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ENGINEERING DESIGN STUDY OF A SPACE SUIT WITH AN INTEGRATED ENVIRONMENTAL CONTROL SYSTEM

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FOREWORD

This study was conducted by Hamilton Standard Division of United Aircraft Corporation Windsor Locks, Connecticut 06096. The effort was performed under Air Force Contract No. F33615-67-C-1946, project No. 7164, "Aerospace Protective Technology," task No. 716411, "Aerospace Pressure Outfits." The study summarized in this report was conducted during the period 1 July 1967 through 30 June 1968.

The principal investigator was Douglas C. Howard who was assisted by Philip Heimlich and Harry Cooke, Advanced Engineering Group. Additionally, acknowledgement is made of the contributions of Thomas W. Herrala, Advanced Systems Group. The contract monitor for the Aerospace Medical Research Laboratories was Mr. Donald A. Rosenbaum, Altitude Protection Branch, Life Support Division, Biomedical Laboratory.

This technical report has been reviewed and is approved.

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ABSTRACT

Continued success in coping with the space environment has led to increased crewman confidence in his ability to perform useful work during extraterrestrial missions. Future missions will require advanced suit/life-support-system concepts. Such a concept might logically take the form of a space suit for extravehicular activity with an integrated environmental control system. A design study of this concept has been performed and drawings prepared in sufficient detail to permit fabrication of a working model in a suitably equipped model shop. Integration of the environmental control system within the hard torso of the suit assembly resulted in a system having a packaging density approaching 80 percent and able to pass through a 27 inch diameter hatch. The system will support a crewman working at 375 Kcal/hour for an indefinite time due to a recharge in space capability. Additionally, the technology utilized to produce this system was entirely within the state-of-the-art. The calculated system reliability is 0.99947.

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SECTION I
INTRODUCTION

The requirements for space suits and associated life support systems are becoming highly sophisticated. Heretofore, design missions were primarily concerned with the ability of life support equipment to function as intended under severely limited extravehicular modes of operation. Crew members were always tethered, had umbilicals supplying vital life support functions, and worked for short periods of 1 to 2 hours. Now that confidence in life support systems, vehicle systems, and maneuvering systems has been gained, new design missions are being generated that use the crewman's full work potential. Space suits and small portable life support systems that will allow the astonaut almost unlimited freedom during the extravehicular activity phases of an earth orbital mission are now required. Ideally, the life support system would be combined with the space suit in such a manner as to allow the easy attachment and operation of a self-propelled maneuvering unit. The combined system would have a center of mass close to that of nude man, have a high mobility range with low joint torque, and be rechargeable while in vacuum. Such a system will permit long time extravehicular activity, such as exploration vechicle assembly, experiment operation and monitoring, and maintenance via checkout and repair.

Heretofore, suit systems were either all soft goods or hard shelled structures. Life support systems were packaged in chest mounted packs, back packs, and integral with the vehicle (using umbilicals). Many other possibilities for combining the suit and the life support system exist. The purpose of this study is to discuss the potential of the best of these possible systems.

The system to be considered consists of a rigid torso assembly with the life support system packaged within it. Attached to and detachable from the hard torso are soft suit arms and legs and a hard helmet.

OBJECTIVES

The objective of the program is to combine the benefits of hard and soft suit technology with life support system technology into an optimum Integrated EVA Space Suit System configuration.

SECTION II
METHODS

A detailed study of the system requirements was made. From this, a system flow chart was generated and is shown in figure 1. Next, evaluation criteria, definition, and priority shown in table I were established. These criteria were used to evaluate all alternate components, systems, or choices of action.

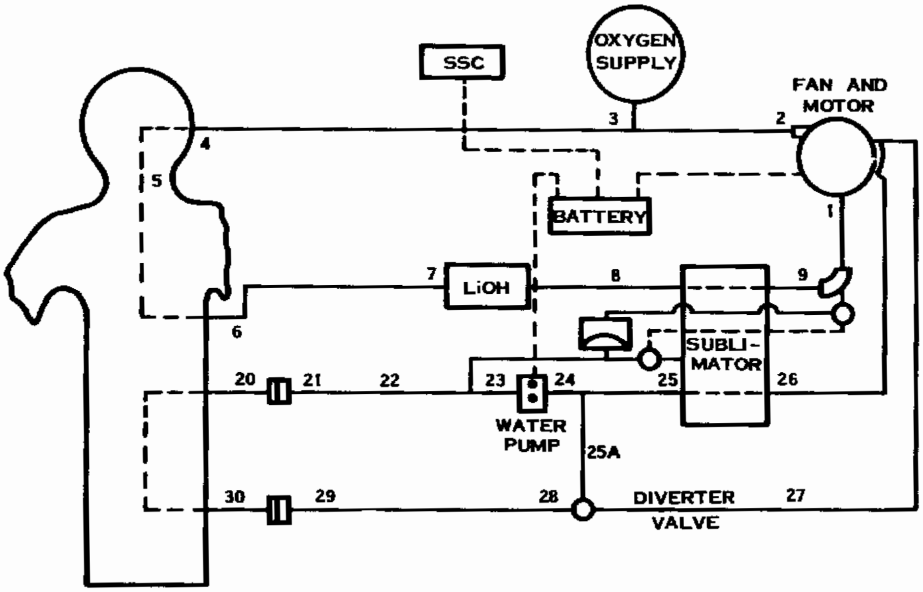
Configuration and systems integration studies were then conducted. These studies determined the subsystem, and component configurations required to meet the requirements. Additionally, system studies determined the optimum arrangement of these components to form the basis for detailed design.

A system review was performed to determine those portions of the suit and Life Support System (LSS) requiring concept definition. These are:

- Hard Torso
- Entry/Closure
- Feedwater Reservoir
- LiOH Canister
- Emergency Expendables Package
- Hard/Soft Suit Interface
- Shoulder Joint
- Waist Disconnect

This review resulted in the following system concept. The suit system consists of a two piece hard torso assembly to which are mated detachable soft suit arms, legs, and helmet with EV visor. The bottom half of the hard torso detaches from the soft pants, contains the Life Support System, and mates with the upper half. The Life Support System will sustain the crewman for 4 hours in a 300 nautical mile earth orbit at an average metabolic rate of 375 Kcal/hour. It will withstand 10 minute peaks of metabolic activity to 1000 Kcal/hour and can be recharged by the unaided crewman during EVA. Crewman thermal control is provided by use of a liquid cooling garment and a ventilation gas stream. Heat pickup of the liquid and gas systems is approximately 79/21 respectively at peak metabolic conditions and 70/30 at average metabolic rates. Carbon dioxide control is provided by a LiOH canister. Additionally, humidity and suit pressure controls are provided. All system expendables have been placed in the front of the lower torso because they must be accessible for recharge during EVA. This action caused the placement of all time independent components in the rear since no room remained in the front. System controls and displays are incorporated frontally for access and visibility. System checkout, start/stop, and recharge procedures are defined and listed in System Logistics. Finally, a reliability program was devised and is outlined in System Reliability. This program will result in the establishment of the system reliability value during the design phase.

The overall system configuration is shown in figure 2. This is a 1/9-scale sketch of the suit system showing the soft arms and legs, the hard torso that contains the LSS, and the helmet. Figure 3 depicts the system functional schematic. All pneumatic, hydraulic,



OXYGEN LOOP		STATION								
DESCRIPTION	UNITS	1	2	3	4	5	6	7	8	9
TEMPERATURE	°C	10.0	1.72	17.2	17.2	22.2	28.9	28.9	74.0	10.0
VOLUME FLOW RATE	LPS	2.78	2.74	2.83	2.83	2.95	3.12	3.12	3.54	2.78
TOTAL PRESSURE	GM/CM^2	337	352	352	351	350	344	343	341	338
TOTAL WEIGHT FLOW	KGM/HR	4.42	4.42	4.58	4.58	4.62	4.70	4.70	4.62	4.62
O_2 WEIGHT FLOW	KGM/HR	4.12	4.12	4.29	4.29	4.14	4.12	4.12	4.12	4.12
CO_2 WEIGHT FLOW	KGM/HR	0.20	0.20	0.20	0.20	0.33	0.33	0.33	0.20	0.20
H_2O WEIGHT FLOW	KGM/HR	0.095	0.095	0.095	0.095	0.145	0.245	0.245	0.295	0.295
O_2 PARTIAL PRESSURE	GM–CM^2	302	323	324	324	305	294	293	298	302
CO_2 PARTIAL PRESSURE	GM–CM^2	11.0	11.5	11.3	11.3	18.1	17.6	17.4	10.7	11.0
H_2O PARTIAL PRESSURE	GM–CM^2	12.7	13.4	12.7	12.7	20.4	32.4	32.4	44.3	12.7
DEWPOINT	°C	10.0	10.0	10.0	10.0	17.2	25.0	25.0	29.4	10.0

LIQUID LOOP		STATION										
DESCRIPTION	UNITS	20	21	22	23	24	25	25A	26	27	28	29	30
WEIGHT FLOW	KGM/MIN	1.82	1.82	1.82	1.82	1.82	1.82	0	1.82	1.82	1.82	1.82	1.82
TEMPERATURE	°C	10.8	10.8	10.8	10.8	10.9	10.9	–	7.2	7.4	7.4	7.4	7.4
PRESSURE	GM/CM^2	334	310	295	282	585	585	–	528	522	497	469	445

Figure 1. Space Suit with Integrated Environmental Control System Program – LSS Flow Chart (Sheet 1 of 2)

DESIGN POINT PRESSURE LOSS	
OXYGEN LOOP	GM/CM^2
PRESSURE GARMENT ASSEMBLY	6.30
LiOH CANISTERS	2.44
SUBLIMATOR	3.73
WATER SEPARATOR	1.09
DUCTING	1.22
PRESSURE RISE ACROSS FAN	14.78
LIQUID LOOP	GM/CM^2
LIQUID COOLING GARMENT	111
CONNECTORS	48
DIVERTER VALVE	25
SUBLIMATOR	56
FAN MOTOR COOLING JACKET	6
DUCTING	57
PRESSURE RISE ACROSS PUMP	303

GENERAL DESIGN DATA		
DESCRIPTION	UNITS	VALUE
DESIGN POINT MISSION TIME	HRS	4.0
MAXIMUM MISSION TIME	HRS	4.0
COMBINED FAN/MOTOR EFFICIENCY		0.10
PUMP EFFICIENCY		0.10
BATTERY EFFICIENCY		0.88
FAN PRESSURE RATIO		1.042
FAN/MOTOR POWER	WATTS	25.0
PUMP POWER	WATTS	10.0
SSC AND ELECTRICAL COMPONENTS	WATTS	5.0
OXYGEN HARD LINE O.D.	CM	1.905

DESIGN AVERAGE HEAT LOADS		
DESCRIPTION	UNITS	VALUE
METABOLIC HEAT RATE	K_{CAL}/HR	375
OXYGEN CONSUMPTION	KGM/HR	0.110
CO_2 PRODUCTION	KGM/HR	0.132
*SYSTEM HEAT LOAD	KCAL/HR	553.0
*TOTAL SYSTEM (DESIGN POINT) LOAD	K_{CAL}	2210
IDEAL WATER STORAGE (1)	KG	4.36
MAXIMUM WATER SEPARATED	KG	0.80
TOTAL POWER REQUIRED	WATTS	40.0
MISSION ELECTRICAL ENERGY	WATT-HR	160
MISSION ELECTRICAL HEAT LOAD	K_{CAL}/HR	18.5

*THE SYSTEM IS DESIGNED FOR NO PERSPIRATION. HOWEVER THE O_2 SUBLIMATOR MUST BE CAPABLE OF HANDLING 100 CC/HR OF PERSPIRATION.

(1) SYSTEM EXPENDABLES SIZED FOR 4 HOUR MISSION PLUS 2 HOUR CONTINGENCY.

DESIGN PEAK HEAT LOADS			
OXYGEN LOOP		K_{CAL}/HR	K_{CAL}/HR
RESPIRATION LATENT		59.5	28.9
SUIT SENSIBLE		14.2	12.0
*ECCRINE PERSPIRATION		59.0	59.0
LiOH SENSIBLE		50.0	42.8
LiOH LATENT		84.3	29.0
FAN/MOTOR		4.6	4.6
O_2 LOOP SUBLIMATOR		271.6	175.5
LIQUID LOOP		K_{CAL}/HR	K_{CAL}/HR
METABLOIC LESS RESP & SUIT SENSIBLE		934.3	333.4
HEAT LEAK		63	63
SSC AND ELECTRICAL COMP		9.9	9.9
PUMP		7.7	7.7
BATTERY HEAT		4.9	4.9
FAN MOTOR COOLING JACKET		18.3	18.3
H_2O LOOP SUBLIMATOR		1038.1	437.0
TOTAL SYSTEM PEAK HEAT LOAD		1250.7	553.0
METABOLIC HEAT LOAD		1008	375
OXYGEN CONSUMPTION	KGM/HR	0.296	0.110
CO_2 PRODUCTION	KGM/HR	0.354	0.132

Figure 1. Space Suit with Integrated Environmental Control System Program - LSS Flow Chart (Sheet 2 of 2)

TABLE I

SUIT PROGRAM
EVALUATION CRITERIA
DEFINITION & CRITERIA

Priority	Criterion	Definition
First Order		
1	Safety	The probability of the safe return of the crewman.
2	Mobility	The degree to which movement is free and unhampered by the suit system (torque and range).
3	Volume	The space required to house the system (particularly the hard torso containing the Life Support System).
4	Weight	System Mass X Earth gravitational field.
5	Reliability	The probability of no malfunction in the system during an EVA mission.
Second Order		
6	Comfort	The sum total of subjective human response to operating the system.
7	Wear	The ability of the system to withstand abrasion.
8	Don/Doff	The time and effort plus any aids required to put on and take off the suit.
9	Stowage	The ability of the system to be folded up and stored.
10	Recharge	The time and effort plus aids required to replenish or replace all expendables.
11	Maintainability	The time and effort required to perform routine maintenance functions.
12	Start/Stop Ease	The time and effort required to checkout, start, and shut down the system.

TABLE I
(Continued)

Second Order	Criterion	Definition
13	Self-Monitoring	The amount of information the system delivers to the crewman about itself.

