausts through this opening and the pressure loss measured is for the inlet and ventilation distribution system. Next, with the visor closed the air passes through the discharge ducting and pressure controller adding their resistance. Finally, the suit is pressurized to 5 psig by restricting flow from the outlet with a common needle valve. This pressure drop is only for the inlet and ventilation distribution system, since the pressure drop was measured from inlet to helmet and can only be compared with the data obtained with visor open to illustrate the effect of pressurization. Results are presented in figure 3.

Pressure Loss with Flow (Pilot in Suit)

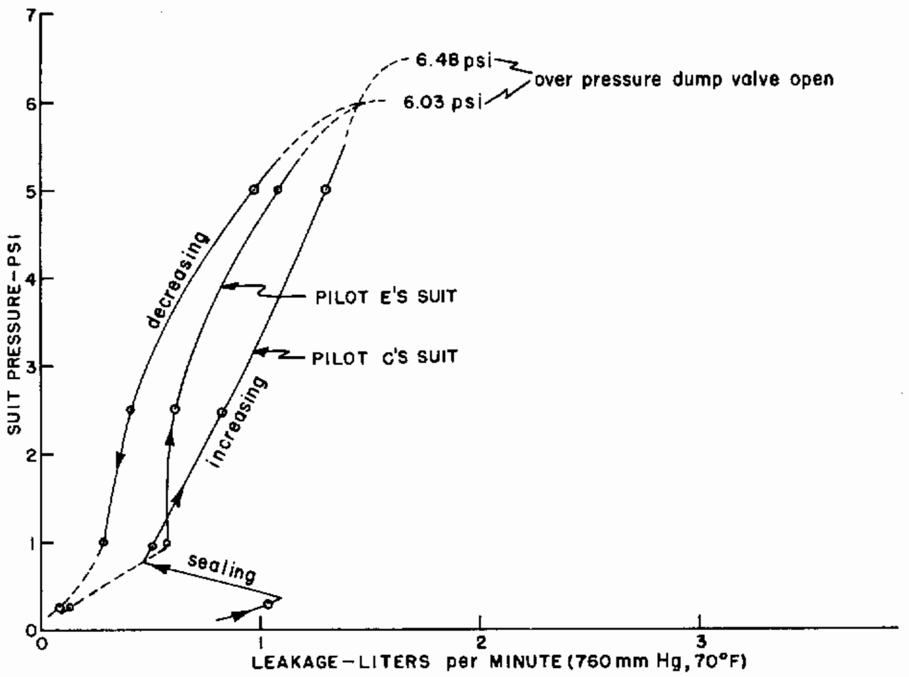
The preceding same method of determination was also used to illustrate the effect of having the pilot wear his suit. Results are presented in figure 4. Note that the pressure drop scale has been doubled and that the drop in pressure has for all practical purposes doubled, with the exception of that for the inlet system at 5 psig. There is a correlation between tightness of fit as well as the physical configuration of the ducts, with the pressure drops measured.

Suit Pressure at Altitudes

The pressure established by the action of the barometric loading device in the controller was measured while approximately 5 cfm of air flowed through the suit. All of the controllers operated as expected, holding a pressure slightly above 5 psia in the suit. During the run with Pilot A's suit, a sudden decompression



Suits for Pilots A, B and D



Suits for Pilots C and E

Figure 1. Leak Rate from Suit

TABLE 2

SUIT STRETCH

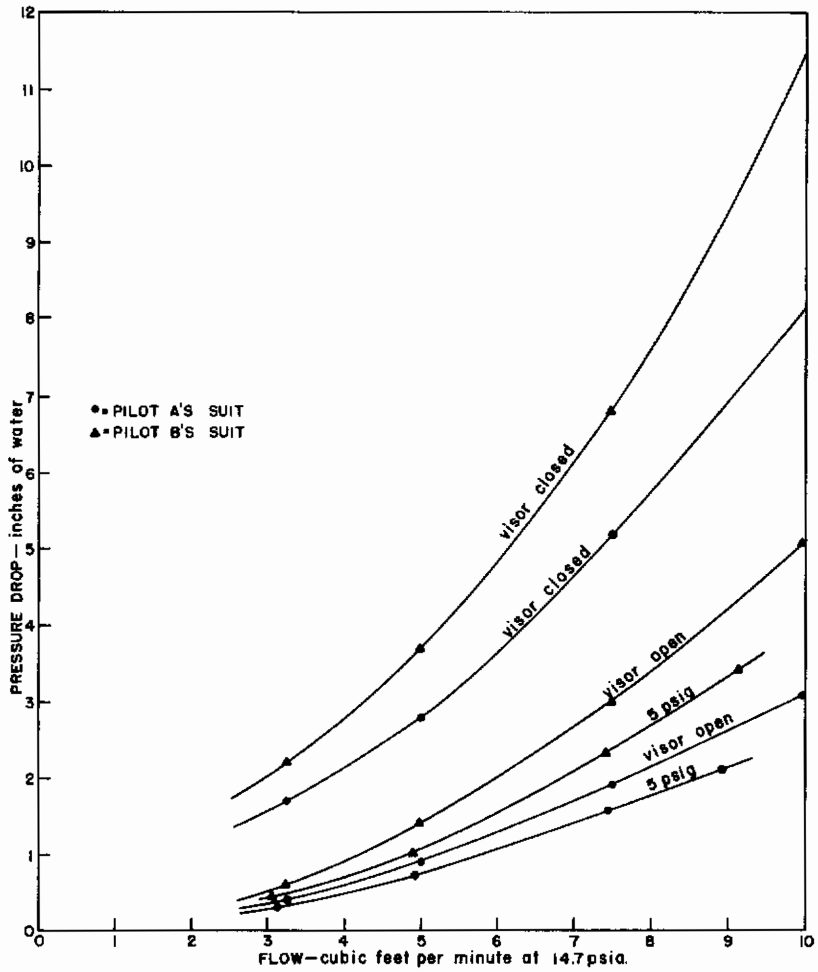
Empty Suit Size at 5 psig Before (1) and After (2) Program (inches)

Circumference	Pilot A (1)	Pilot A (2)	Pilot B (1)	Pilot B (2)	Pilot C (1)	Pilot C (2)	Pilot D (1)	Pilot D (2)
Axillary Chest	41.5	41.4	44.4	45.6	42.0	44.0	42.3	44.6
Upper Thigh	24.4	24.1	26.2	26.3	28.4	28.0	24.1	25.5
Mid Calf	17.8	17.9	18.3	18.7	18.7	18.4	17.5	17.2
Arm Scye	21.0	20.8	22.4	22.3	22.7	23.4	19.5	20.0
Percent Axillary Chest Circumference Increase	0		2.7		4.7		5.4	

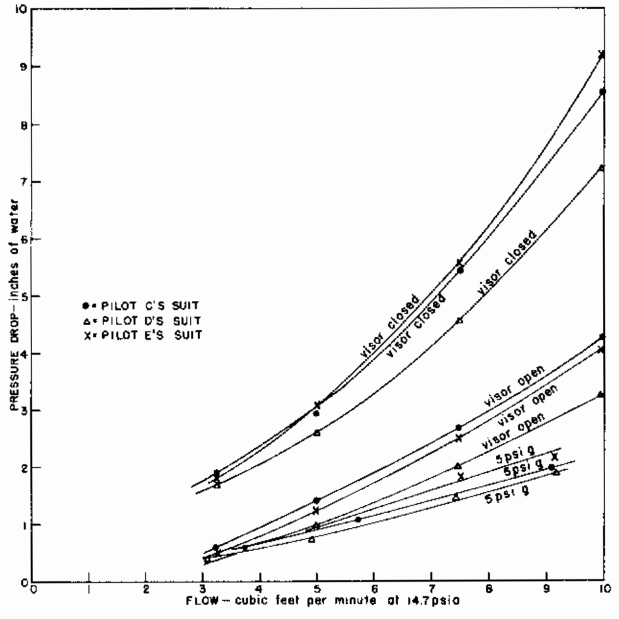
Axillary Chest Circumference

Arm Scye

Figure 2. Measurement of Empty Suit (Pressurized to 5 psig)