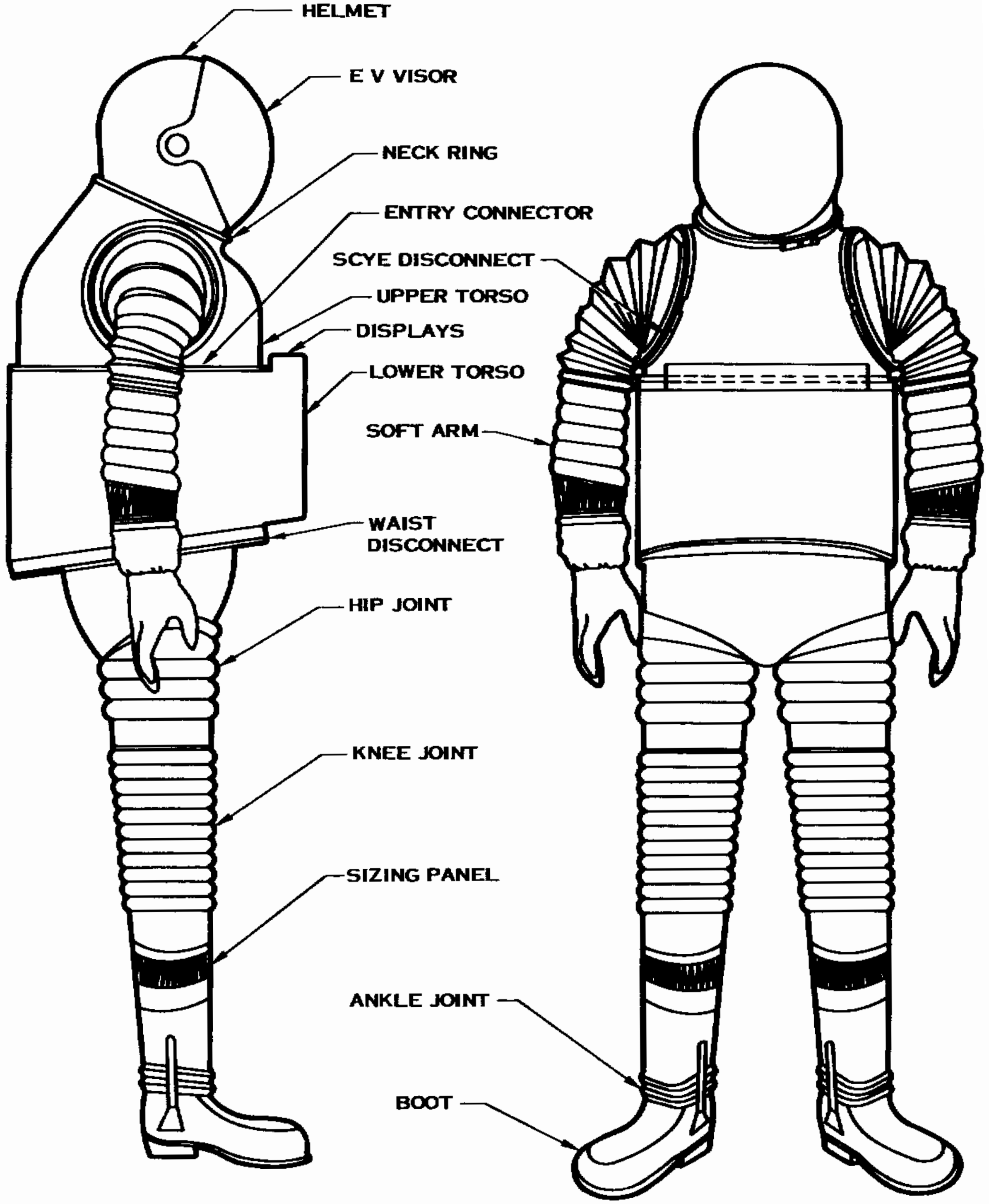


Figure 2. Space Suit System

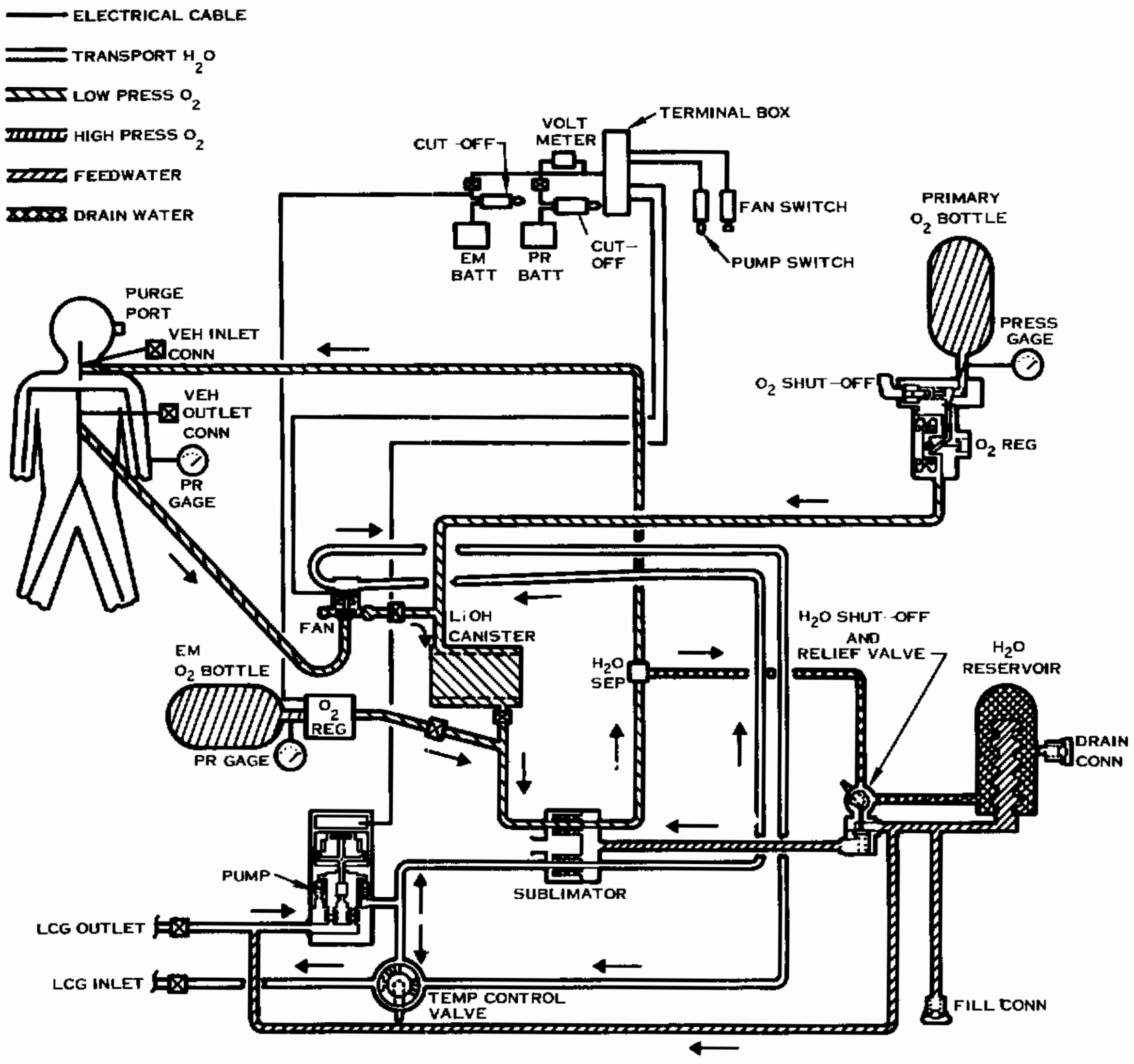


Figure 3. System Functional Schematic

and electrical functions are shown. Table II is an item list for the IEVA System. This list breaks the system down into its principal components for use in the detail design phase, reliability assessment, and establishing operational procedures.

SYSTEM REQUIREMENTS

The system requirements were established by considering the requirements of the Work Statement. Next, a system of evaluation criteria and priorities was generated. This is required as go-no go or quantification gage when performing an analysis of candidate components or subsystems for the IEVA system. The criteria, their definitions, and priority are shown in table 1.

Design Point Flow Chart

After setting forth the system requirements, a LSS design point flow chart was generated. This is a series of calculations made to show critical parameter values throughout the system when operating at its design point or peak load conditions. Included is a complete parametric description of the life support system oxygen and transport water loops, electrical system, and general design data. Pressure drop values for all oxygen and transport water loop components are shown to indicate the performance level required of the fan and pump. Additionally, design point data on average thermal conditions is included.

TABLE II

SUIT SYSTEM ITEM LIST

Item No.	Item Name
100	HARD SUIT
110	Helmet
111	Vent Duct
112	Neck Ring
113	Purge Port
114	EV Visor
115	Pressure Shell
120	Upper Torso
121	Pressure Shell
122	Neck Ring
123	Arm Connector
124	Vent System
125	Entry Conn. (Upper Half)
130	Lower Torso
131	Maneuvering Unit Attachment
132	Control Panel
133	Exp. Pack. Retention Mechanism
134	Entry Conn. (Lower Half)
135	Pants Conn. (Upper Half)
136	Feed Water Reservior
137	Back Cover
138	Expendables Package Doors
200	LIFE SUPPORT SYSTEM
210	Primary O_2 Subsystem
211	Oxygen Bottle
212	O_2 Regulator & Fill Port
213	O_2 Shut-Off Valve
220	Contaminant Control Subsystem
221	LiOH & Charcoal Canister
222	Fan Motor Assembly
223	Vent System
230	Thermal Control Subsystem
231	Sublimator
232	Water Separator

Item No.	Item Name
233	Pump
234	Water Conn. (LSS Half) (Seaton-Wilson)
235	Feedwater Reservior Bladder
240	<u>Controls and Displays</u>
241	Fan, Battery Switch
242	High Pressure O_2 Gage (EOS Carleton Controls)
243	$PPCO_2$ Sensor and Gage
244	Suit Pressure Gage
245	Diverter Valve
246	Water Shut-Off Valve (& PRV)
247	Pump Switch
300	<u>SOFT SUIT SYSTEM</u>
310	<u>Thermal Meteoroid Garment</u>
311	Jacket
312	Pants
313	Boots
314	Mittens (Gloves)
315	Hood
320	<u>Liquid Cooling Subsystem</u>
321	H_2O Conn. (LCG Half) (Seaton - Wilson)
322	Liquid Cooling Garment
330	<u>Arms</u>
331	Shoulder Joint (Convolutes & Cables)
332	Sizing Panel
333	Upper Arm Bearing
334	Elbow Joint
335	Wrist Disconnect
336	Wrist Joint
337	Glove
338	Vent System
339	Wrist Transition
340	<u>Pants (Leg Assembly)</u>
341	Torso Connector (Lower Half)
342	Hip Joint
343	Thigh Sizing Panel
344	Knee Joint
345	Ankle Joint
346	Soft Boot
347	Vent System

Item No.	Item Name
350	Electrical Subsystem
351	Battery
352	Battery Connector
353	Wiring (circuit change only)
354	Terminal Board
360	Emergency Return Subsystem
361	O_2 Bottle
362	O_2 Regulator & S.O. Valve
363	Emergency Battery
364	Emergency Battery Switch
365	Emergency Battery Connector
366	O_2 Connector

SECTION III

CONFIGURATION STUDIES

HARD COVER

The hard cover portion of the suit consists of the helmet and the torso.

HELMET

The helmet is a one piece pressure shell that encloses the head and is detachable from the hard torso via a neck ring and latch assembly. It will provide continuous unobstructed vision ±120° horizontally from the vertical center line and from 90° above to 105° below the horizontal centerline. Attached to the helmet is an extravehicular (EV) visor assembly that may be rotated to cover the primary visor or not, according to the crewman's wishes. Three coatings, one on the outside of the EV visor, one on the outside of the primary visor, and one on the inside of the primary visor control the amount of solar radiation reaching the crewman's eyes. The EV visor coating (Perkin-Elmer L-EV-26) has a visible transmittance of 20 ± 5%. The outside coating on the primary visor (Perkin-Elmer LEV-20) has a 70% visible transmission and a 90% infrared reflection. These first two coatings will provide the crewman with adequate vision during intra- and extravehicular activities, and at the same time protect him from solar rays. The inner coating on the primary visor is another Perkin-Elmer coating designated LR, which has a very low reflectance in the visible range. This will keep the crewman from being distracted by reflection of items within his helmet.

The helmet neck ring is provided with a duct of sufficient area to accept the full oxygen flow from the life support system. This is because all gas flow must be directed to the helmet to provide CO_2 purging and visor defogging.

The helmet is fixed to the torso by a neck ring and latch assembly that may be operated by either hand. The head is free inside the helmet for the full range of head swivel and 75% front to back nodding motion. Impact attentuation will be provided by a soft bump hat capable of being fitted with earphones and microphones.

TORSO

The Integrated EVA Suit torso must be a rigid shell assembly. This shell must house the life support system, detach from the helmet, arm, and soft pants, and provide a means of donning and doffing the suit. The detachability and life support housing requirements require a new and unique approach to space suit system design. A design trade-off study was conducted on all reasonable torso/integrated life support system combinations to ensure that the optimum concept would be used. This study and its results are summarized in figure 4. Four basic concepts were selected as finalists and subjected to further study. Each of these concepts is discussed below.

KEY

EXCELLENT - 1 FAIR - 3
GOOD - 2 POOR - 4
UNACCEPTABLE - 5

	x6 SAFETY	x5 MOBILITY				x4 VOLUME	x3 WEIGHT	x2 SECOND PERFORMANCE CRITERIA						x1 DESIGN CRITERIA										
CONCEPT	SAFETY	WAIST-HIP JOINT	SHOULDER	ARMS	ABILITY TO GO THRU HATCH UNASSISTED	SYSTEM VOLUME	SYSTEM WEIGHT	RELIABILITY	CREWMAN COMFORT	DURABILITY/ TOUGHNESS	DON/DOFF EASE	EASE OR STOWAGE (Vol. Wt. & Config.)	EASE OF EVA RECHARGE	DEVELOPMENT POTENTIAL	DESIGN FEASIBILITY	SIMPLICITY	EASE OF SEALING (# No. of Seal Surf)	PACKAGING INT. STRUCTURAL	GG CLOSE TO THAT OF MAN	INTEGRATION OF TMG	LINE OF SIGHT	ESTHETIC VALUE	TOTAL SCORE (Lowest is Best)	ELIMINATED DUE TO UNACCEPTABILITY
1. TWO PIECE HARD/HARD TORSO - Torso consists of two sections with detachable pants. All LSS integrated into lower section with expendables mounted in front section for replacement.	6	5	5	10	5	4	9	2	2	2	2	4	4	2	1	2	2	2	1	1	2	2	75	
2. TIM-TDM, PLSS TDM MOUNTED IN FRONT - All time ind. components mounted on crewmans back - either permanent or detachable. Replaceable components mounted in front.	6	5	10	15	5	12	3	6	2	2	2	2	4	2	1	2	3	1	1	1	2	2	89	
3. 1 PIECE TORSO - ALL HARD - DETACHED AT WAIST - Torso completely hard with integral arms and helmet. Pants detachable at waist hip. Time dependent components mounted outside suit.	6	10	5	10	10	4	9	4	2	2	10	8	4	3	1	2	2	3	1	1	2	1	100	*
4. SOFT SUIT - BREADBOARD PACKAGING - Present suit technology with torso section oversized to include time and components. All flexible connections. Time dependent components mounted outside in front.	12	5	5	15	5	16	3	8	2	8	2	6	4	2	4	5	2	5	1	2	2	1	115	*
5. 1 PIECE HARD TORSO - FRONT ENTRY - One piece hard torso with permanent arms. Zipper from crotch to split neckring - hinged in back. Removable helmet and pants section, TOM external on front.	12	10	5	10	5	8	9	8	4	8	4	8	4	4	3	4	4	4	1	2	2	3	122	
6. 1 PIECE HARD/SOFT SUIT ZIPPERS UP SIDES & ARMS - Hard torso with integral helmet and arms. Zippers up sides and arms for don/doff. TDM mounted outside in front, pants detachable.	12	10	10	15	5	8	9	6	4	4	2	6	4	4	3	3	3	4	1	2	2	2	119	
7. 1 PIECE SOFT SUIT - ECS MOUNTED TO HELMET & SHOULDERS - Present soft suit technology with TIM mounted on the head and shoulders. TDM mounted outside on front.	6	5	10	15	10	8	6	4	2	4	2	2	4	2	1	2	3	3	4	1	3	2	99	
8. 1 PIECE HARD TORSO, BACK ENTRY - Same as 5 above, only closure in back.	12	10	5	10	5	8	9	8	4	8	10	8	4	4	3	4	4	4	1	2	3	2	128	*
9. TOTAL HARD SUIT (CYLINDER) WITH SOFT ARMS - Total hard suit from feet to underarms (cylinder). No legs or waist hip mobility. All of ECS mounted internally.	6	25	5	10	15	4	12	2	2	2	2	8	4	1	1	1	1	2	1	1	1	2	108	*
10. CHEST MOUNTED ECS - TDM & TIM mounted separately on front of soft space suit.	6	10	5	15	5	12	3	4	2	2	2	2	4	1	1	2	2	1	4	1	2	4	90	

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Figure 4. Torso Concept Study

Front Door Concept - See figure 5.

This concept consists of a totally hard torso assembly with soft arms and legs attached. Entry is accomplished by opening a door in front and stepping in with your back to the suit. Once the crewman is fully inside, he closes and latches the door which makes the necessary pressure seal.

Since the torso is rigid, the door opening at the shoulder will have to be approximately 15.2 to 20.3 cm. wider than the crewman's shoulders. This is because the crewman needs that much room to fold up his hand and arm in preparation for insertion into the suit arm. (This assumes that one arm has already been inserted.) However, this additional width will destroy shoulder mobility since hinges and seals will have to cut through a portion of the suit normally devoted to suit shoulder construction.

Therefore, this concept is unacceptable.

Single Back Hinge Concept - See figure 6.

This concept is hinged vertically in the rear from the neck ring to the waist ring. The front breaks vertically with a latch and lock. Split neck and waist rings will be necessary to provide the necessary entry and closure dimensions. This means that there are four "T" joints, one at each place that the neck and waist rings are split. "T" joints are formed when one seam meets another at right angles. They are notoriously ineffective in providing positive sealing capability because of this discontinuity in sealing surfaces. The total seal length required is approximately 380 centimeters.

The LSS components will have to be packaged at the torso sides and to the rear of the arms to preserve arm mobility. However, the hinge area will have to be kept clear in an arc of about 45 degrees so that the hinge can open sufficiently to permit the crewman to enter and leave. This means that flexible or telescopic pneumatic, hydraulic, and electrical connections have to be made between the two areas to permit the components to function. This is extremely difficult to do reliably because sliding connections have a low system reliability value. Also, the maximum cross section of this concept is approximately 90 centimeters.

Due to numerous "T" joints, unreliable connections and large cross section, this concept is unacceptable.

Double Back Hinge Concept - See figure 7.

This is basically the same concept as B, however, it has two vertical hinges in the rear, 30.5 to 38.1 centimeters apart. This allows packaging of the life support components in the center of the back. Frontal latch and "T" seals would remain the same. However, two "T" seals more would be added in the rear, upper, and lower. Again the problems noted with "T" seals would be present. Total seal length is increased to 444 centimeters. Also, the telescopic connections would still have to be made.

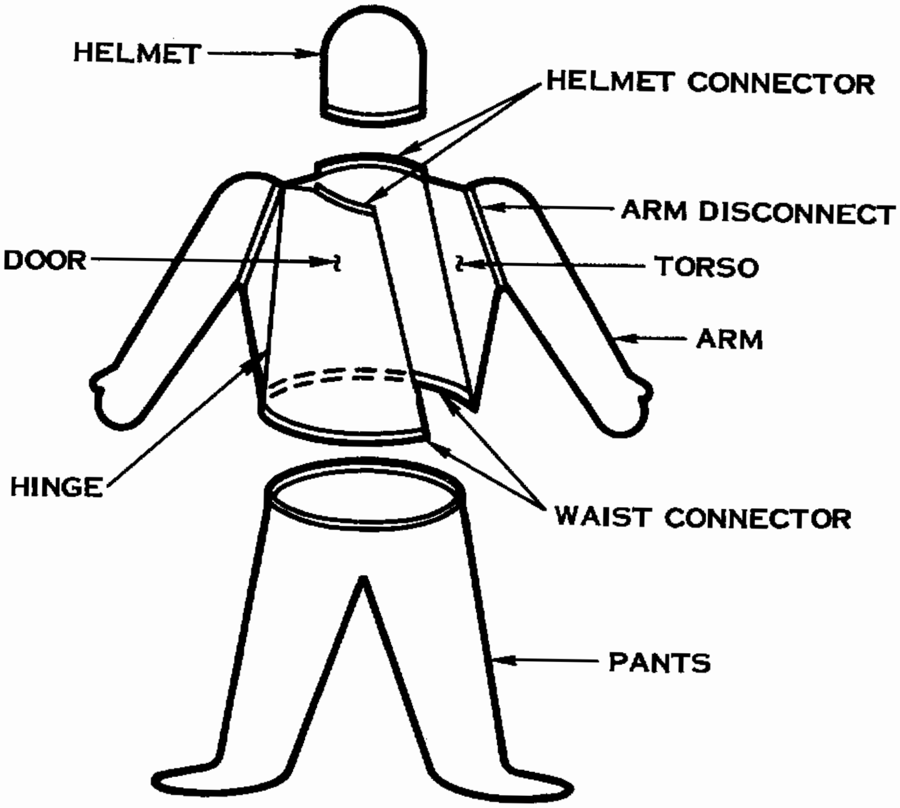


Figure 5. Front Door Torso Concept

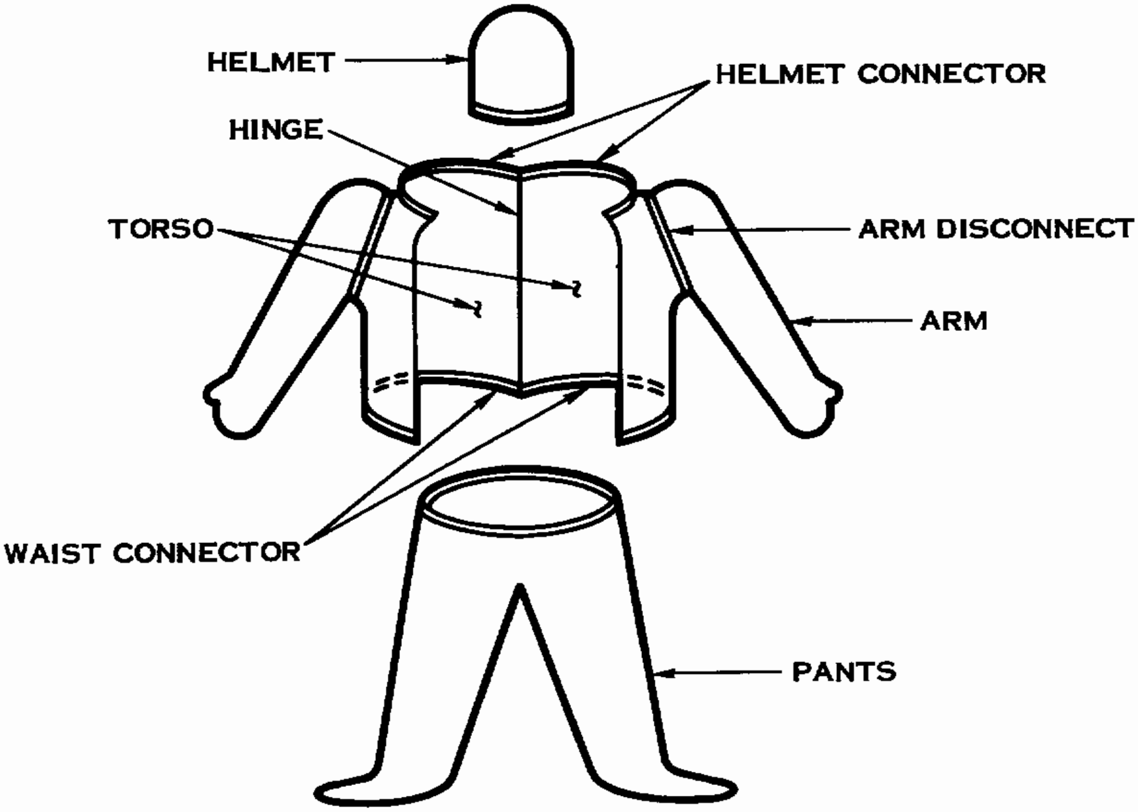


Figure 6. Single Ball Hinge Torso Concept

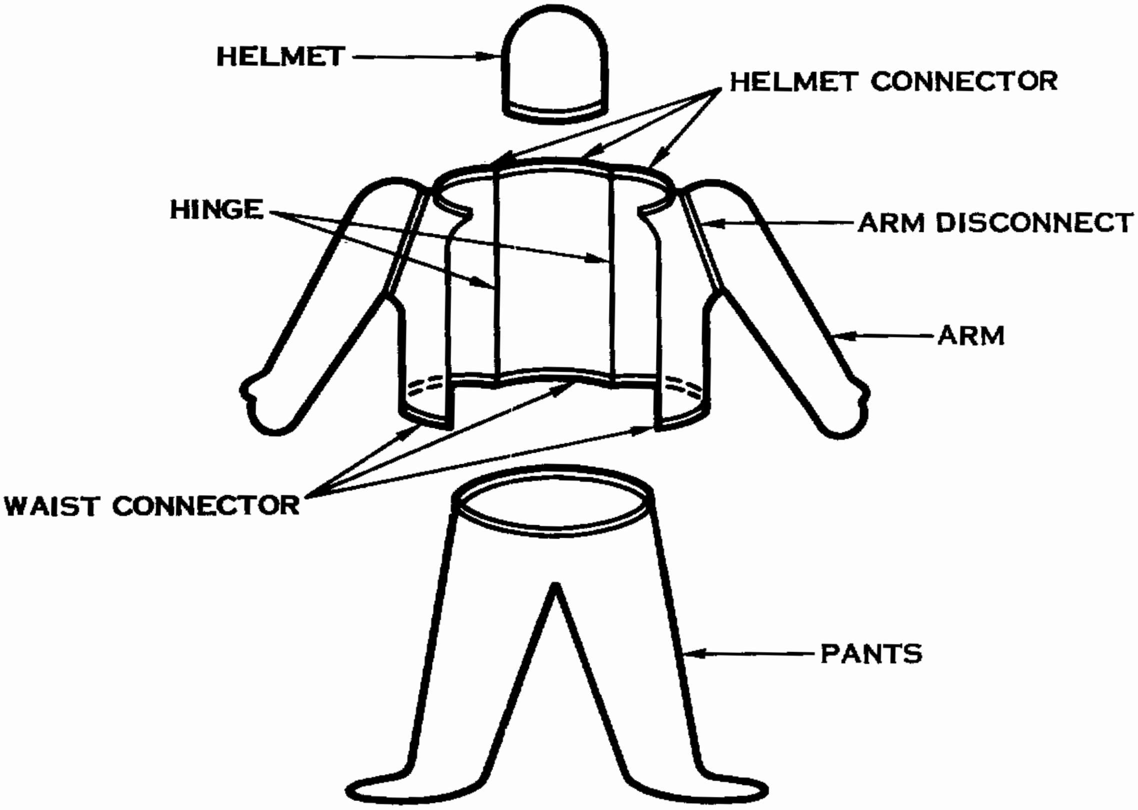


Figure 7. Double Back Hinge Torso Concept

This concept will be the heaviest due to multiple seals, split rings, and structure required to maintain rigidity. It will also be the most unreliable or unsafe due to the multiple seals, "T" seals, and hinges. System volume will be smaller than B because of more room to package life support system. Cross-section will be smaller for the same reason, approaching 71.4 to 76.4 centimeters. This system was eliminated because of the multiple problems presented by "T" seals, telescopic connections, and weight.

Horizontal Split Concept - See figure 8.

This entry scheme involves the use of a horizontally split torso at the mid-chest line. Thus, the lower torso which contains the life support system may be donned like a pair of pants after attaching the soft suit legs. The upper torso is donned T-shirt style with the soft arms attached. This is the simplest concept considered. One horizontal circular seal is required with the integral latch assembly. This concept is also the most reliable since it has no T-seals or telescopic pneumatic/hydraulic/electrical connections. Total seal length is 132 centimeters.

Figure 9 summarizes the results of this study. Concept D, the horizontal split, concept is superior to the other candidate systems. Therefore, this concept will be used in the IEVA system.

After defining the method of entry, the suit closure design must now be determined. The closure latch assembly must provide positive locking, be able to carry the plug load of approximately 454 kg., and be operable by the crewman from inside the suit, preferably one-handed.

Four basic mechanisms were considered. These are:

Cam Locking
Spring Latching
Clamp Locking
Ball Latching

Cam Locking - See figure 10.

This concept is similar to the design of the Apollo PLSS LiOH Canister Cover. The mechanism consists of an upper and a lower half and an outer race with camming keys. This outer race is trapped outside the upper half of the connector with the camming keys protruding radially inward through slots in the upper half of the connector. These keys engage camming slots in the lower half of the connector.

The two halves of the connector are mated and the outer race rotated to lock the device. The outer race is then pinned to prevent it from backing off. The pressure seal may be a face or radial lip seal.

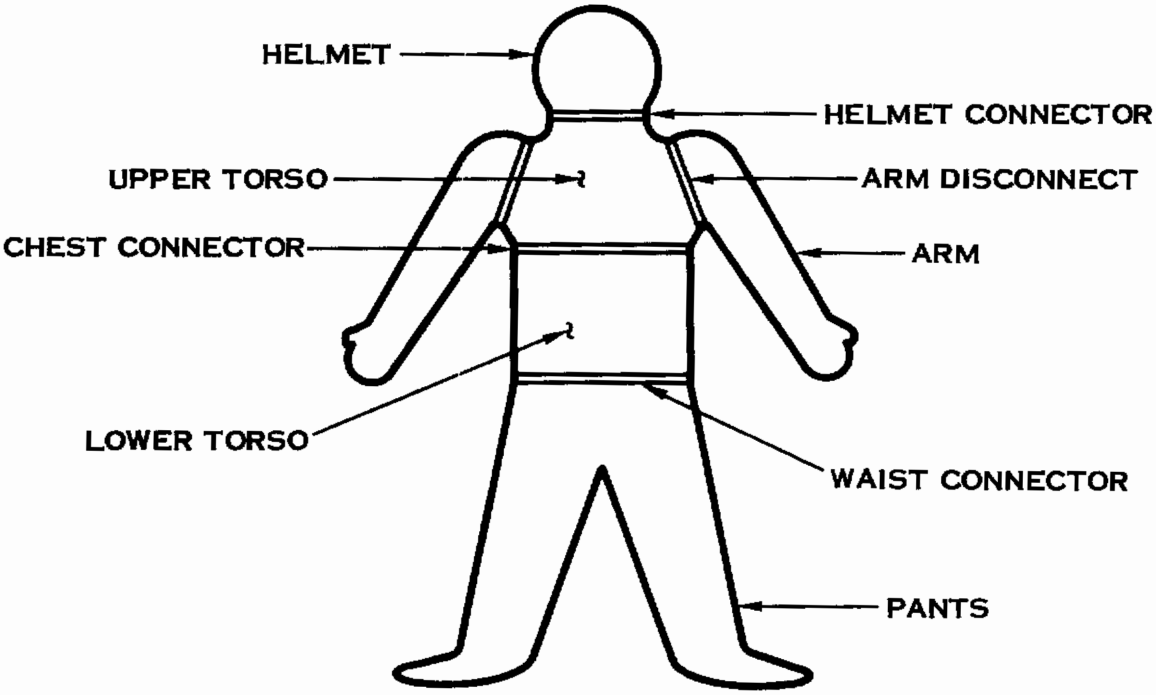


Figure 8. Horizontal Split Torso Concept

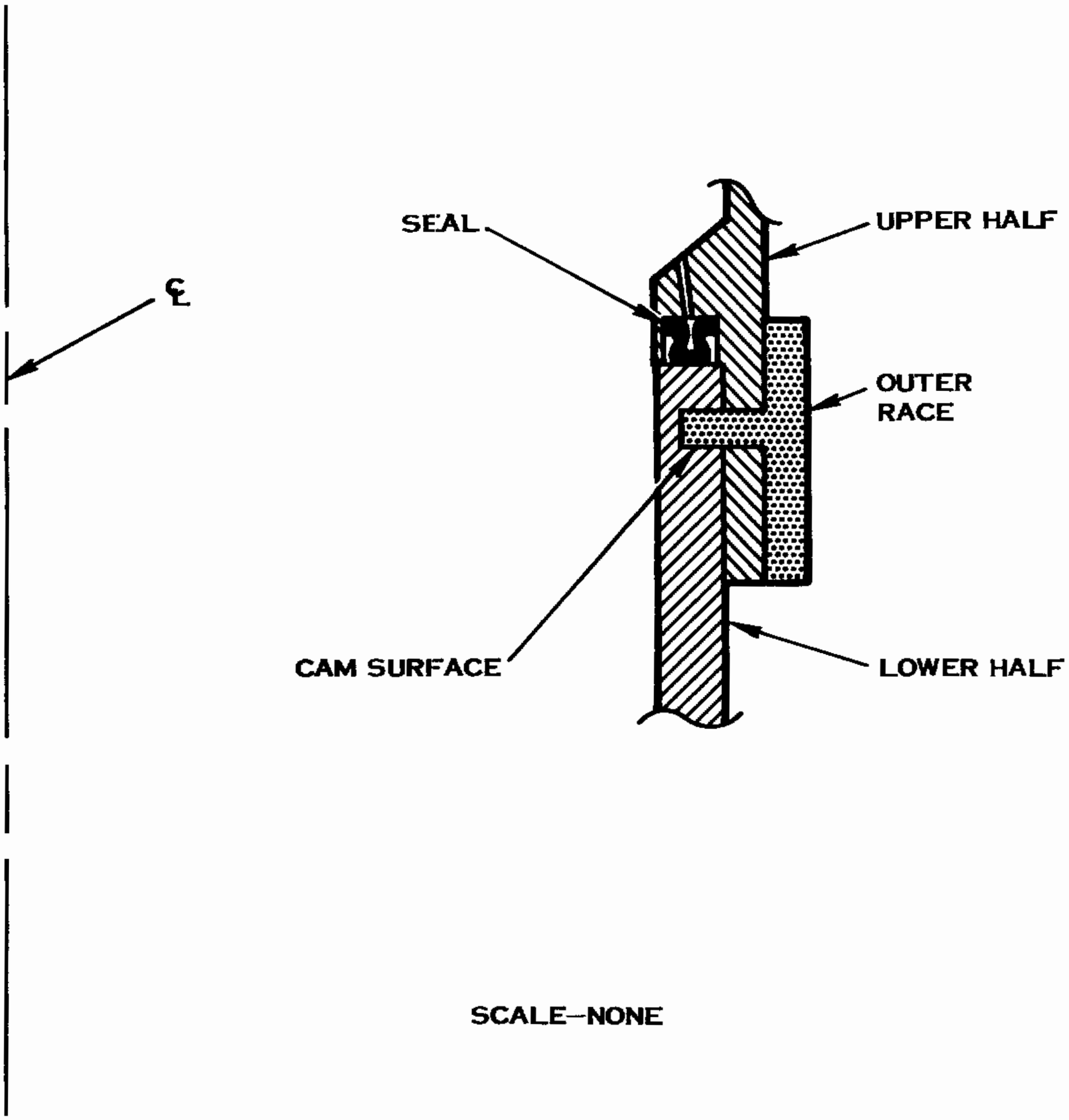
CONCEPT NAME	Safety	Mobility	Volume	Weight	Reliability	TOTAL*
Front Door	2	4	1	2	2	11
Single Back Hinge	3	2	4	2	4	15
Double Back Hinge	4	1	2	3	4	14
Horizontal Split	1	1	1	1	1	5

*Lowest is best

Legend

1 - Excellent
2 - Good
3 - Fair
4 - Poor

Figure 9. Torso Finalist Trade Study



SCALE–NONE

Figure 10. Cam Locking Concept

Spring Latch - See figure 11.