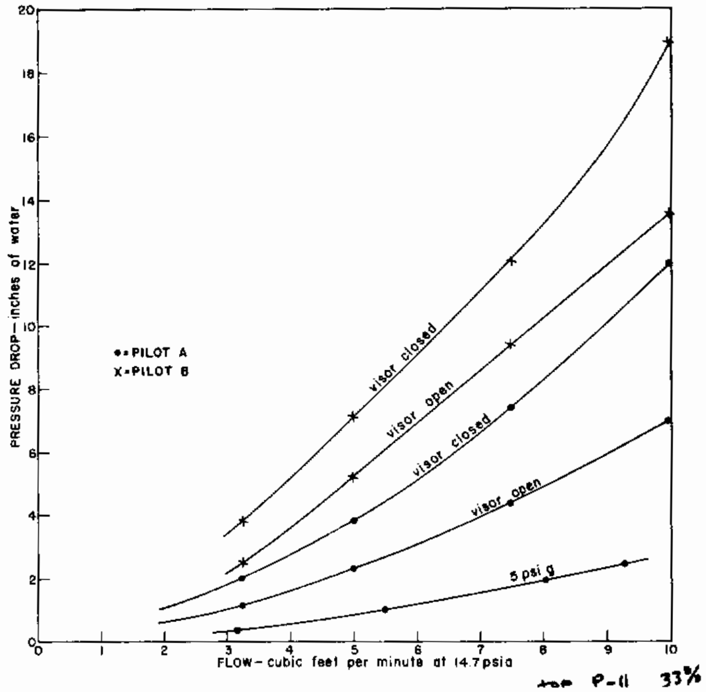
Suits for Pilots A and B



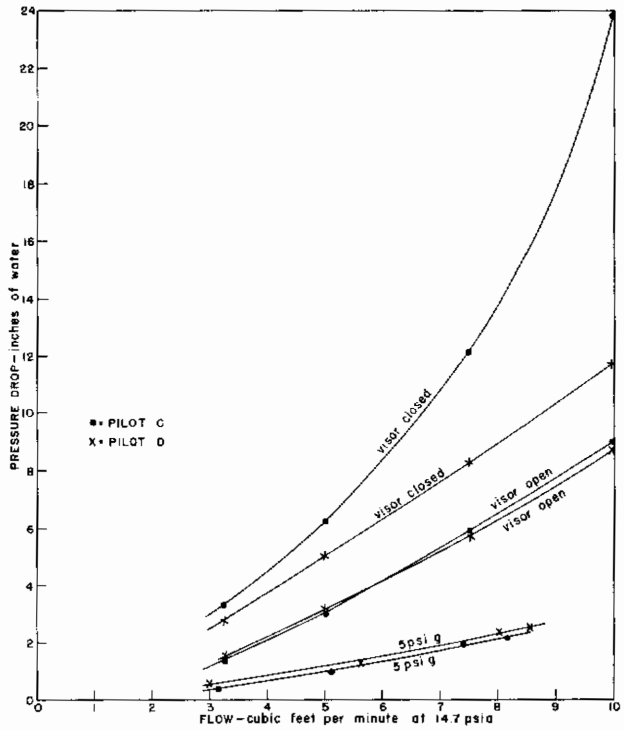
Suits for Pilots C, D and E (left)

Figure 3

Pressure Drop versus Flow (Suit Only)



Pilots A and B



Pilots C and D

Figure 4. Pressure Drop versus Flow (Pilots Suited)

occurred at about 3 psig. This helmet visor was capable of closing too far when released. It would hold pressure at lower levels and then dump. Raising the visor until its metal lip caught on the undercut lower rim of the visor opening produced an effective seal. The results are presented in figure 5. Note the two plotted values that can be added at any given point to obtain the absolute pressure in the suit.

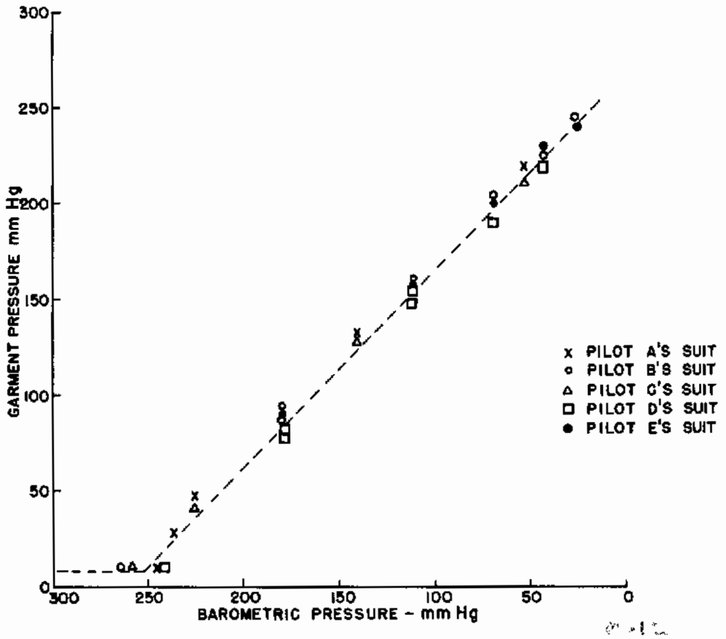


Figure 5. Barometric Pressure versus Suit Pressure (Established Automatically by Restriction of Discharge Flow)

Physical Measurements of Pilots (Nude and Suited)

To determine later whether there had been any appreciable change in body weight or error in garment sizing, each pilot was weighed and measured in the nude before the test series. These measurements are given in table 3. To demonstrate the enlargement with pressure, measurements were taken with the pilots in their suits at 0.4 psig, at 3.5 psig and at 5 psig. These "ballooning" measurements are given in table 4. Figure 6 shows the procedure.

TABLE 3

NUDE WEIGHT (pounds) AND NUDE MEASUREMENTS (inches)

	Pilot A	Pilot B	Pilot C	Pilot D
Weight	140	189	154	159
Height	64.9	71.25	66.95	68.3
Chest Circ	36.5	39.4	38.2	38.7
Waist Circ	30.0	34.2	32.2	32.1
Buttock Circ	35.1	39.4	37.0	36.7
Upper Thigh Circ	20.6	23.5	23.0	20.5
Lower Thigh Circ	15.3	17.3	14.8	16.3
Calf Circ	13.9	15.5	14.2	14.1
Ankle Circ	7.9	9.5	8.5	8.4
V.T.C.*	62.9	67.6	64.1	62.5
Sleeve Length	31.7	34.9	33.7	35.0
Crotch Height	31.8	32.5	31.25	32.5
Chest Breadth	11.25	12.85	12.65	13.45
Waist Breadth	10.45	12.15	11.9	12.1
Hip Breadth	12.45	14.35	13.05	13.1

*Vertical Trunk Circumference

TABLE 4

BALLOONING MEASUREMENTS (in inches)—PILOT WEARING SUIT

	Pilot A			Pilot B		
	0.4 psi	3.5 psi	5 psi	0.4 psi	3.5 psi	5 psi
Axillary Chest Circ	41.7	42.7	42.9	43.2	45.35	45.5
Waist Circ	38.9	39.6	39.75	41.7	42.7	42.9
Axillary Arm Circ	(16.4 ?)	15.3	15.4	16.5	18.2	18.2
Forearm Circ	13.8	14.2	14.5	14.2	14.7	15.2
Thigh Circ	19.7	20.4	20.6	19.5	21.3	21.6
Calf Circ	17.2	18.3	18.6	17.2	19.2	19.3
Shoulder Breadth	21.65	22.5	22.65	20.85	22.05	22.5
Elbow-Elbow Breadth	20.25	21.5	22.15	22.7	25.2	25.7
Hip Breadth	13.55	14.55	14.35	15.35	15.5	16.25
Hand Length	---	---	---	7.9	7.45	---
Thigh Clearance	26.8	28.2	28.25	26.55	27.9	28.1
Helmet Rise*	35.75	36.1	36.1	37.0	38.45	38.6
	Pilot C			**Pilot D**		
	0.4 psi	3.5 psi	5 psi	0.4 psi	3.5 psi	5 psi
Axillary Chest Circ	43.0	44.0	44.5	43.0	44.8	44.7
Waist Circ	40.2	40.75	41.0	40.1	40.8	41.0
Axillary Arm Circ	17.1	18.0	18.3	15.3	16.2	16.2
Forearm Circ	14.2	14.3	14.4	14.2	14.4	14.5
Thigh Circ	20.0	21.7	21.6	19.6	20.3	20.3
Calf Circ	17.6	18.5	18.5	17.5	18.5	18.7
Shoulder Breadth	22.35	23.2	23.25	22.3	23.3	23.3
Elbow-Elbow Breadth	22.1	23.8	23.9	20.9	21.85	22.4
Hip Breadth	14.95	15.25	15.25	13.8	14.3	14.3
Thigh Clearance	27.3	28.95	28.85	24.2	25.7	25.2
Helmet Rise*	35.1	36.1	36.45	36.6	37.6	38.0

*Sitting height

Forearm Circumference

Shoulder Breadth

Figure 6. Physical Measurements of Suited Pilots

Dexterity of the Hands

The manipulative dexterity of the hands was measured in three conditions:

Barehanded, but wearing full ensemble otherwise, and unpressurized

Gloved, but unpressurized while wearing full ensemble

Gloved and pressurized in full ensemble to 2.5 psig

The procedures as outlined by the Purdue Pegboard Manual were followed, except that the pegboard was turned 180° during the pressurized trials so that mobility restrictions of the pressurized suit would not influence test results. This 180° rotation brought the board cups close to the subject so that he did not have to extend his arm but use only his wrist-and-finger mobility.