This device is similar to the helmet neck ring assembly. The heart of the device is a circular leaf spring, one end of which is attached to the upper half of the connector. The body of the spring is retained in an annular groove in the upper half of the connector until the leaf spring pops into an annular groove in the lower half, thus holding the two halves of the connectors together. Upon insertion of the lower half, the leaf spring is cammed back radially on a ramp on the lower half of the connector until it drops into the annular groove. A positive lock is thereby achieved because the leaf spring must then be pulled in a direction to increase its diameter to unlock. Sealing is achieved by a radial lip seal between the two halves of the connector. A key slot will have to be added to this connector to produce angular alignment of the two halves of the connector.

Clamp Lock - See figure 12.

This concept is similar to a Marman-type clamp. The two halves of the connector are simply clamped together. The clamp can be a separate piece if it is made out of a spring material; ie, it can be stretched over a lip on each of the two halves of the connector and then locked in place with a quick disconnect. The clamp can also be made such that it is permanently attached and hinged to one of the halves of the connector. In this case, the clamp can be made out of spring or rigid material and hinged. Sealing is achieved by either a face or radial type lip seal.

Ball Latch - See figures 13 and 14.

This concept may be used in either manual or automatic actuation modes as shown in figures 13 and 14, respectively. Basically the device is a ball bearing locking mechanism. The upper half of the connector contains the ball bearings trapped in a race but free to move radially. Radial movement is accomplished by a ball cam race which slides vertically by pressing and releasing a spring loaded disconnect button. When this button is released, the ball is forced radially inward until it engages a raceway in the lower half of the connector. To disconnect, simply press the button which moves the ball cam race downward allowing the ball bearings to disengage from the lower half race.

The results of the comparison of the various types of latches considered are shown in Table III. The spring latch device is best suited for the Suit System.

Following the definition of the torso concept, material selection must be made. Two possible materials considered were aluminum and fiberglass. It was decided to use fiberglass because of its amenability to the manufacture of complex shapes. Also, fiberglass structures may be changed easily without costly machining or metal working as might be required for aluminum. Furthermore, fiberglass structures have the property of not permanently deforming unless the ultimate strength is exceeded. Therefore, the structure will not dent over its life. The structural strength requirement is that the working stress be 50% of the ultimate stress. This is in accordance with standard

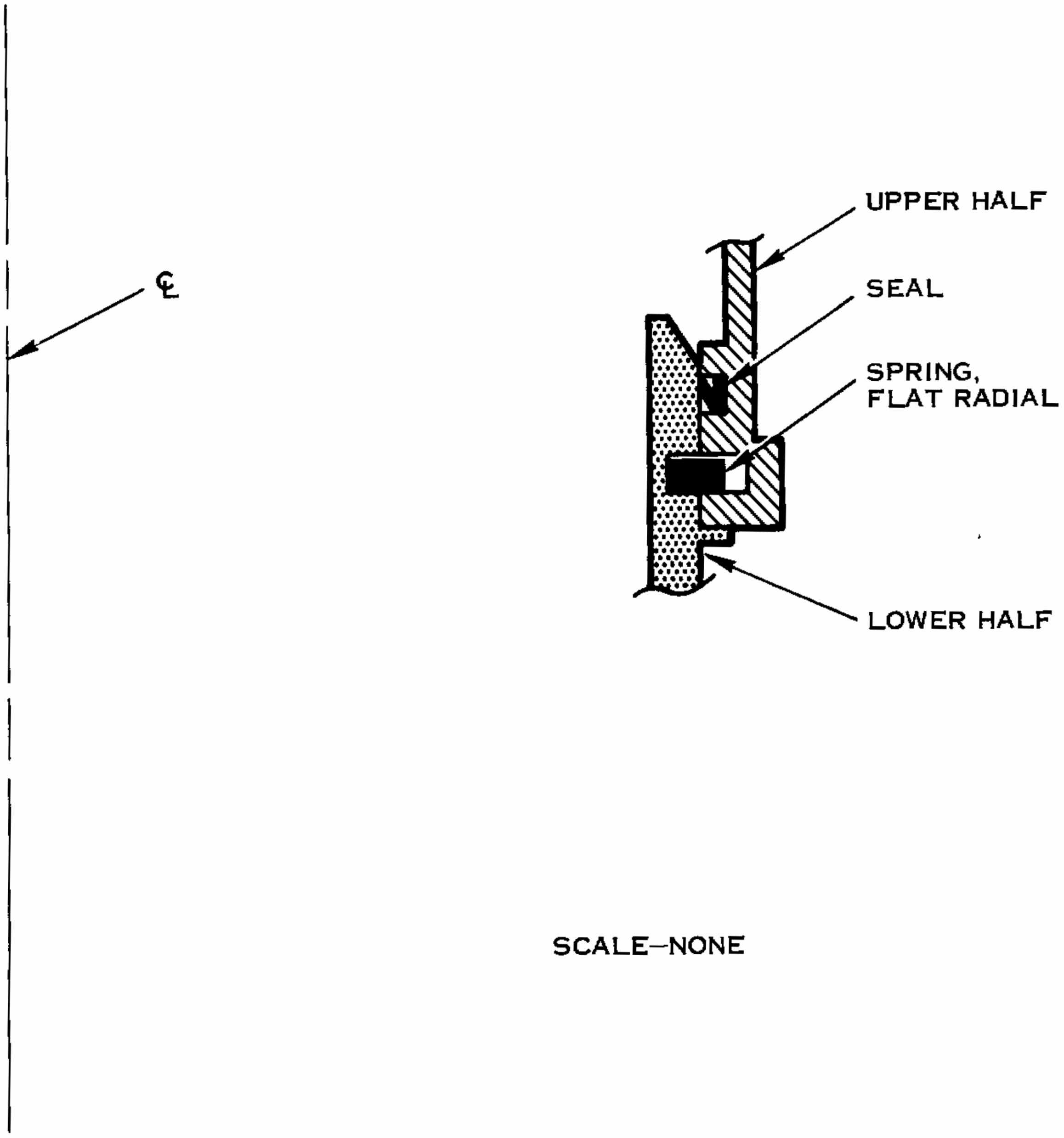


Figure 11. Spring Latching Concept

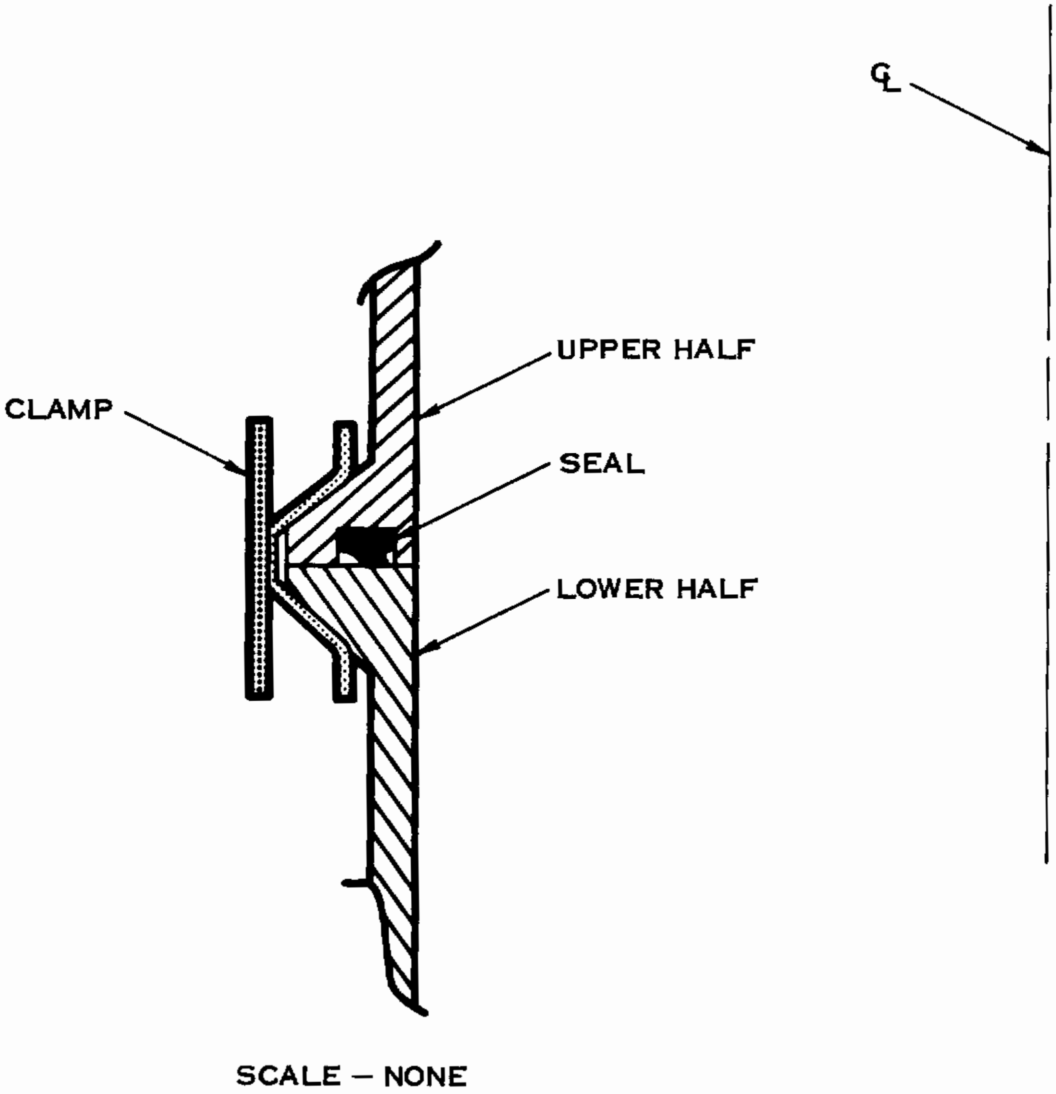


Figure 12. Clamp Concept

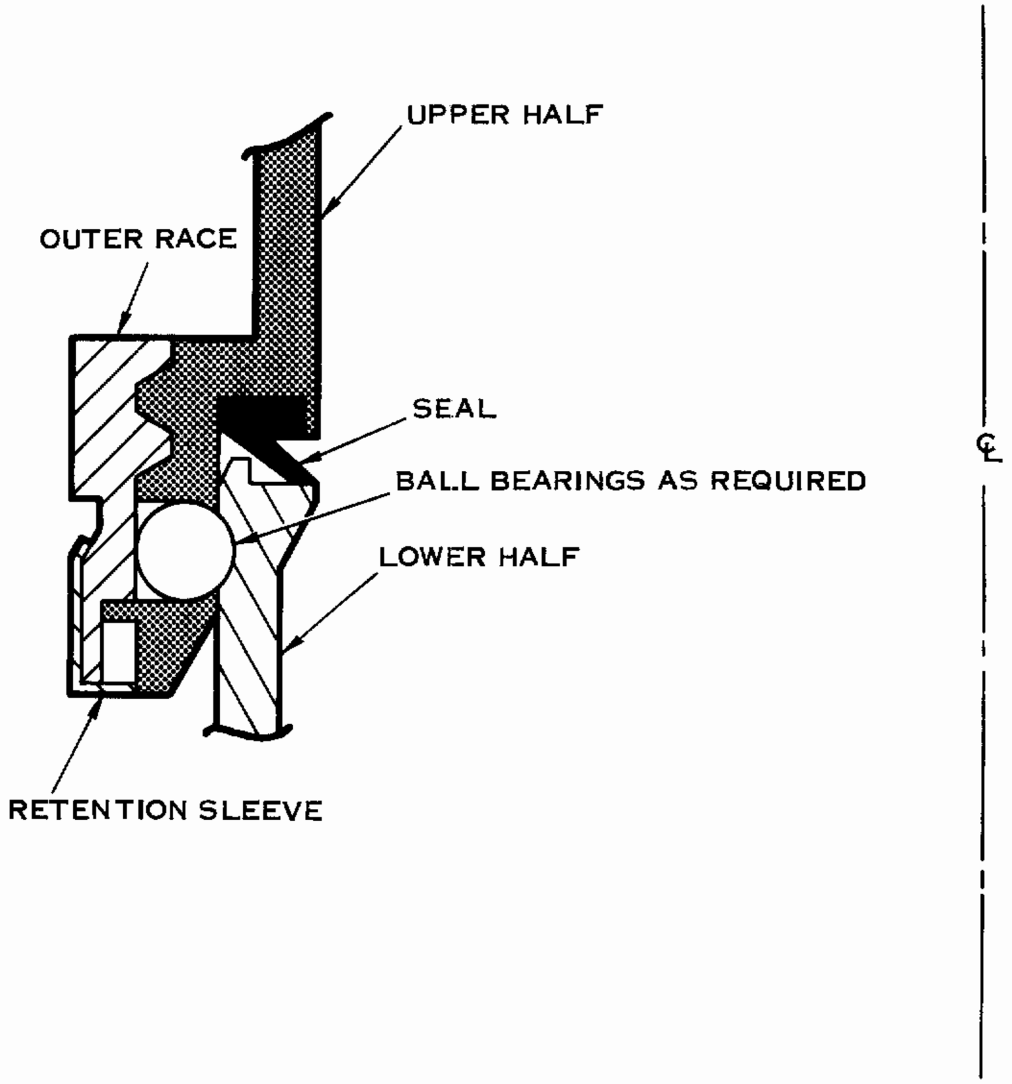


Figure 13. Ball Locking Concept – Manual Actuation

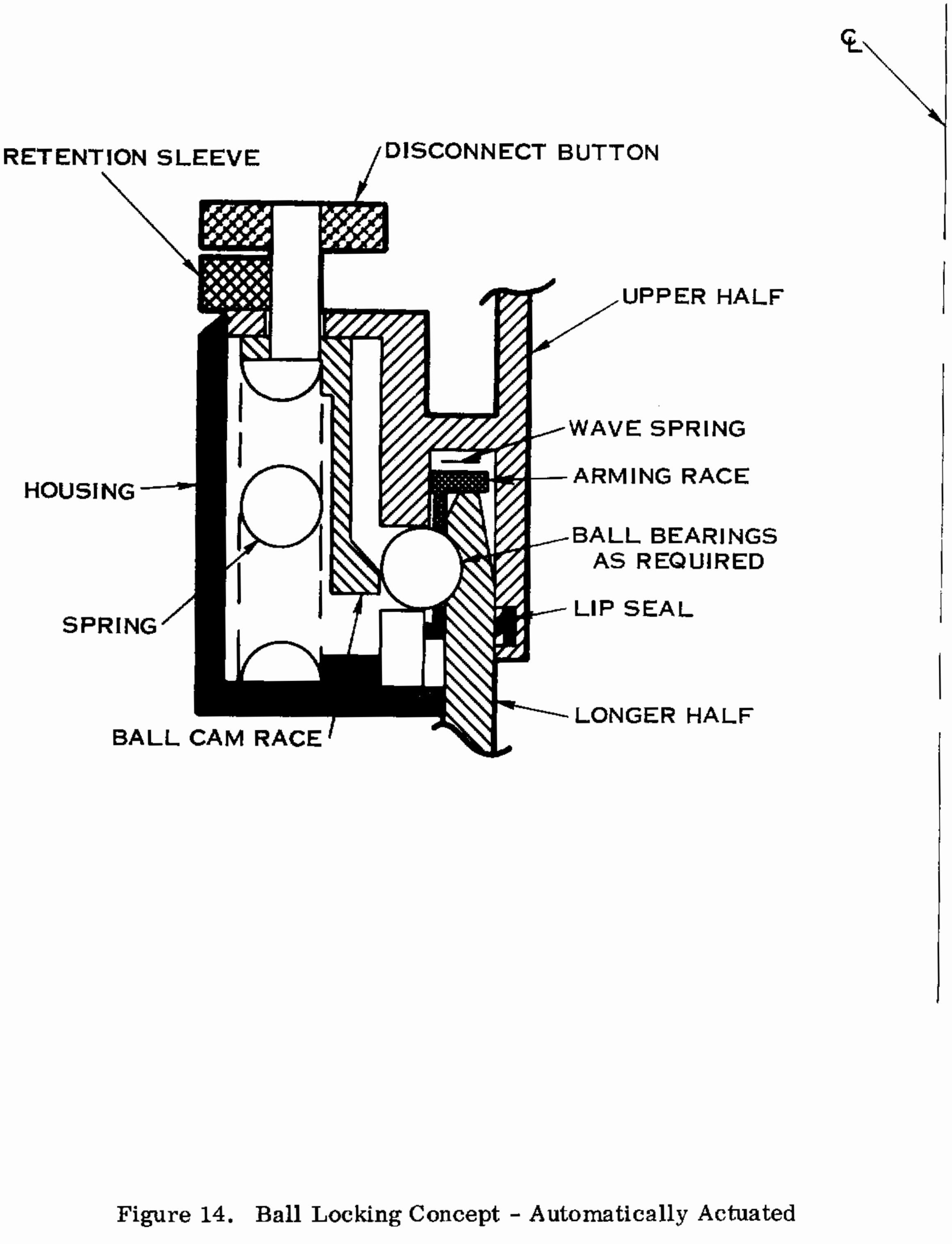


Figure 14. Ball Locking Concept - Automatically Actuated

TABLE III
TORSO CLOSURE LATCH TRADE STUDY

Legend
1 - Excellent
2 - Good
3 - Fair
4 - Poor

Latch Type	Type Description	Safety	Volume	Weight	Reliability	Ease of Operation	Dev. Req.	Mfg. Cost	Total Score *
I	Spring Latch Manually Actuated Helmet Neck Ring Type	2	1	1	1	2	1	2	10
II	Ball Lock Manually Actuated	2	2	2	2	2	3	3	16
	Ball Lock Automatic Actuation	1	3	3	3	1	4	4	19
III	Cam Lock Manually Actuated	3	2	1	1	1	2	2	12
IV	Clamp Lock Manually Actuated Marman Clamp Type	3	2	1	1	3	2	2	14

* Lowest is best.

pneumatic practice that proof pressure be 1.5 times working pressure and burst pressure be 2.0 times working pressure. A stress analysis was conducted on the upper and lower torso pressure shells which resulted in factors of safety of 10 to 1 and 4 to 1 respectively.

The reason for the high factor for the upper torso is that the pressure shell is exposed and subject to impact and abrasion. The 10 to 1 factor of safety will degrade to 2 to 1 over a period of one year's use. The pressure shell for the lower torso is protected by the components which are attached to the outside of it. Therefore, any impact is attenuated by the surrounding structure and a 4 to 1 factor of safety is sufficient. This safety factor also compensates for any structural instability, bowing, or buckling incurred during filling operations.

SOFT SUIT

The soft portions of the suit are the arms and legs. These are detachable from the hard torso and will consist of bladder and restraint cloth. The joints are formed of cloth convolutes and restrained by a steel cable system. The method and configuration of the attachment of the soft sections to the hard torso constitutes a hard/soft interface.

Shoulder

Specific requirements for shoulder joint performance were defined for this program. These were:

- 120° joint excursion in abduction (figure 15)
- 150° lateral-medial excursion (figure 16)
- 170° flexion (figure 17)
- Maximum torque at maximum excursion shall not exceed 20 ft-lb.

The shoulder joint selected to meet these requirements is a soft convolute shoulder with a cable restraint system. The torque and range curves of this shoulder for the three required motions described above are shown in figure 18, 19, and 20. Another concept that could lead to better performance in the form of reduced torque is presently being investigated. This concept consists of three bearings interconnected with restraint cables in the shoulder joint area. A typical shoulder bearing concept is shown in figure 21. Should bearings prove to be better than convolutes or some combination of bearings and convolutes prove superior to either alone, that concept will be designed into the integrated EVA suit system. The present size opening retains the capability to integrate either concept to the torso.

Arm and Glove Assembly

The arm and glove assembly of the Integrated EVA suit system is a state-of-the-art soft suit item derived from current pressure suit technology. Starting just below the shoulder, the arms consist of: an upper arm bearing, a sizing panel, a convoluted

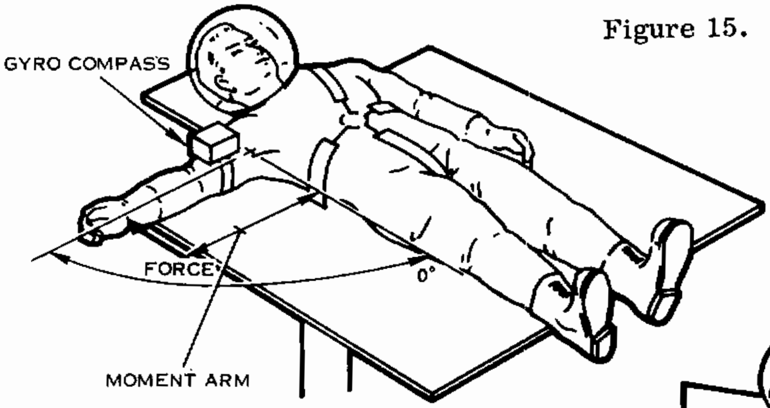


Figure 15. Shoulder - Frontal Abduction

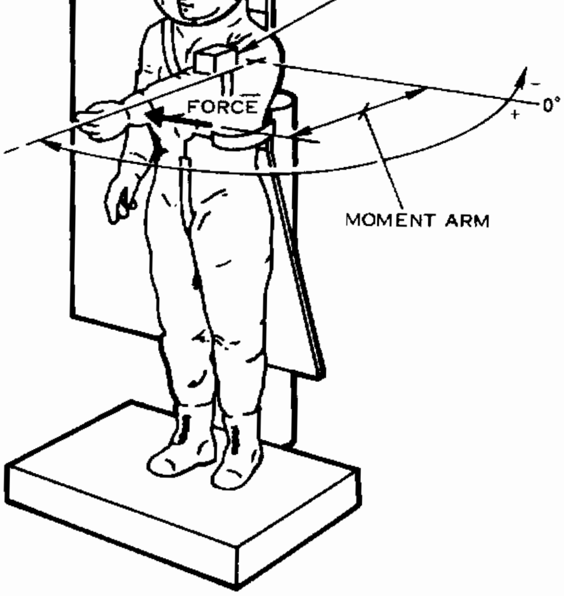


Figure 16. Shoulder - Lateral Medial

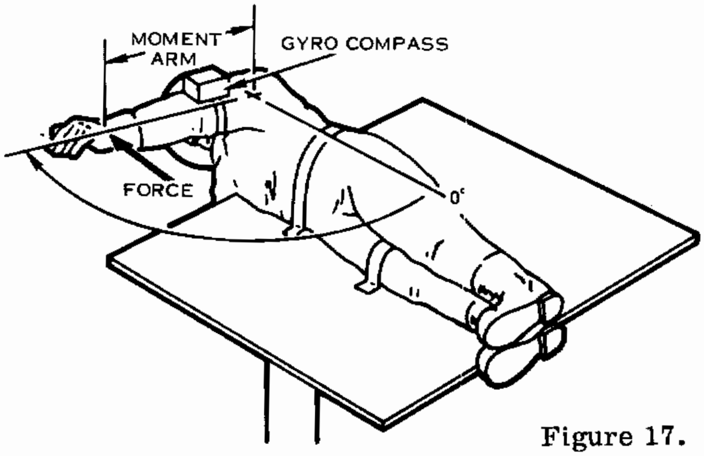


Figure 17. Shoulder - Flexion

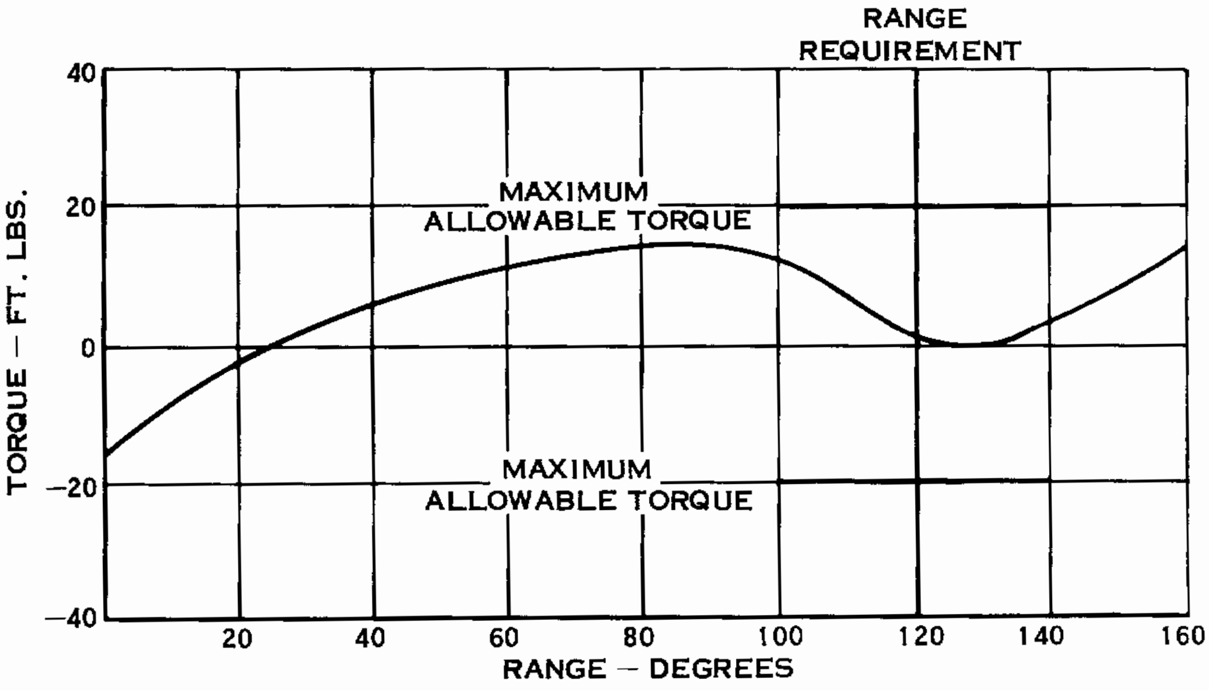


Figure 18. Shoulder Abduction

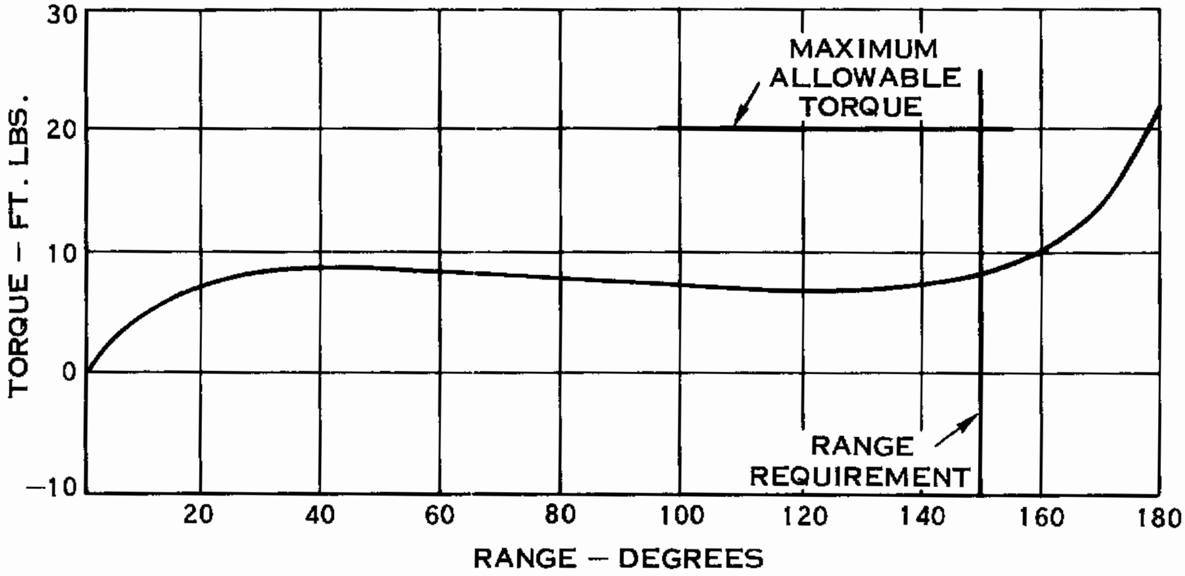


Figure 19. Shoulder - Lateral Medial

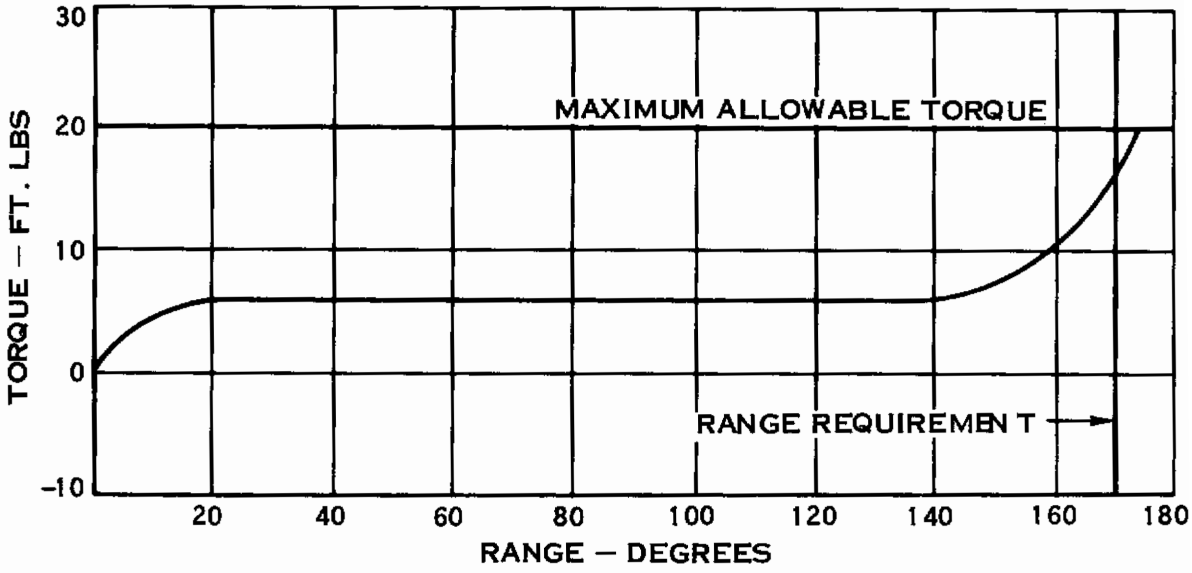


Figure 20. Shoulder Flexion - Extension

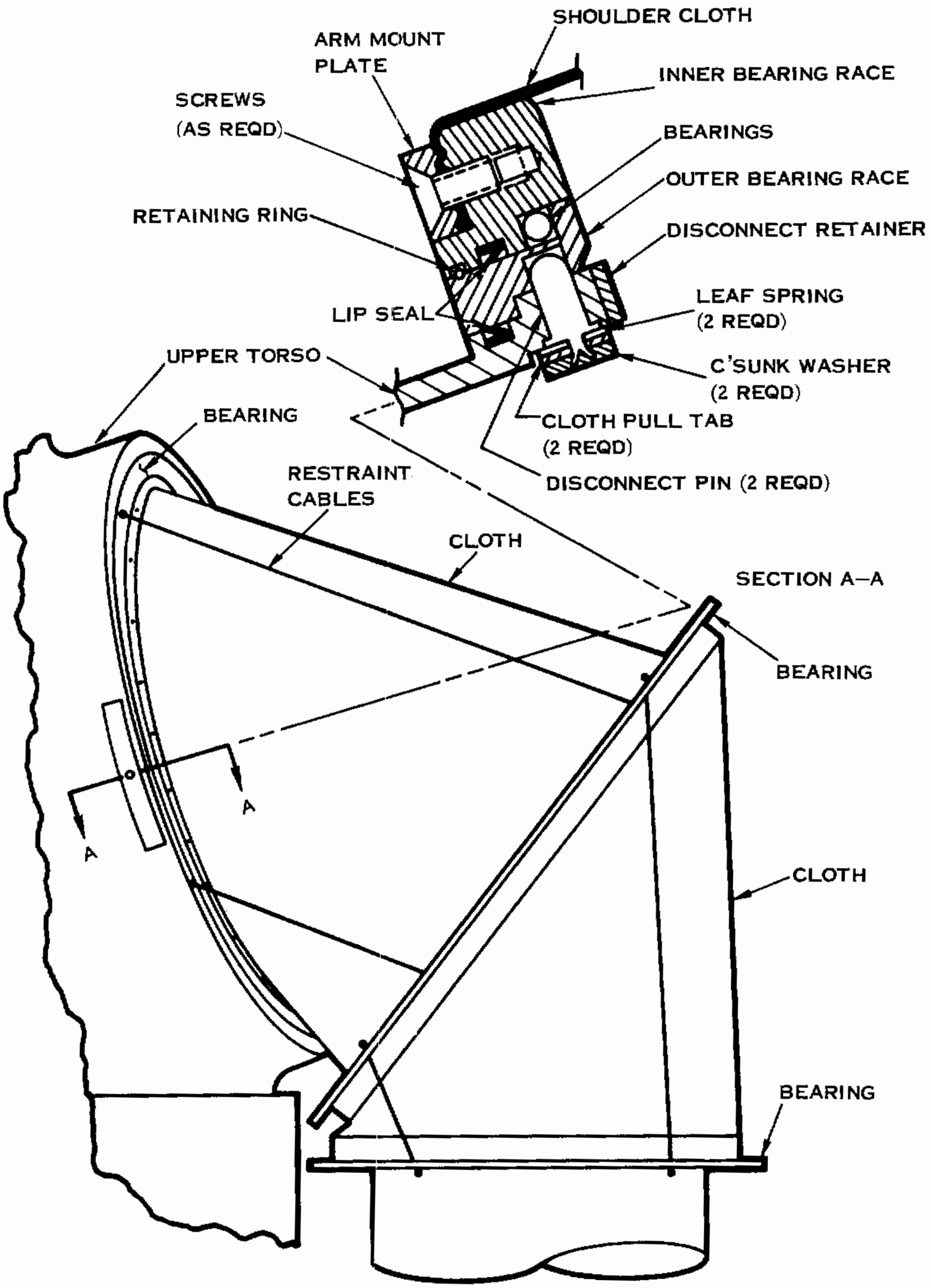


Figure 21. Three Bearing Shoulder Joint Concept

elbow joint, a forearm with sizing panel, a wrist disconnect, and a pressure glove. The upper arm bearing has a full rotating pressure seal which permits pressurized arm rotation in any position that the arm is capable of attaining.