The hands ranged in length from 180 mm to 205 mm or from about the 14th to the 96th percentile, and in circumference from 202 mm to 216 mm (since circumference was not taken in 1950, no mass percentile figures are available for this dimension). Note, however, that all gloves had been tailored to the four subjects. All subjects considered themselves right-handed.

The results shown in table 5 were obtained from the four subjects. The scores represent totals for three trials.

Table 6 summarizes these results. If Condition 1 is considered to be optimal performance, ie, 100%, then figures for Conditions 2 and 3 are the percentages of performance retained in each situation. Thus, despite the small sample, the trend in loss of dexterity for this task seems clear. Figure 7 shows the method used.

Visual Fields Through the X–20A Visor

Visual field measurements were made using the apparatus shown in figure 8. The results were as follows:

Ventilation Pressure

With head and eyes fixed in primary position, the visual fields showed a slight constriction downward with no significant change upward.

With head and eyes turned maximally, helmet fixed, visual rotation fields showed approximately 50° superior and 30° lateral constrictions from the normal rotation fields. There was no downward constriction, the inferior field being cut off by the projection of the seat rather than by the helmet.

TABLE 5

HAND DEXTERITY

Subjects	Right Hand	Left Hand	Both Hands	Assembly
		Barehanded (Condition 1)		
Pilot A	51 (50%)	54 (83%)	44 (84%)	146 (93%)
Pilot B	47 (25%)*	52 (73%)	40 (53%)	145 (93%)
Pilot C	58 (91%)	59 (97%)	47 (94%)	140 (89%)
Pilot D	44 (13%)	42 (12%)	35 (16%)	102 (17%)
TOTALS	200	207	166	533
		Gloved (Condition 2)		
Pilot A	41	38	30	99
Pilot B	32	30	23	67
Pilot C	33	39	27	69
Pilot D	31	31	22	71
TOTALS	137	138	102	306
		Gloved (Condition 3)		
Pilot A	26	23	18	61
Pilot B	22	16	10	42
Pilot C	25	29	17	47
Pilot D	25	15	14	51
TOTALS	98	83	59	201

*All percentages (in parenthesis) indicate the rating of each subject in the standard percentile tables of the Purdue Pegboard Manual.

TABLE 6

MEAN PERCENTILES ($\overline{X}$%) TOTALS

Condition	Right Hand	Left Hand	Both Hands	Assembly
1	100	100	100	100
2	68	67	61	57
3	49	40	36	38

Condition 1

Condition 3

Figure 7. Dexterity of the Hands

Figure 8. Visual Field Apparatus

Pressurized to 5 psig

Pressurization showed no significant changes from the fields taken with ventilation pressure. There was a slight increase in the superior field and a corresponding decrease in the inferior field. This was apparently due to a rise of the helmet, since no restraints were used. All visual and rotational fields are considered to be completely adequate for the required tasks.

Visor Fogging

The visor fogging evaluation was designed to produce a maximum of information in the least amount of test time. It was necessary to establish ventilation rates, temperatures and altitudes in combinations expected to gradually increase the probability of fogging within the range of conditions expected in the X-20. To determine the effect of an antifog solution (Sprite ® applied sparingly), only part of the inside surface of the visors were treated. The conditions achieved during these four simulated flights are illustrated by figure 9 and by table 7 which present conditions and typical data.

The visor was divided into four quadrants, with antifog solution applied to the upper right and lower left quadrants. Thermisters were attached to the center of the visor to measure the temperatures of the inner and outer surfaces. Separate visual acuity readings with each eye were taken at five-minute intervals. The decrement in acuity was used as a measure of the degree of fogging on the inside surface of the visor. The data on Pilot C were not used. No fogging occurred on either of the

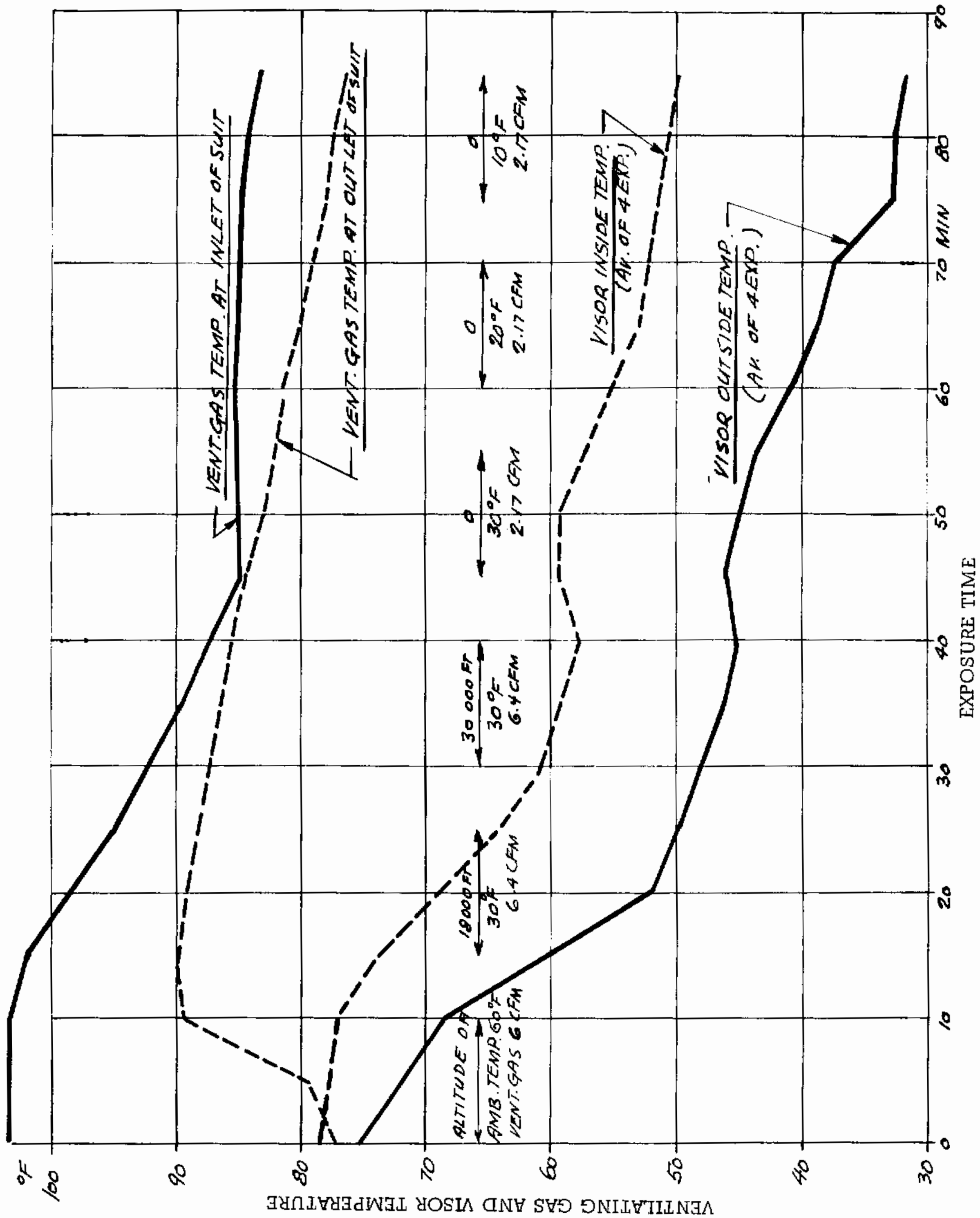


Figure 9. Visor Fogging

TABLE 7

VISOR FOGGING - TYPICAL CONDITIONS AND DATA

	TEST CONDITIONS			VENT GAS		SUIT CONDITIONS			
Subject	Time-min	Altitude x 1000 ft	Temp °F	lb/min	ft^3/min	% O_2	PPO_2 mmHg	Pressure mm HG	Remarks
Pilot A	10	0	60	0.45	6	29	- -	15	Air Flow 100 ft/min Air and Walls Cooled
	15	18	30	0.23	6	37	- -	10*	
	15	30	30	0.18	6.4	100	- -	40	
	10	0	30	0.18	2.2	100	- -	5*	
	15	0	20	0.18	2.2	100	- -	5*	Moderate Fogging of Untreated Area
	15	0	10	0.18	2.2	100	- -	5*	
Total	80								
Pilot B	Sinus pain during descent check necessitated omission of 30,000 foot portion. Otherwise conditions and results were similar to Pilot A's.								Visor opened to accomplish valsalva maneuver. Heavy fog on untreated area
Pilot C	10	0	60	0.45	6	29	185	12*	Air Flow 100 ft/min Air and walls Cooled
	15	18	30	0.23	6	37	135	10*	
	15	30	30	0.18	6.4	100	250	45	
	15	0	30	0.18	2.2	100	700	5*	
	15	0	20	0.18	2.2	100	700	5*	Light Fogging of small side areas
	20	0	10	0.18	2.2	100	700	5*	
Total	90								
Pilot D	Conditions similar to Pilot C's								Moderate Fogging during last 30 minutes

* Estimate of readings below calibration marks

upper quadrants of his visor because the antifog solution was inadvertently applied to the visor over the visual points of both eyes. Figures 10, 11 and 12 show the relationship of visual acuity and inside visor temperature versus elapsed time. Figure 13 shows the mean readings for the three individuals.