The convoluted elbow joint with cable restraints performs nearly as well as a nude joint as shown in figure 22. The sizing panel, located in the forearm area, may be used to adjust the overall arm length ± 1.9 centimeters from nominal medium regular. The wrist disconnect is a full rotating, manually operable, connector and seal. Distal to the wrist connector is the pressure glove which contains a wrist joint whose performance is shown in figure 23 and 24. The pressure glove is also a state-of-the-art assembly derived from today's soft suit technology.

Soft Pants Assembly

The soft pants assembly is again soft suit technology derived soft goods assembly. Its principal parts are:

- Lower half of the waist disconnect mechanism
- Hip joints (2)
- Knee joints (2)
- Sizing Panels (2)
- Ankle Joints (2)
- Soft Boots (2)
- Vent System

The lower half of the waist disconnect is identical to the lower half of the suit entry closure mechanism. A leaf spring is sprung radially into an annulus for positive locking. Redundant locking is accomplished by mechanically restraining the leaf spring in the shortened radius configuration.

Each leg has a hip joint consisting of the typical soft convolute and restraint cable system. Hip joint performance is shown in figures 25 and 26. The knee and ankle are constructed in the same manner as the hip and their range and torque curves are presented in figures 27 and 28. A sizing panel is included in the calf sections. The soft boot contains a semirigid sole for walking in a gravity field and for foot purchase in zero gravity.

Hard/Soft Interface

The hard/soft interface is the area where the soft suit material meets the hard torso section. This occurs in two places, the scye and the waist. These areas present special problems in that not only must the soft suit sections detach from the hard torso at these points, but major joint movements are also involved.

Scye

The arm disconnect will be made at the scye opening using a flange with the soft material attached to it. In this manner, the shoulder joint performance will be nearly unaffected.

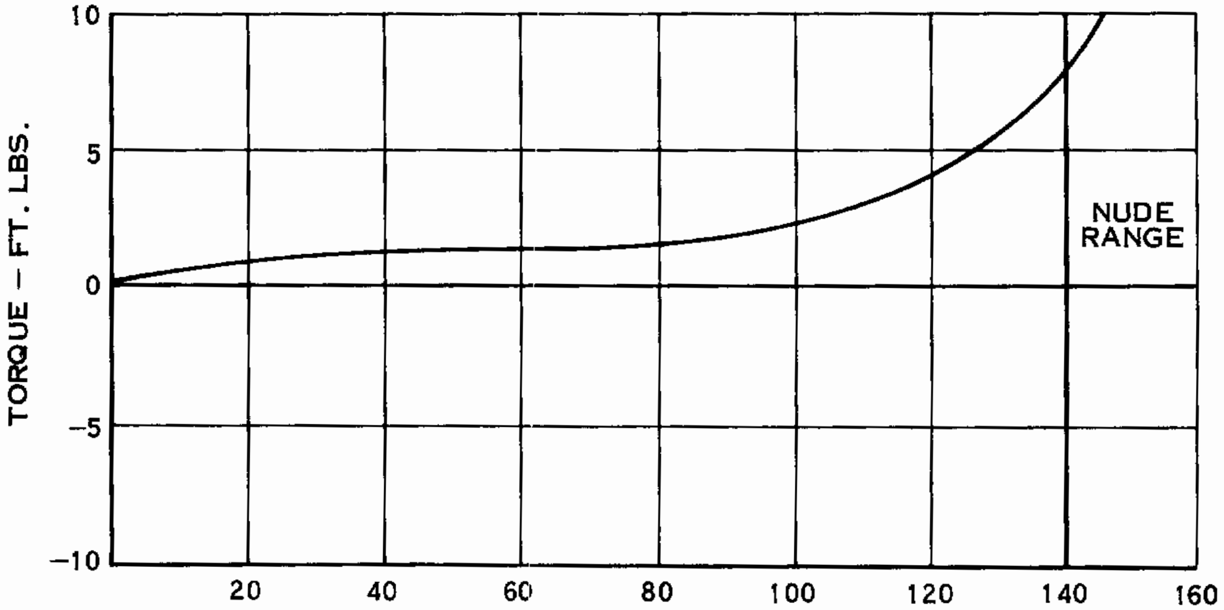


Figure 22. Elbow Joint Performance

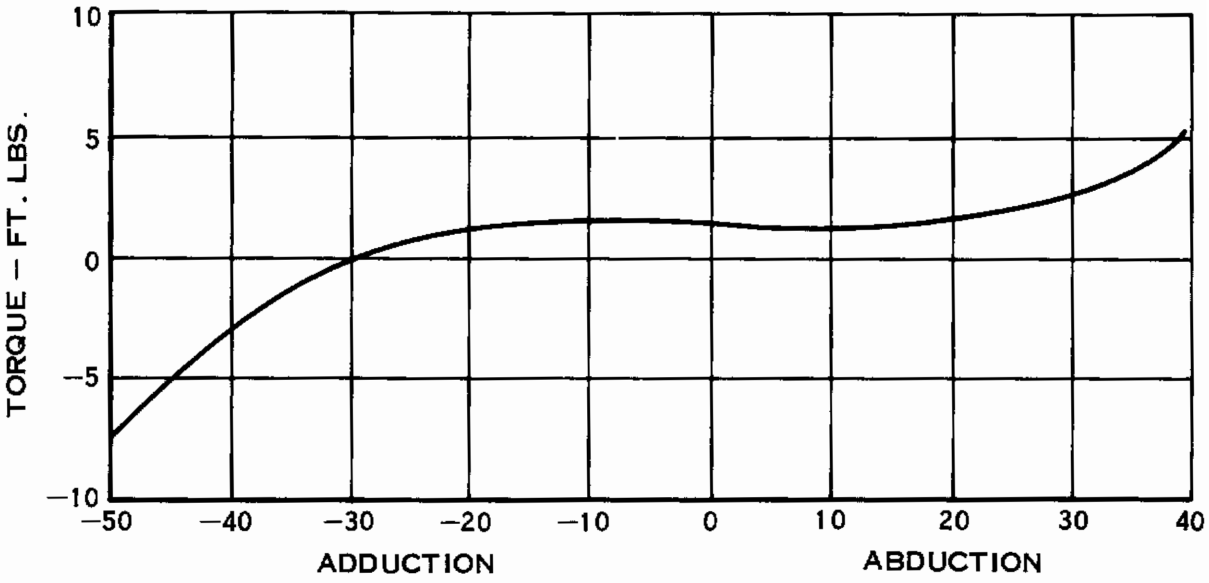


Figure 23. Wrist Joint Performance, Abduction - Adduction

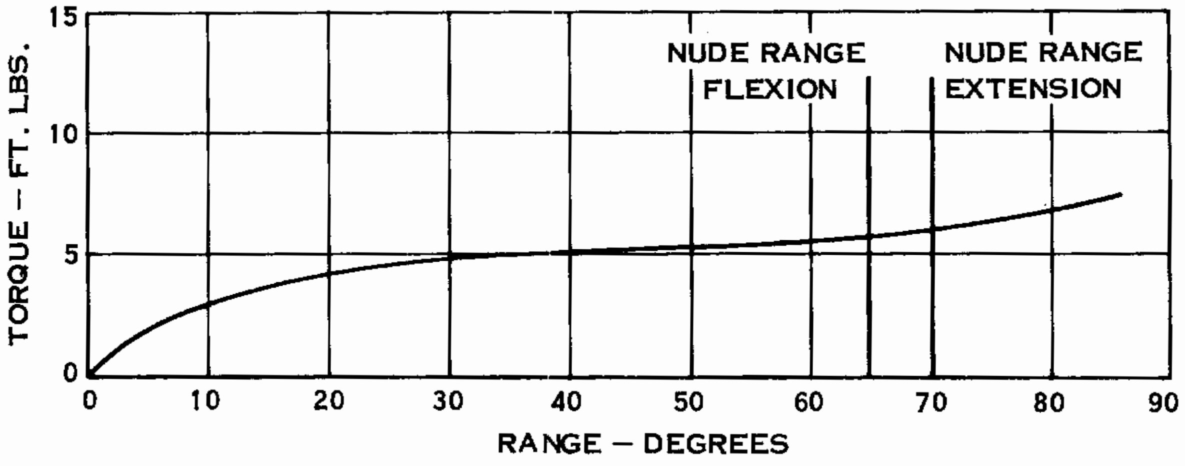


Figure 24. Wrist Joint Performance, Flexion - Extension

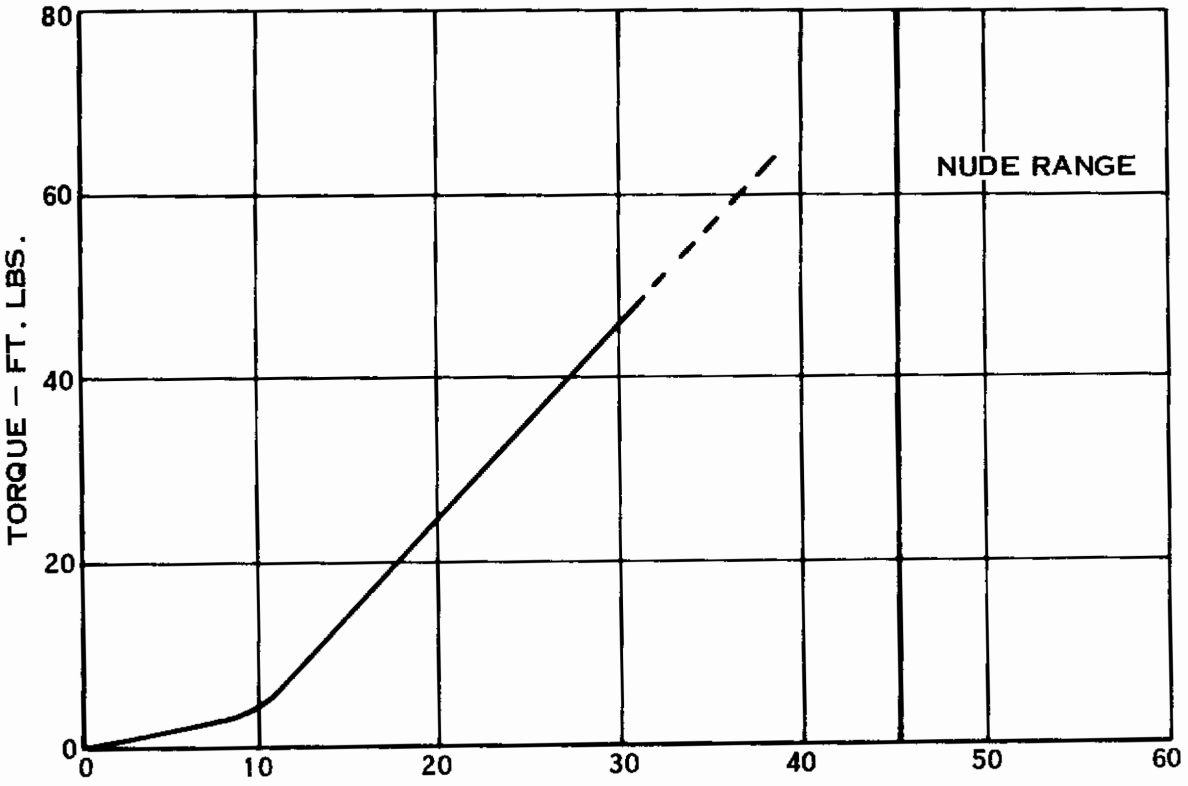


Figure 25. Hip Joint Performance, Frontal Abduction

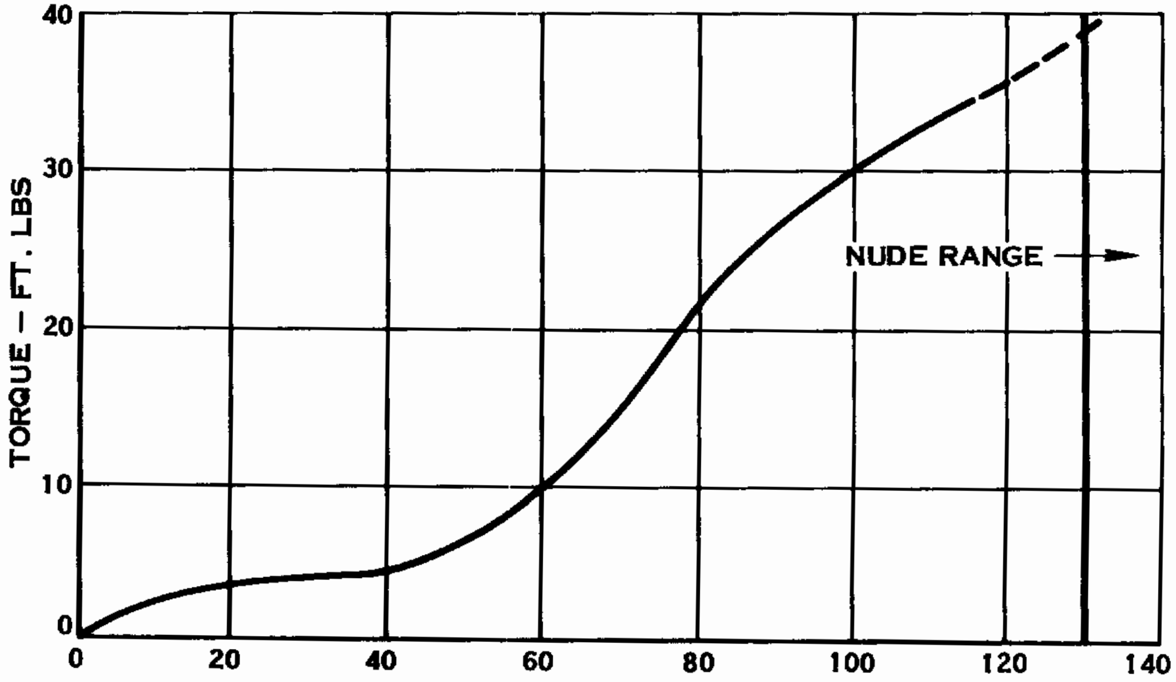


Figure 26. Hip Joint Performance, Sagital Flexion

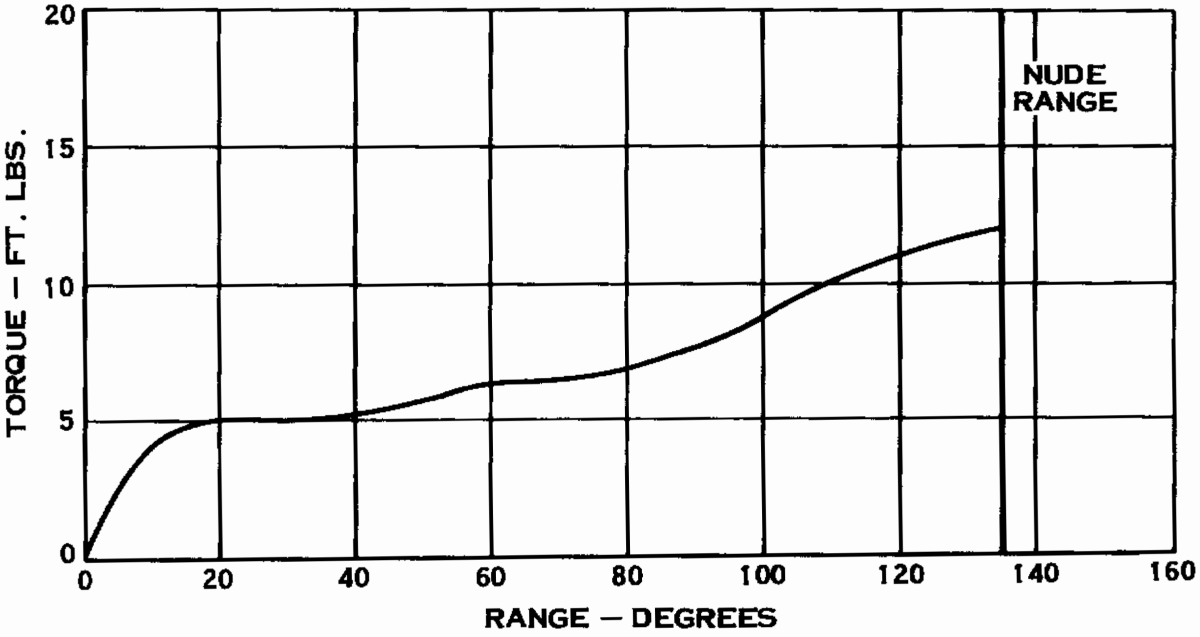


Figure 27. Knee Joint Performance - Flexion

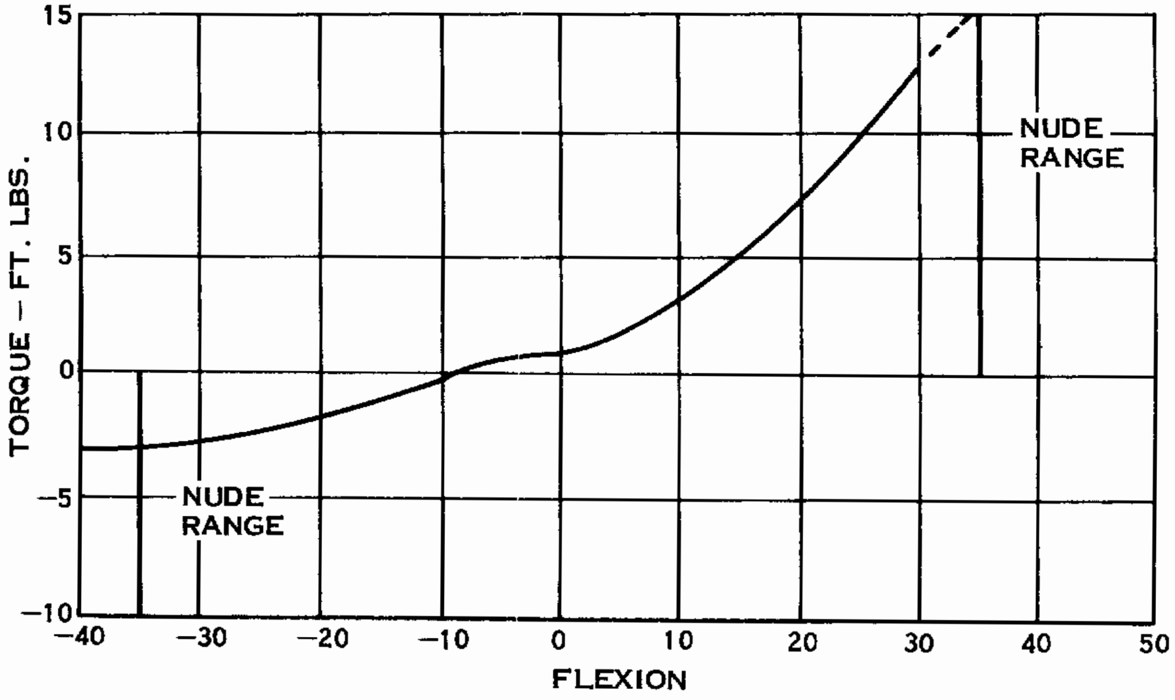


Figure 28. Ankle Joint Performance, Flexion - Extension

The flange will be designed to mate with the torso scye flange primarily to achieve a failsafe disconnect and to allow the suit pressure to force the seal closed. Therefore, the arm will have to be inserted through the scye opening, glove first, from inside the upper torso. Two locking pins will then be inserted to prevent the arm from falling back inside the torso when depressurized and to prevent rotation. These pins will be designed so that they will not carry the arm plugloads. Figure 29 is a schematic representation of this concept.

Waist

The waist disconnect will be identical to the closure mechanism for the same reasons. The soft suit material will be joined to the lower half of the disconnect as shown in figure 30. Since hip joints only will be installed in this area, no significant joint interference is anticipated. The connection would be made to the lower torso before donning to ensure positive locking of the connector.

LIFE SUPPORT SYSTEM

This portion of this report will describe the Life Support System (LSS) for the Integrated EVA suit. The design and engineering studies required to define the equipment which will meet the life support requirements are presented.

Oxygen Supply and Pressure Control

The IEVA Suit O_2 supply must be sufficient to satisfy metabolic plus leakage requirements. The crewman's metabolic needs are shown in figure 31 which indicates that, at the mission average metabolic rate of 375 Kcal/hr, 0.110 Kgm/hr of O_2 are required. In addition, a system leakage of 0.018 Kgm/hr (230 scc/min) must be allowed for. Thus the system must be able to supply 6 x 0.128 or 0.775 Kgm.

There are four basic ways in which to accomplish this:

High pressure oxygen (527,000 gm/cm^2)
Low pressure oxygen (66,900 gm/cm^2)
Cryogenic oxygen
Chemical O_2 supply

High Pressure Gas

Gas storage at 527,000 gm/cm^2 is a very attractive choice from a volume standpoint. The storage vessel will occupy approximately 2140 cm^3 including regulator and weigh approximately 2.95 Kgm. Furthermore, the technology exists today to develop a storage bottle. A 527,000 to 352 gm/cm^2 psi regulator is available from Apollo PLSS technology. Only a minor amount of rehousing and redirection of ducting will be required.

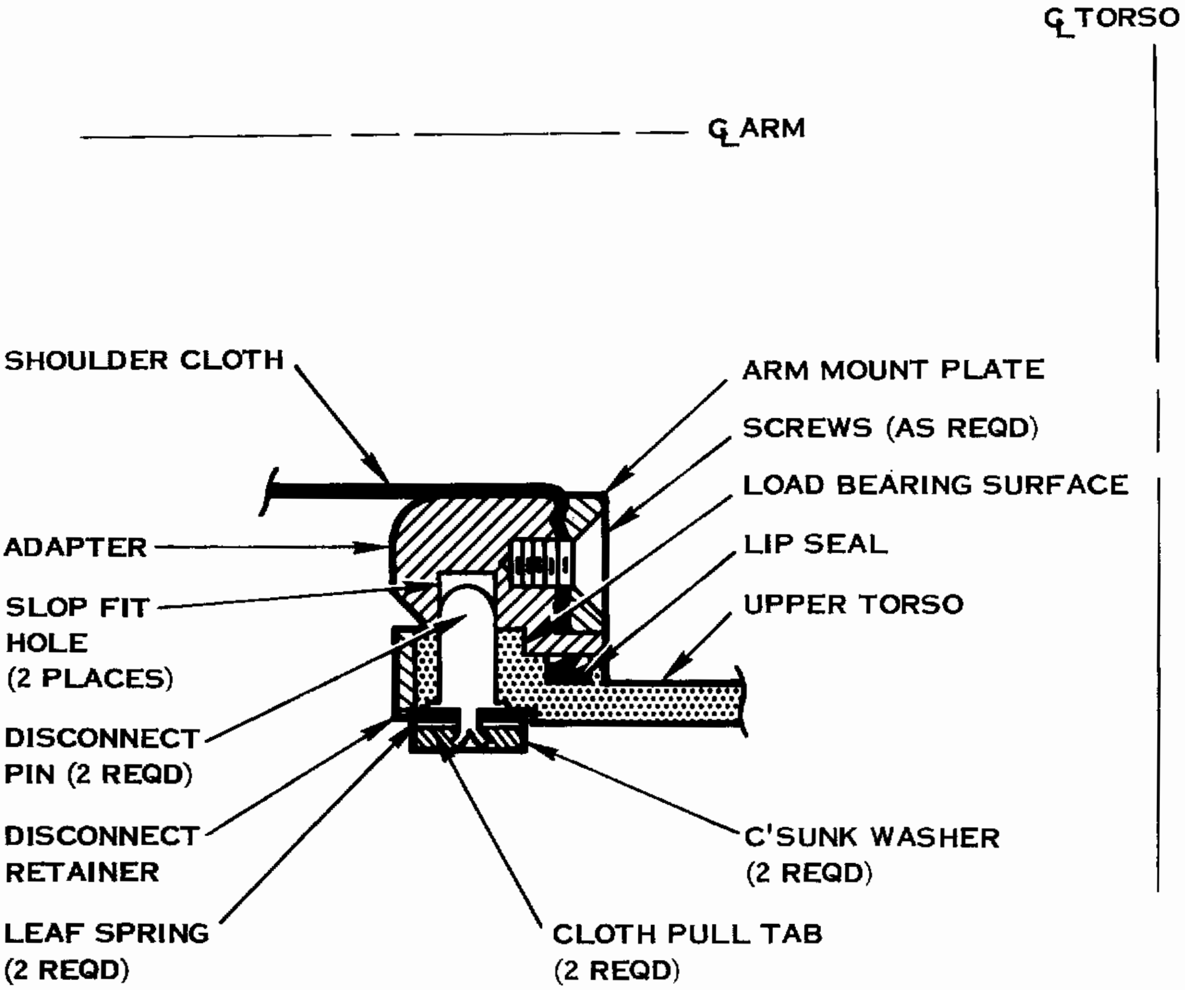


Figure 29. Scye Hard/Soft Interface

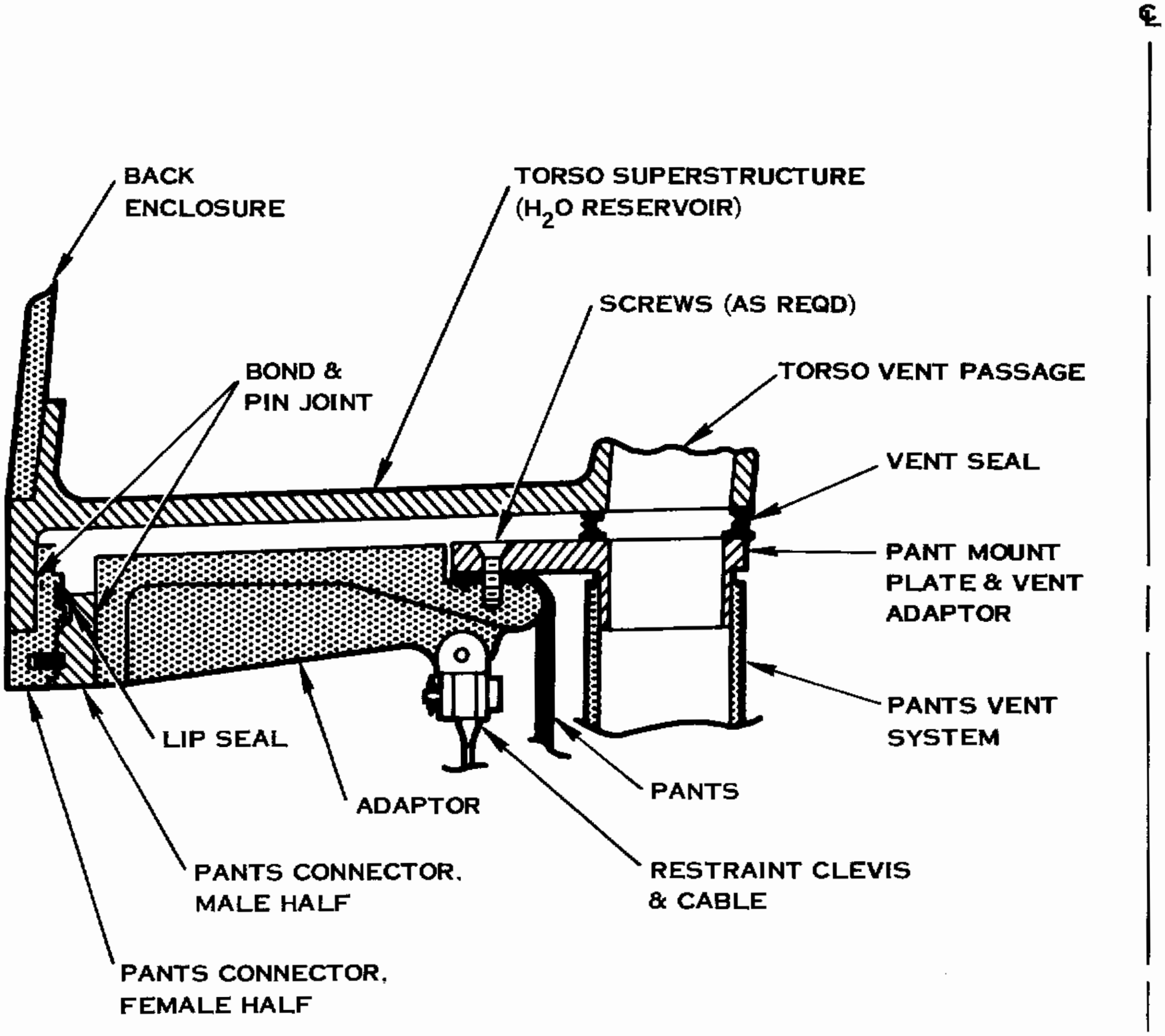
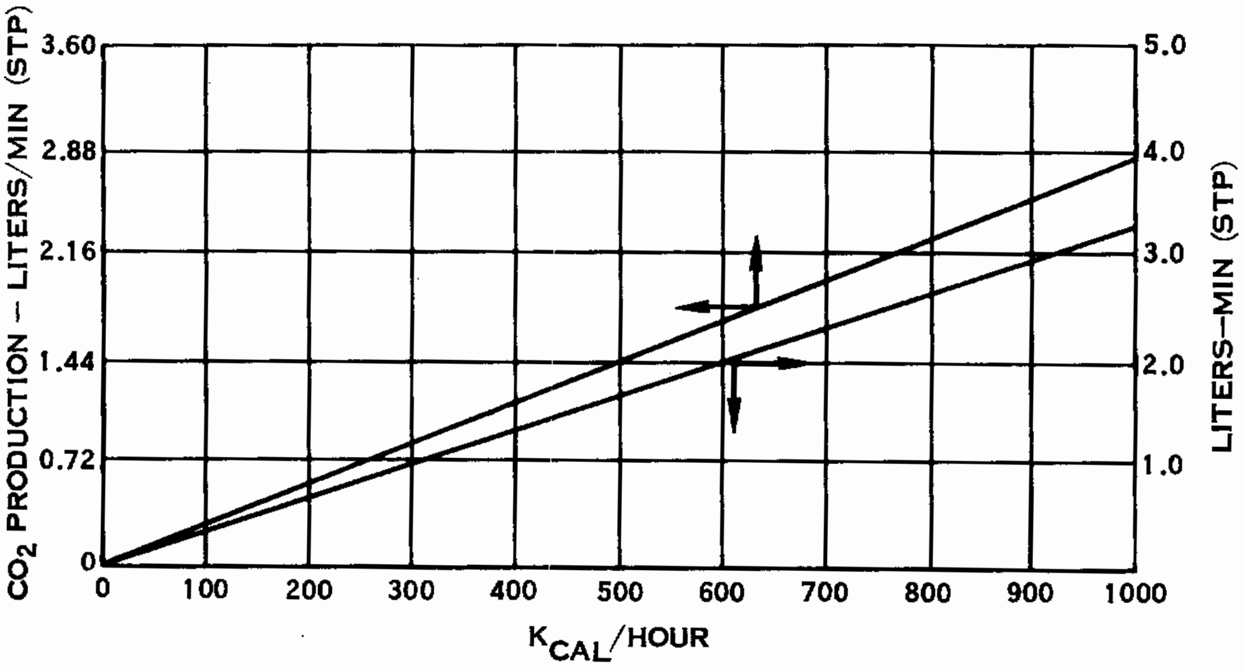


Figure 30. Waist Hard/Soft Interface



Figurd 31. Metabolic Rate vs Oxygen Consumption and Carbon Dioxide Production

Low Pressure Gas

Low pressure gas storage at 66,900 gm/cm^2 will result in a vessel volume in excess of 13,100 cm^3 and weigh 3.06 Kgm. This volume is totally incompatible with IEVA system requirements and, therefore, this concept will be considered no further.

Cryogenic Oxygen

Storage volume for cryogenic oxygen is quite low, approximately 980 cm^3; however, other cryogenic system requirements result in severe volume penalties. These requirements are: insulation, cryogenic pressure regulation controls, and heater controls and accompanying increases in battery weight and volume. These penalties, which may reach 16,400 cm^3, removed cryogenic oxygen from further study.

Chemical O_2 Supply

An area of great promise is the concept of having a chemical reaction bed supply oxygen as a by-product of reacting with carbon dioxide. This system is very attractive from a weight and volume standpoint with a system weight of approximately 2.72 Kgm and a volume of 1770 cm^3.