Evaluation

In no case did decrement to vision occur through the quadrants that were coated with antifog solution. Pilot B reported some moisture on the upper left quadrant (coated quadrant) after 55 minutes, however, he still had 20/20 reading capability through it.

Fog began to appear on the untreated side after about 30 minutes, when the temperature of the inner surface had reached about 60° F, although a decrement in vision did not occur in all cases since the fog was patchy, with some clear areas. In all cases, the fog became solid on the untreated side about 10 to 15 minutes after the temperature had reached 60° F. In two cases the fog remained solid throughout the remainder of the test, but Pilot A reported that the fog began to get patchy again at 75 minutes and his vision improved, even though the temperature of the inner surface was down to 51° F.

Summary

The antifog solution proved to be completely effective in keeping the visor free of fog under the test conditions. Without treatment the visors began to fog when the temperature of the inner surface reached about 60°, and became completely fogged after remaining at this temperature for 10 to 15 minutes. Figure 14 shows a pilot ready to begin the visor-fogging run, and figure 15 shows the test setup for projecting the image on a screen mounted in the chamber window.

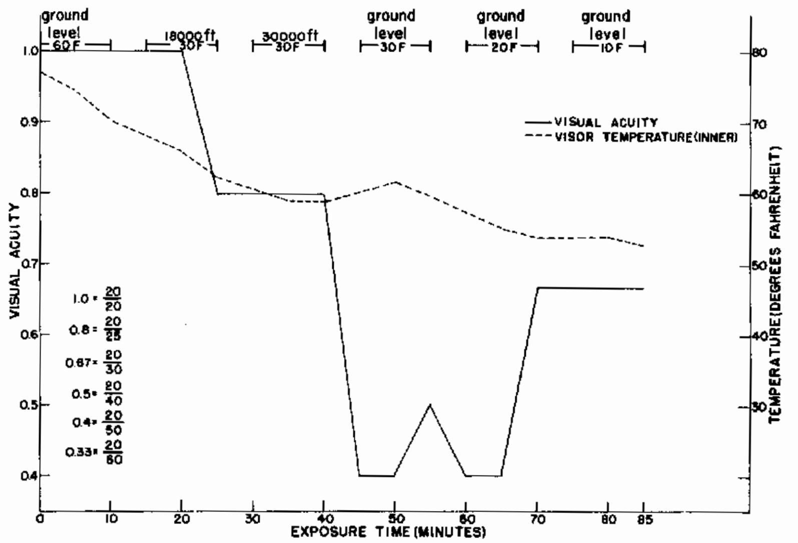


Figure 10. Visual Acuity and Inside Visor Temperature versus Elapsed Time (Pilot A)

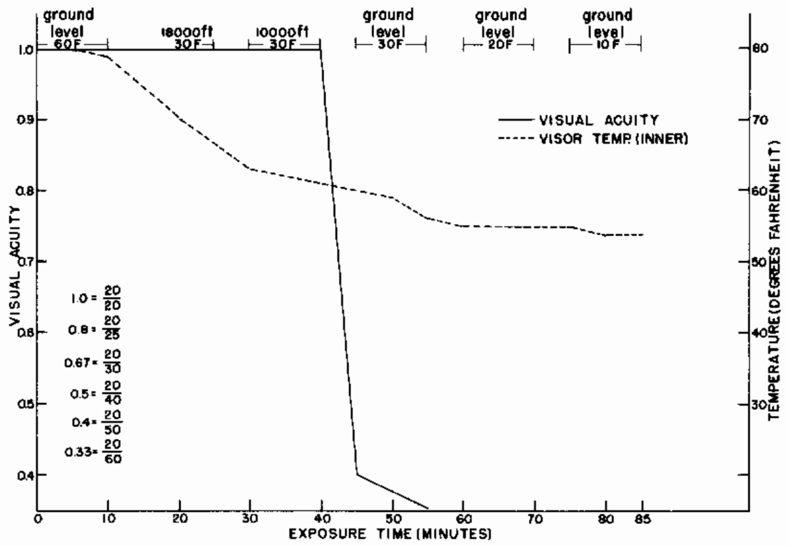


Figure 11. Visual Acuity and Inside Visor Temperature versus Elapsed Time (Pilot B)

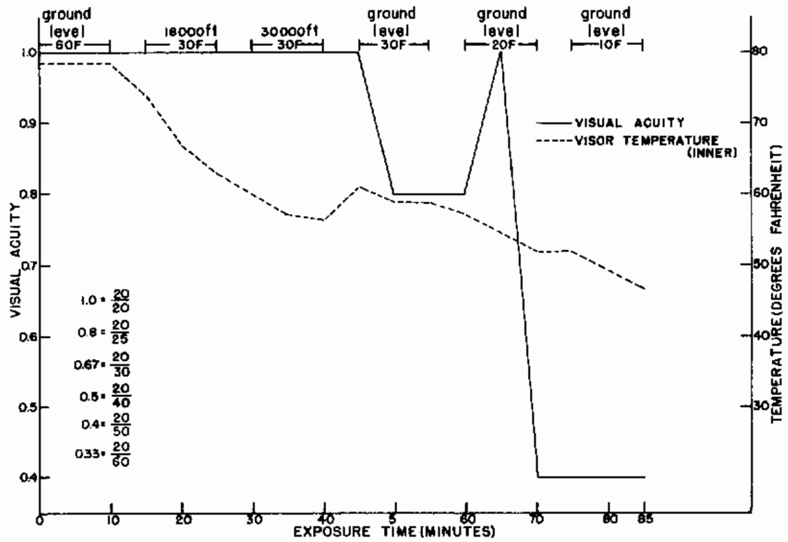


Figure 12. Visual Acuity and Inside Visor Temperature versus Elapsed Time (Pilot D)

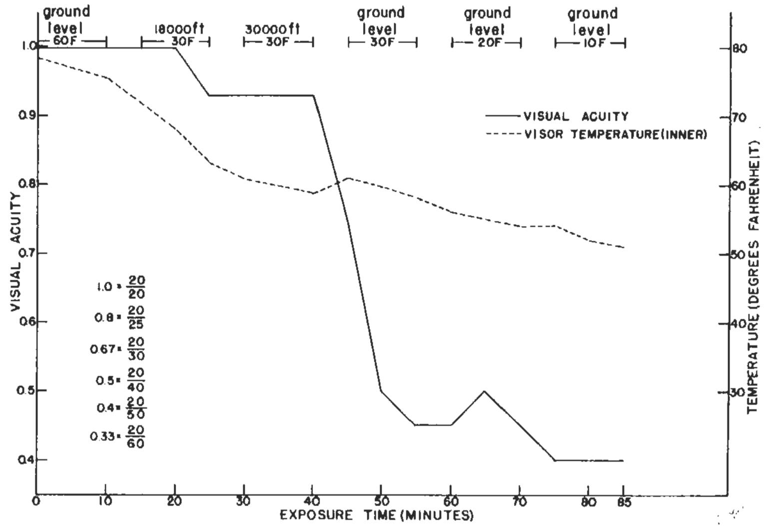


Figure 13. Mean Values of Visual Acuity and Inside Visor Temperature versus Elapsed Time (Pilots A, B and D)

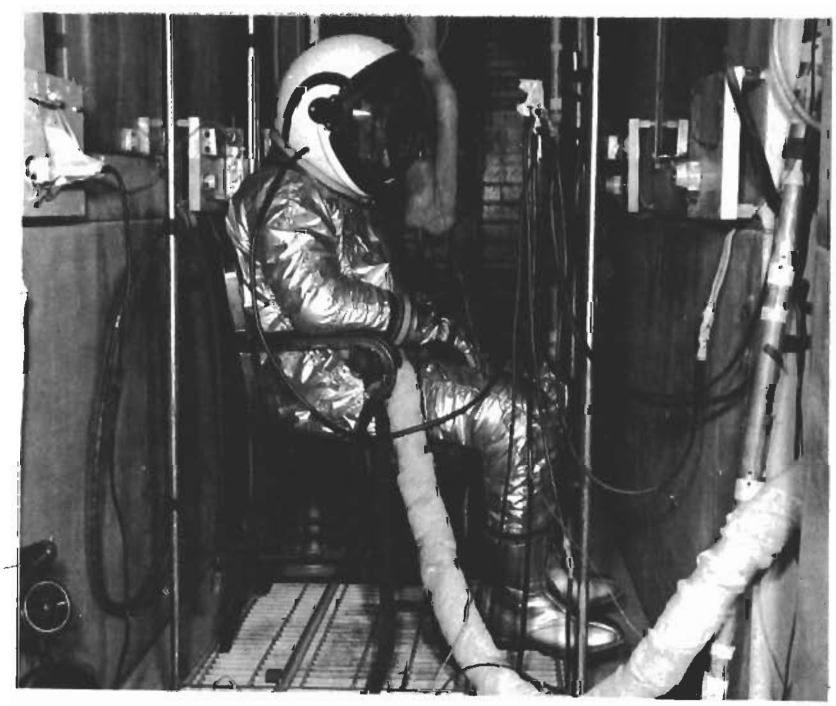


Figure 14. Beginning Visor Fogging Run

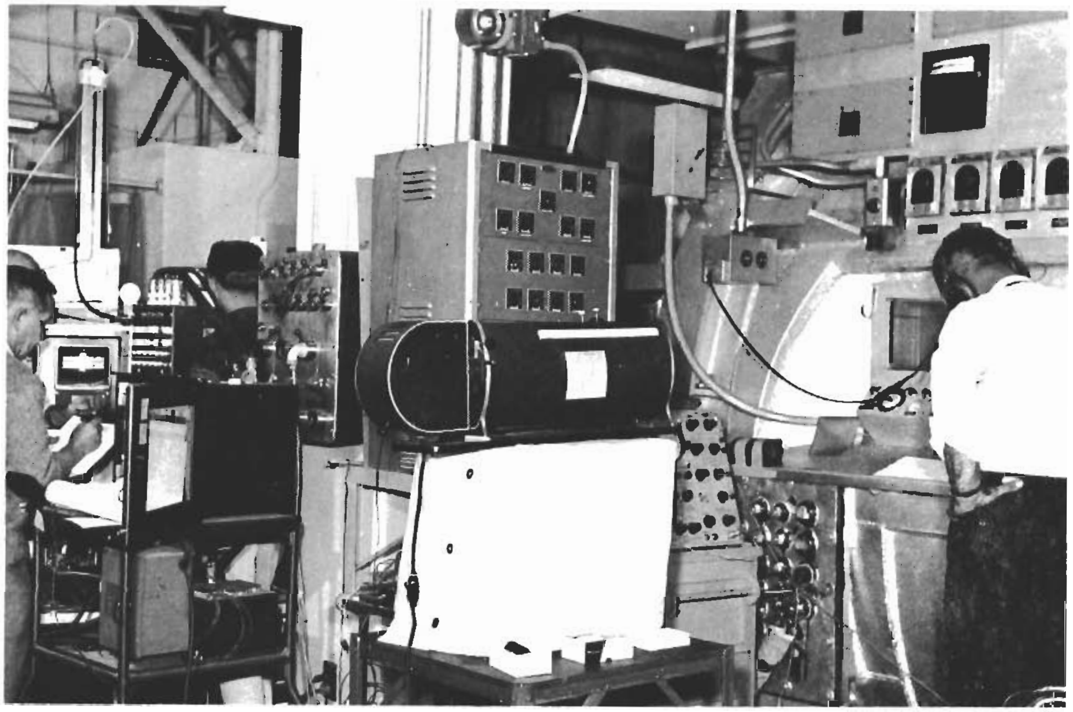


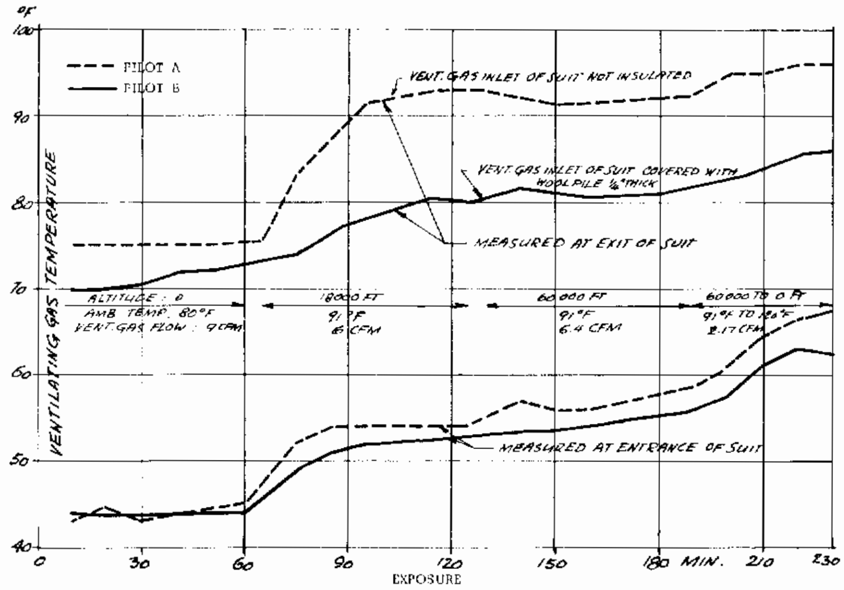
Figure 15. Test Setup for Projecting Image

Mission Simulation

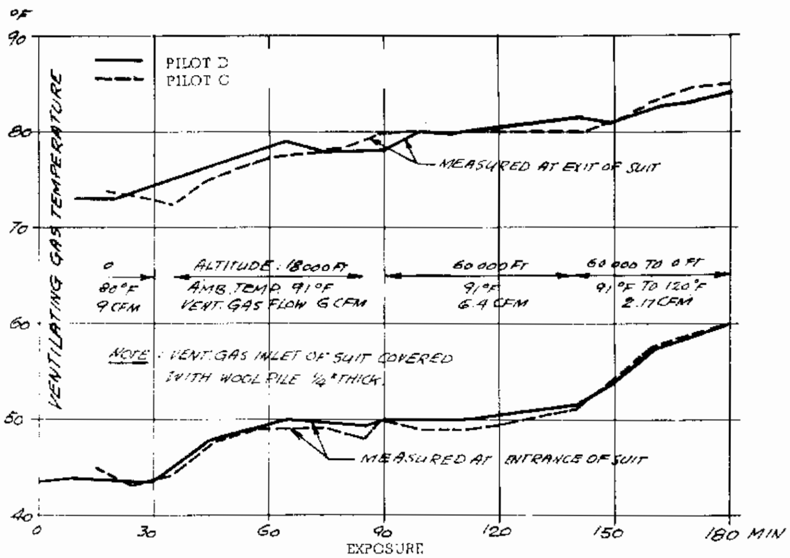
Mission simulation was designed to produce all possible combinations of temperature, altitude, and ventilation that would be most stressing to the pilot. Prelaunch conditions were followed by normal flight conditions; then by cabin decompression and emergency ventilation conditions; and finally by reentry and landing, utilizing only the emergency ventilation. The total mission was intended to take at least as long as a flight mission , including ground time on each end.

Each set of conditions was held constant for a period sufficient to determine rate of evaporation from weight loss as measured by the automatic balance in the test chamber. Figure 16 shows the ventilating gas temperature at the suit inlet and outlet. Even though the ventilation hose was well insulated, it was impossible, at the small flow rates required after launch, to hold the ventilation gas temperature as low as desired. The resultant loss of heat-removal capacity was very small due to the low mass-flow rate.

All of the pilots felt that the ventilation was inadequate during flight simulation.and practically nonexistent at ground level when an emergency flow of 2.2 cfm was employed. Nevertheless they all completed the simulation minus undue stress , as indicated by the heart rates shown on figure 17. Whether the pilots would have been able to accept the added stress of an actual flight reentry and landing with emergency ventilation was not determined. Compilation of typical conditions and results are presented in table 8. Figure 18 shows pilots prepared for this run, and figure 19 shows a part of the weighing system.

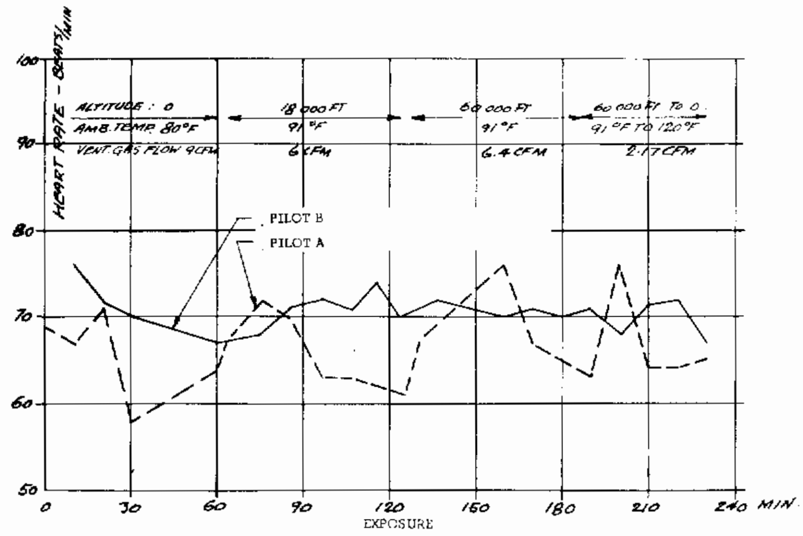


Pilots A and B

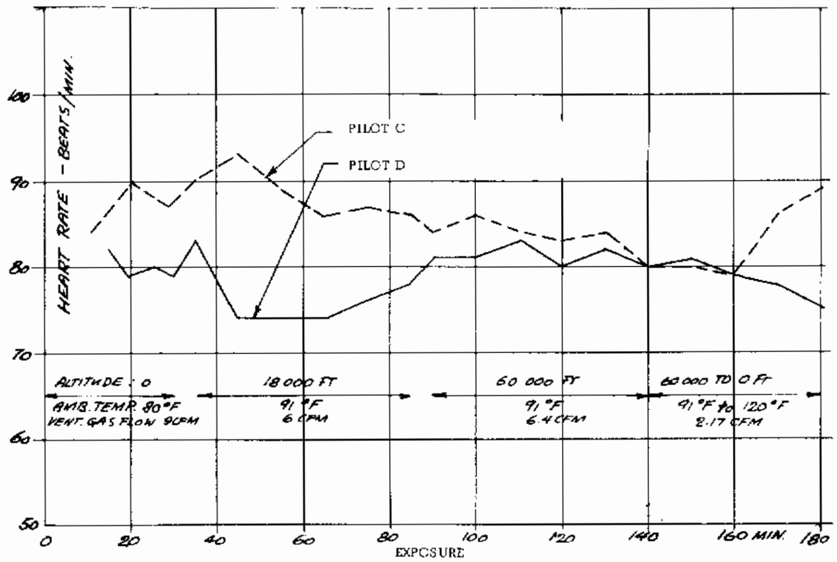


Pilots C and D

Figure 16. Ventilating Temperature at Inlet and Outlet of Suit



Pilots A and B



Pilots C and D

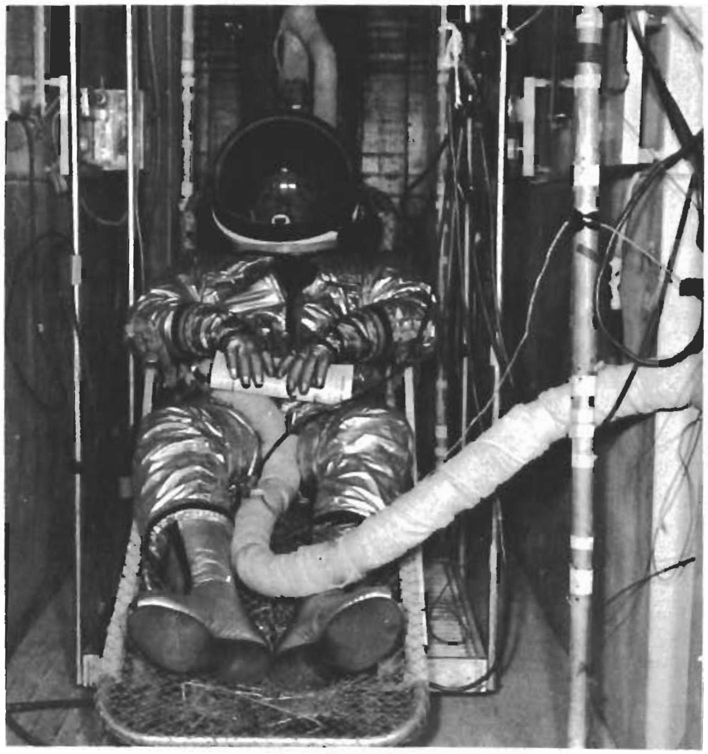
Figure 17. Heart Rate During Mission Simulation

TABLE 8

MISSION CONDITION SIMULATION

Subject	Test Conditions			Vent Gas			Suit Cond		Sweat Evap Grams/hr	Total Sweat Loss/Grams	Total Sweat Evap/Grams
	Duration Min	Altitude × 1000 ft	Ambient Temp °F	lb/min	ft^3/min	$\% O_2$	$pp O_2$ mm Hg	Press mm Hg			
Pilot A	60	0	80	0.68	9	26	--	23	40		
	65	18	91	0.23	6	37	--	10*	40		
	65	60	91	0.18	6.4	100	--	216	67		
	40	Reentry	91-120	0.18	2.2	100	--	5*	50		
Total	230									312	188
Pilot B	60	0	80	0.68	9	26	--	30	70		
	65	18	91	0.23	6	37	--	10*	65		
	65	60	91	0.18	6.4	100	--	218	195		
	40	Reentry	91-120	0.18	2.2	100	--	5*	75		
Total	230									756	408
Pilot C	30	0	80	0.68	9	26	190	25	60		
	55	18	91	0.23	6	37	135	10*	55		
	55	60	91	0.18	6.4	100	245	220	160		
	40	Reentry	91-120	0.18	2.2	100	670	5*	70		
Total	180									444	276
Pilot D	30	0	80	0.68	9	26	185	20	75		
	55	18	91	0.23	6	37	132	10*	70		
	55	60	91	0.18	6.4	100	230	230	200		
	40	Reentry	91-120	0.18	2.2	100	560	5*	75		
Total	180									524	344

*Estimate of reading below calibration marks.



Entering Test Chamber

Beginning of Run

Figure 18. Mission Simulation

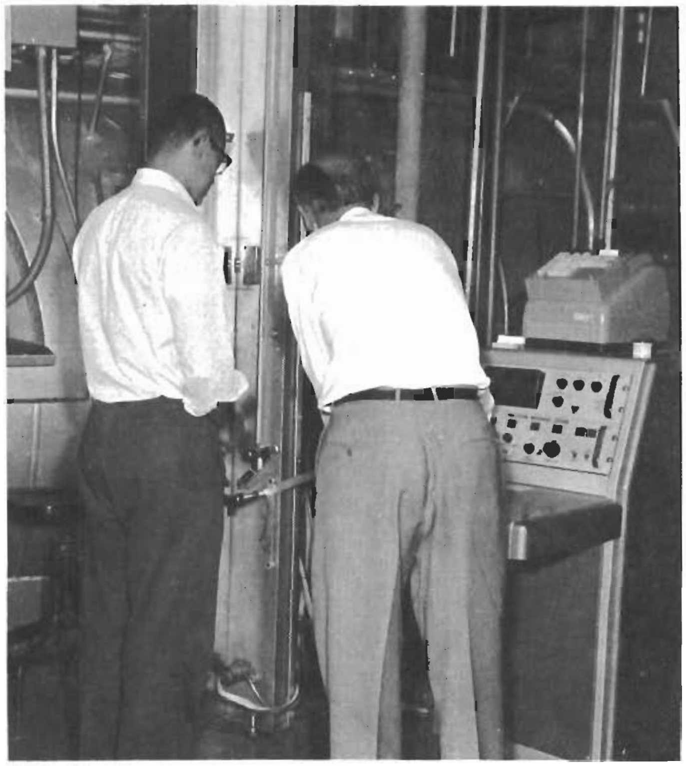


Figure 19. Part of Weighing System

ACOUSTIC EVALUATION

Noise attenuation characteristics of the pressure suit and helmet assembly were determined from two points of view: (1) how well the assembly reduces outside noise at the ear, and (2) how well the assembly reduces outside noise at the helmet microphone.

Noise Reduction at the Ears

Test Procedure:

Noise reduction at the ear is measured by determining the shift free field in hearing threshold induced by the assembly, and is in accordance with the American Standard Association Method for the Measurement of Real-Ear-Attenuation of Ear Protectors at Threshold (REAT)*. (See figure 20.)

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*Standard Z24.22-1957. American Standards Association, United Engineering Center, 345 East 47th Street, New York, N.Y.

Figure 20. Measuring Noise Reduction at Ear

Threshold data for nine discrete frequencies, 125 cps, 250 cps, 500 cps, 1000 cps, 2000 cps, 3000 cps, 4000 cps, 6000 cps and 8000 cps were obtained with the pilot in shirt sleeves, suited: (a) without helmet, (b) with helmet, visor open, (c) with helmet, visor closed, and (d) with helmet pressurized to 5 psi.

Threshold values were obtained for all conditions with airflow off excepting 5 psi. Airflow was shut off to prevent the inducement of a masking noise. Since the 5 psi condition could not be maintained with the airflow shut off, the masking of threshold values simulating higher threshold shift were expected for this condition.

Results:

Figure 21 presents the mean data for four pilots. For all frequences, 0 db represents the mean hearing threshold without the helmet (open ear).

The "visor open" condition affords attenuation at all frequencies, except at 250 cps where a resonance must occur that causes the signal to be amplified instead of attenuated.

The "visor closed" condition gives an additional 15-26 db of attenuation over the visor-open condition, except at 250 cps where a 43 db difference in attenuation occurs.

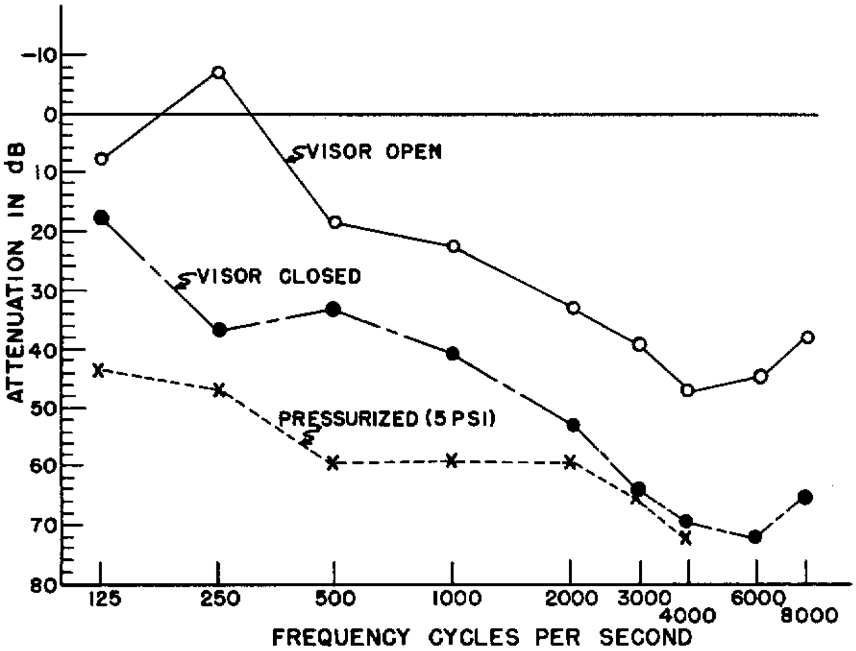

Figure 21. Noise Reduction at the Ear
(Mean Values for Four Pilots)

When pressurized, the flow of air is expected to mask threshold values, particularly at the lower frequencies. The apparent attenuation, resulting from this evaluation method, when pressurized increases approximately 20 db over the visor-closed condition up to 2,000 cps, from there the pressurized condition approximately equals visor closed. Values for 6,000 cps and 8,000 cps were not obtained, due to the limits of the measuring system. This apparent attenuation, however, is an evaluation effect resulting from the method applied. The real figures for attenuation when pressurized are expected to follow closely the visor-closed curve.

Noise Reduction at the Microphone

Test Procedure:

This procedure incorporates the use of two calibrated condenser microphones. One condenser microphone was placed inside the helmet at the position of the standard helmet microphone; the other condenser microphone was placed just outside the faceplate. The pilot was seated in a chair directly in front of an intense, wide-band siren (approximately 150 db overall sound pressure level (SPL)). See figure 22.

Figure 22. Noise Reduction at the Microphone

The outside noise was recorded on one channel of a two-channel tape recorder and the noise transmitted to the inside microphone was simultaneously recorded on the other channel. Two conditions for each Subject were used: (1) with visor closed (airflow), and (2) pressurized to 5 psi. The noise recorded on tape was later analyzed in third-octave bands to determine the noise reduction for each band.

Results:

Figure 23 presents noise reduction data for two pilots. All values for the two pilots, visor-closed and pressurized, fall within the two plotted lines (shaded area). There was essentially no difference between conditions, therefore, the maximum and minimum noise reduction values are shown.

Characteristics of the helmet assembly cause major resonances at 100 cps, 500 cps and 2000 - 2500 cps. Maximum values of noise reduction can be measured at 200 cps with minimum values at the major resonant frequencies.

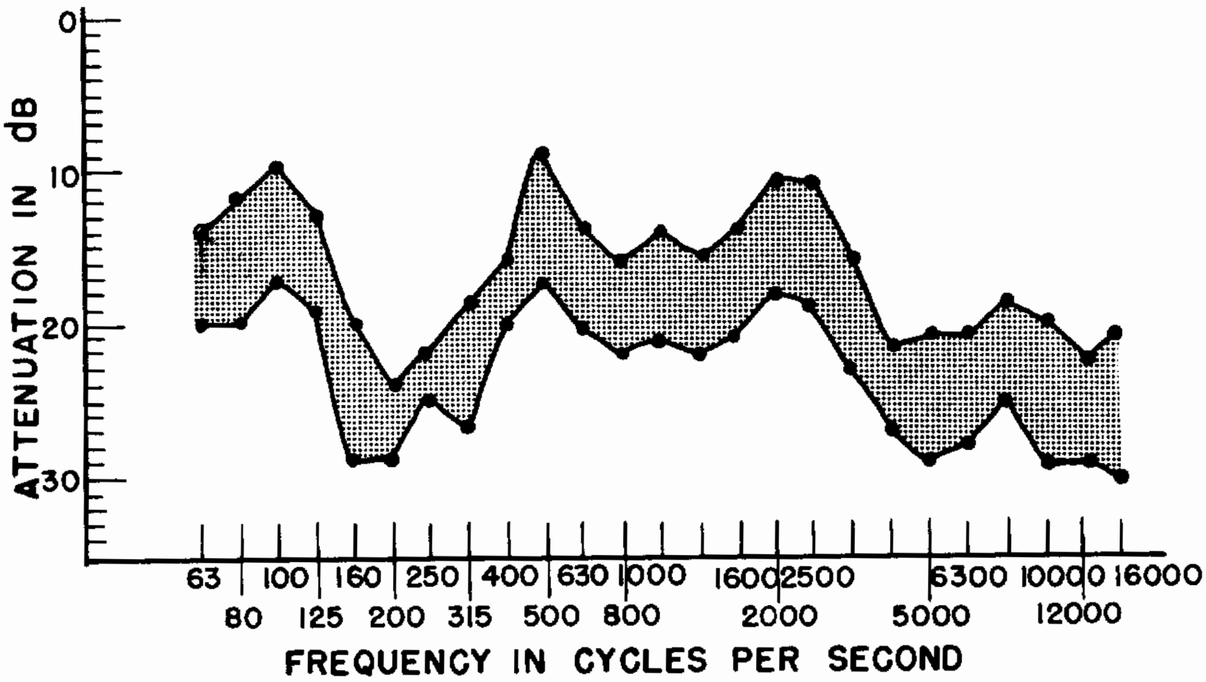

Figure 23. Noise Reduction at the Microphone (Range of Values for Two Pilots, Visor-Closed and Pressurized conditions)

Supplemental Tests

Headset:

Attenuation characteristics of the headset were obtained for one pilot fitted in the exact manner he stated he wears a headset. Visual inspection revealed that this unit did not provide as good a seal as other types of over-the-ear protectors. The attenuation of the unit by itself shows a resonance peak at 125 cps and 250 cps. These resonances amplify the signal over the open-ear condition by 9 db at 125 cps, and 6 db at 250 cps.

Subjective Test:

Two pilots were exposed to a simulated Apollo-launch spectrum which had its peak energy in the 60-100 cps band with an overall SPL of approximately 124 db. The pilots were asked to comment on the efficiency of their suit in attenuating the sound, both with the visor open and closed.

One pilot indicated he noticed the sound to be amplified with the visor open. In general both felt the suit with the visor closed did a good job of attenuating the sound.

MEDICAL OBSERVATIONS

All thermal-altitude chamber runs were continuously monitored by a Flight Surgeon. In addition to visual and intercom monitoring, the heart rate and electrocardiogram (single lead) were continuously monitored. On two of the runs the Beckman partial-pressure sensor provided a constant reading of ppO_2 (partial pressure of oxygen) in the helmet. At no time during the test program were any electrocardiogram abnormalities noted.

In the mission simulation "flights" the chamber temperature increased from 80°F, at ground level, to 91°F at 18,000 feet. At the same time the ventilation gas flow decreased from 9 cfm to 6 cfm, the "Normal" flow rate. After one hour at 18,000 feet, the chamber was decompressed to 60,000 feet, at which point the pilot's suit pressurized to 27,000 feet (5 psia) and the emergency ventilation flow of 100% oxygen began (0.18 lb/min) providing a vent-gas flow of 6.4 cfm. (See table 8.) The temperature remained constant at 91°F for one hour at 60,000 feet cabin altitude, at which time reentry was simulated. In this phase, the temperature was raised from 91° to 120° F during descent to ground level. The ventilation remained constant (0.18 lb/min of oxygen) but, because of the suit pressure change from 27,000 feet (5.0 psia) to ground level (14.7 psia), the volume flow of ventilation decreased from 6.4 cfm to 2.2 cfm. This emergency flow was inadequate from the pilots' viewpoint, especially during the simulated reentry with the temperature increasing and ventilation decreasing.

Subjectively there was no effective ventilation at ground level with the air temperature at 120°F. Moreover, all the pilots complained at the higher temperatures and agreed that, were they doing any work, the conditions would have been exceedingly uncomfortable which might preclude satisfactory mission completion. Objectively there was no undue stress under the test conditions, since the heart rates remained fairly constant throughout the mission simulation. (See figure 17.)

The visor-fogging tests produced no undue discomfort, although all pilots complained of cold hands at the lowest temperature (10°F). The liquid detergent applied to the visor was a very effective antifog solution even when one pilot was vigorously exhaling through his nose in an attempt at a Valsalva maneuver with his visor closed. Thus the antifog solution prevented visual decrement under cold conditions. Other tests demonstrated that each pilot wearing his helmet had adequate vision for the required tasks.

One pilot experienced moderate sinus pain on a descent during the visor-fogging test, therefore, the scheduled ascent to 30,000 feet was cancelled. This however did not affect test results, and the pilot had no sequelae.

One minor complaint the pilots had concerned the lack of deflection in the absolute pressure gauge located on the left leg. Since this gauge registers suit pressure only above 30,000 feet (pressure below 4.4 psia), it will never show a deflection so long as the suit maintains its design pressure of 27,000 feet (5.0 psia). This caused some apprehension in one pilot until he realized his misinterpretation. This situation suggests that a garment designed to pressurize to 5.0 psia should have a pressure guage that begins to register at pressures above 5.0 psia (eg, 25,000 feet or 5.4 psia).

The X-20 suit was shown to adequately protect the pilot under the conditions simulated. While ventilation during the simulated reentry and landing phases was marginal, it must be remembered that only the "emergency" oxygen flow of 0.18 lb/min was delivered to the pilots in these tests. Under usual conditions, the ventilation selector would have been returned to "normal" and the pilot would have received about 0.23 lb/min equivalent to three cubic feet at sea level pressure.

Nevertheless, the emergency ventilation must be considered inadequate for completing a mission from the medical standpoint, particularly with the anticipated additional stress of an actual mission.

CONCLUSIONS

Visor Operation

Improper closing of visors occasionally allowed leakage past the seal on Pilot A's and Pilot D's helmets. Pilot A's visor would drop down too far while Pilot D's visor would sometimes not close far enough. When properly positioned, both sealed well.

The inside location of the visor has the advantage of sealing well with pressure, however, ventilation causes a pressure buildup in the garment. This makes it difficult to open the visor without first reducing the ventilation to a low value.

Leakage

The leakage was well within limits required for the intended use of the garment but was considerably in excess of that desired for a garment to be used with a true "closed loop" ventilation system. Pilot A's suit was suspected to be leaking around the instrumentation port. Pilot B's suit exhibited the largest leakage, mostly at the top of the visor seal.

Pressure Drop

Pressure loss with flow is excessive but of little importance in the X-20 system which uses a continuous flow of gas from cryogenic stores. Pressure drop with flow should be measured while a properly fitted individual wears the garment if the information is to be used in system design.

Physical Measurements

Suit stretch during the program was negligible, except for the torso. Increases in torso circumference ranged from 0 to over 5 percent. These data provide a base for comparison with garments tested in the future. They may also prove useful in estimating the size increment to be expected when a pilot wears a pressure suit.

Dexterity of the Hands

The results obtained at 2.5 psig showed a hand-dexterity loss greater than 50%. This type of evaluation could be further developed to provide an objective measurement of glove function.

Visual Fields

The very wide visual fields available with this helmet are adequate for the X-20 application.

Visor Fogging

The helmet visor can be kept fog free under the conditions imposed herein, by the application of a wetting agent such as a liquid household detergent. The visor should be cleaned , in turn, with soap and water and methyl or ethyl alcohol, then coated very sparingly with a liquid detergent. The visor should then be wiped clear with soft, lint-free material such as Colitho Pads.* Other tests have shown vision can be preserved by such applications until the inside visor surface reaches +32° F. The duration of effectiveness depends largely upon the amount of condensation occurring, but two hours effectiveness is practically assured.

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*Colitho Division, Columbia Ribbon and Carbon Co. Inc., Glen Cove, New York, N.Y.

Mission Simulation

The pressure garment, ventilation quantity and oxygen partial pressure, and cabin temperatures and altitudes all were tolerable in combination and allowed completion of all four tests.

Acoustical

The following acoustical characteristics apply to the helmet models tested. The flight configuration has been designed to eliminate the amplification at 250 cps, but had not been delivered for evaluation at the time this research was completed.

Noise Reduction at the Ear: At 250 cps with the visor opened, a resonance occurs which amplifies the signal approximately 7 db above the threshold without protection.

The visor-closed condition gives an additional 15 db to 26 db attenuation over the visor-opened condition, except at 250 cps where the visor-closed condition gives 46 db more attenuation than the visor-opened condition.

Under pressurization, attentuation is expected to follow closely the visor-closed condition, although the exact attenuation for this condition has not been measured.

Noise Reduction at the Helmet Microphone: Characteristics of the helmet cause major resonances at 100 cps, 500 cps and 2000-2500 cps.

Maximum values for transmission loss occur at 200 cps, with minimum values at 100 cps, 500 cps, 2000 cps and 2500 cps.

Medical Observations

While donning the snug custom-fitted suits required considerable assistance, all pilots could doff their suits unaided. No significant heat stress occurred in the mission simulation (including reentry and landing), but each pilot complained of being uncomfortably warm with the emergency ventilation provided. The pilots performed no work while the temperature was increased. Therefore, any physical activity during an actual mission would increase the thermal stress, and the emergency vent flow would be even less adequate. The suit pressure gauge registers only at pressures below 4.4 psia (ie, above 30,000 feet on the scale) and therefore does not indicate if the suit is properly pressurized (27,000 feet or 5.0 psia). The pilots would prefer a gauge which registers when the suit is pressurized to reassure them that the pressure is proper and that the gauge is functional.

RECOMMENDATIONS

The design ventilation rate for a gas-cooled pressure suit should be variable from 4 to 10 cfm at the pilots option. If high cabin temperatures or heavy work rates are anticipated, volumetric flow rates up to 15 cfm will be needed.

The total pressure loss with flow through the occupied pressure garment should, in general, be limited to 10 inches of water with a flow of 10 cfm at 14.7 psia when worn as in the application. When blower power is critical, some applications may require even less pressure loss with flow.

The internal-mounted visor should be modified to assure a reliable seal each closing. The intended automatic altitude release is desirable, in addition to a positive lock so that the visor cannot be opened by frontal pressure. The visor-opening lever should be a more accident-proof device.

Dome helmets of the type used here with no neck or face seal barrier do not create the physical conditions necessary for an emergency airway. A useful additional feature would be a manually operated passage or opening that would provide for breathing but would exclude water entry in survival situations. The visor could then remain sealed for water-survival conditions.

Insulation incorporated in a pressure garment is an aid to world-wide survival, but in routine use it inhibits desirable heat transfer through the suit wall. Most applications of pressure suits should provide the insulation in an exterior coverall which can be worn if needed.

The absolute pressure gauge for a suit designed to maintain 5.0 psia (27,000 feet) when pressurized should register at 5.4 psia (25,000 feet). The pilot will then see a deflection when the suit is pressurized, thus, will have visual reassurance that he is adequately protected.

The headset used in the helmet assembly should be of greater volume to allow the receiver to be placed deeper in the cup so the pilot can obtain a seal with the rim of the cup against his skull before his ear touches the receiver.

A David Clark 19A or equal and interchangeable ear cup should replace the David Clark 10A cup which is now used. This would increase the volume and allow the receiver to be placed deeper in the cup. The better seal and larger cup would both contribute to better attenuation values.

In addition, greater attenuation of the ear muff could be obtained by using a head-band suspension system, which would add tension to the earcups and thus provide a good acoustic seal with the skull.