The three principal materials that have been found to produce this reaction are:

1) KO_2 - Potassium Superoxide
2) Li_2O_2 - Lithium Peroxide
3) NaO_2 - Sodium Superoxide

Li_2O_2 has a low oxygen generation rate due to low bed temperatures and some recombination of the oxygen. These development problems have not been solved to date and therefore this substance was considered no further. The oxygen producing reaction for the superoxides has been found by experiment to be extremely sensitive to gas stream dewpoint. To adequately control the oxygen production, elaborate humidity controls must be developed. If such controls should be developed in the future, Superoxides quite likely will be superior to all other concepts. However, until that time, chemical oxygen supplies will not be considered for the IEVA Suit System.

Conclusion

Figures 32 and 33 compare the effects of various oxygen supplies on system weight and volume as a function of mission duration. Table IV indicates an overall comparison of various oxygen supply systems on the basis of the previously established first order evaluation criteria. The best system from the standpoint of volume, weight, and development status is high pressure (527,000 gm/cm^2) gas storage with LiOH for CO_2 control.

Suit pressure control will be provided by a single stage regulator. The regulator was developed by Carleton Controls Corporation for use in the Apollo EMU emergency

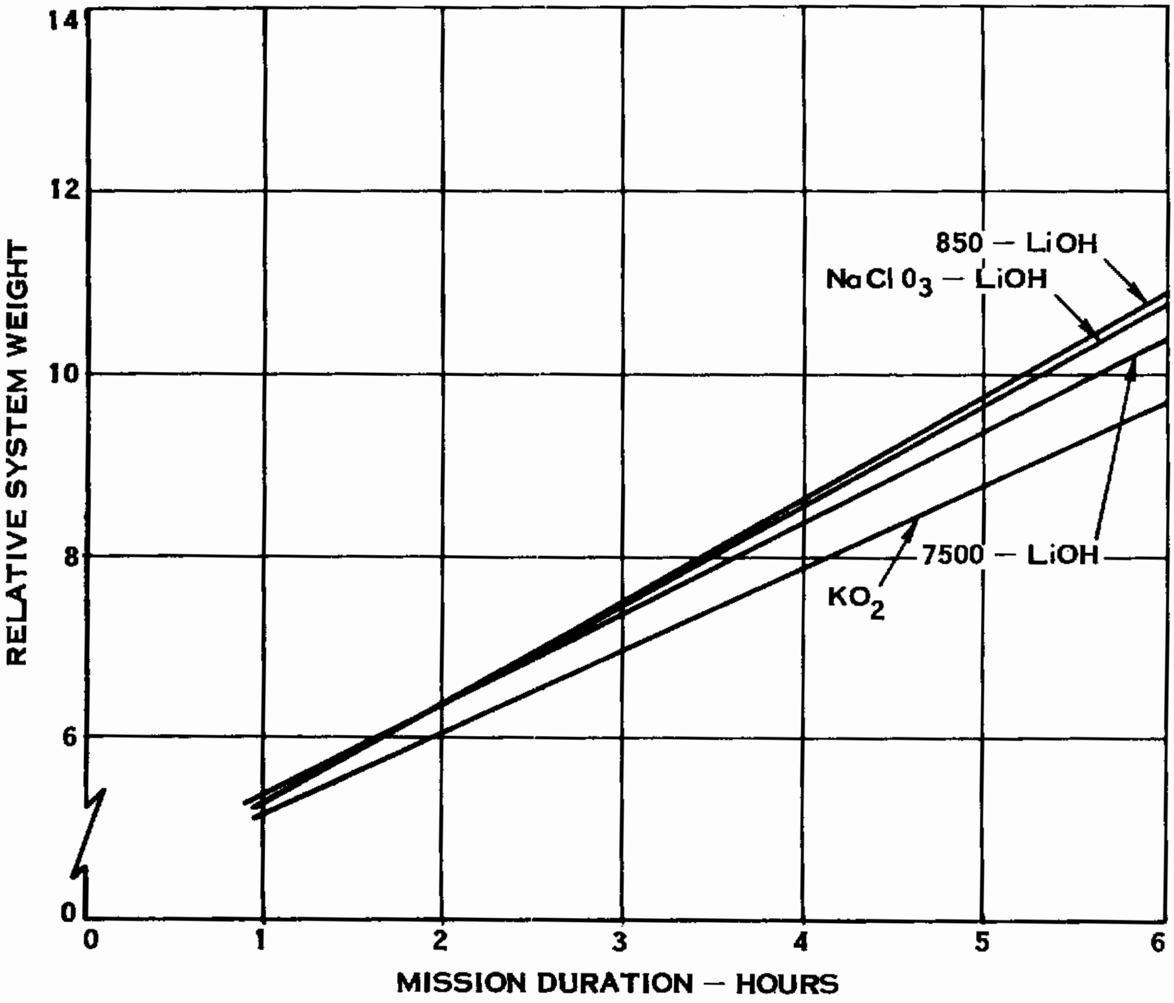


Figure 32. System Weight vs Mission Duration for Various O_2 Supplies

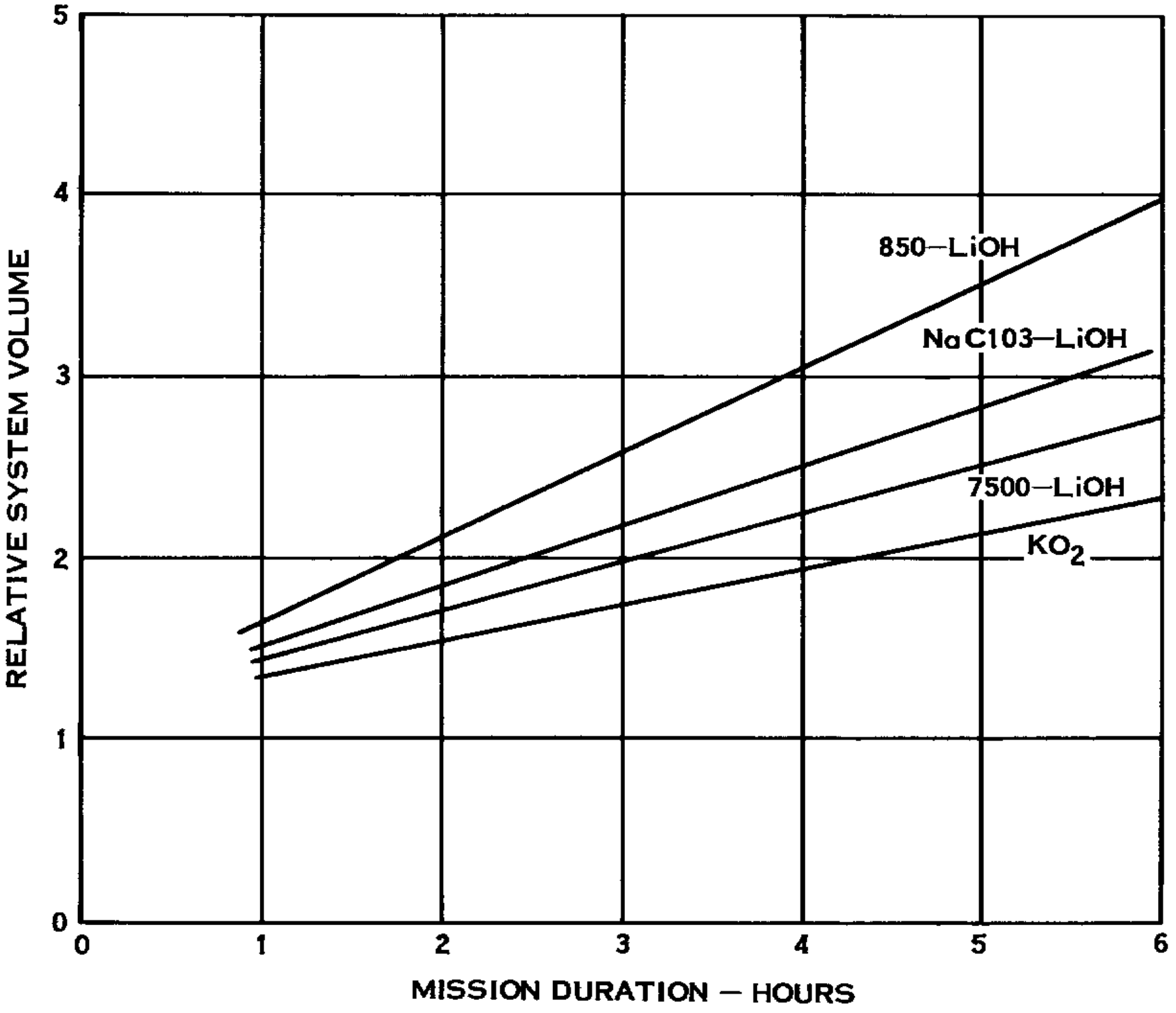


Figure 33. System Volume vs Mission Duration for Various O_2 Supplies

TABLE IV
SUMMARY COMPARISON
IEVA OXYGEN SUPPLY SYSTEMS

System	Safety	Volume	Weight	Development Required	Total*
7500 psig Oxygen	2	2	2	1	7
950 psig Oxygen	2	3	3	1	9
Cryogenic Oxygen	1	4	4	2	11
Chemical Supply	2	1	1	4	8

*Lowest is best

Legend

1 - Excellent
2 - Good
3 - Fair
4 - Poor

oxygen system. If the regulator fails closed, an emergency return system will be activated. A failed open regulator would result in over pressurizing the suit and rupture. Therefore, a relief valve sized to provide the necessary pressure control will be installed. This relief valve will open at 388 gm/cm^2 psi and provide flow to 1.64 Kgm/hr (the maximum regulator output).

Contaminant Control

The Life Support System (LSS) must be capable of removing various chemical and physical contaminants in the gas stream in order to provide the crewman with a habitable and comfortable atmosphere. An orlon felt filter will be used to remove particulate matter from the gas stream. This filter will remove 99% of all particles greater than 7 microns in diameter and 100% of all particles greater than 25 microns in diameter. The principal chemical contaminant is carbon dioxide (CO_2) a product of metabolism. Water vapor may also be considered a contaminant; however, control of this constituent will be treated under humidity control. Experiments show CO_2 production rates of 134 gm/hour at a metabolic rate of 375 Kcal/hour, as indicated by figure 31. Thus, the IEVA LSS equipment must be able to remove 4 x 134 gm/hr or 0.535 Kgm of CO_2 for a four hour mission. Furthermore, this removal must be carried out under gas stream conditions of 2.83 liters/sec, 258 mm/Hg, 18-21 C dew-point, and 24-27°C. At all times, the inspired partial pressure of CO_2 must be less than 8.0 mmHg. Since the free volume of the system is approximately 56.6 liters, a maximum of 10.9 gm of free CO_2, or 4.9 minutes of CO_2 production at 375 Kcal/hr, is allowed. This means that the contaminant control canister must essentially remove the CO_2 as it is produced. Another way to express it is to say that the CO_2 removal efficiency must be 100 (1-0.024/1.18) or 98%.

The two basic devices of controlling CO_2 for short duration missions are: (1) molecular sieves, and (2) chemical absorbent beds. Molecular sieves operate on the principle of physical adsorption of the undesirable material (the adsorbate) on a zeolite bed. These beds have the highly desirable quality of being regenerable through the use of heat and lowered adsorbate partial pressure. Unfortunately, this quality also results in high system fixed weight due to comparatively low CO_2 adsorption efficiency and additional hardware required. Figure 34 shows the trade between system weights and mission duration. Molecular sieve systems have a considerably higher initial system weight, but due to their regeneration capability, have a lower slope in terms of system weight per mission day: 1.93 Kgm/day for vacuum desorption, 3.3 Kgm/day for heated vacuum desorption, and 4.58 Kgm/day for LiOH systems. For example, Linde 5A zeolite adsorbs 8 gm of CO_2/100 gm of zeolite. This means that the LSS would have to carry 6.7 Kgm of zeolite to adsorb the 0.535 Kgm of CO_2 generated in 4 hours at 375 Kcal/hr. This does not compare favorably with the 1.82 Kgm of LiOH required for the same mission. For this reason, molecular sieves were considered no further.

Table V shows a comparison of chemical CO_2 removal systems performance. At first glance, it would seem that a chemical CO_2 absorbant that gives off O_2 is highly desireable. However, test results have shown that O_2 production from any of the three shown is highly dependent on the humidity of the gas stream. Therefore, elaborate

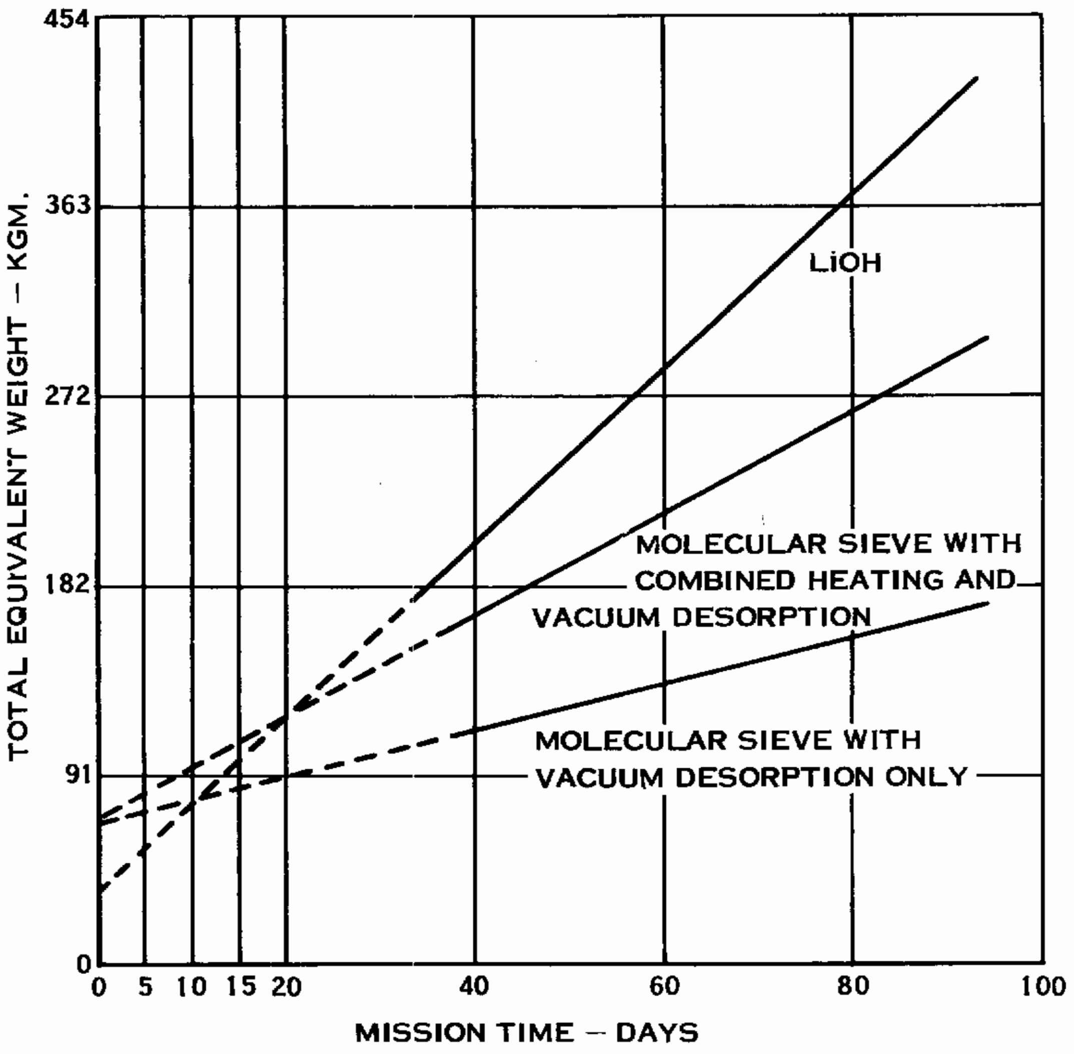


Figure 34. Weight Comparison of CO_2 Removal Systems

TABLE V
PERFORMANCE OF CHEMICAL CO_2 REMOVAL SYSTEMS

Compound	MOL Wt. & Formula	CO_2 Removal Kgm CO_2/Kgm Chemical		O_2 Produced Kgm O_2/Kgm Chemical		CO_2 Removal Efficiency	Density (gm/cm^3)	(Kgm) per 4-hr Mission	(cm^3) per 4-hr Mission	Heat Generated	
										CO_2 (Cal/gm)	O_2 (Cal/gm)
		Theor.	Actual	Theor.	Actual						
Lithium Hydroxide	23.95 LiOH	0.41	0.132	--	--	32	0.48	1.82	3780	700	--
Lithium Oxide	29.88 Li_2O	0.667	0.495	--	--	74	0.26	0.49	1920	1230	--
Lithium Peroxides	45.88 Li_2O_2	0.445	0.245	0.159	--	56	0.61	1.00	1120	995	153
Potassium Superoxide	71.10 KO_2	0.141	0.077	0.159	0.118	55	0.66	3.90	5900	760	195
Sodium Superoxide	54.99 NaO_2	0.182	0.145	0.195	0.163	80	0.61	1.68	2760	672	466

humidity controls would be necessary to keep the system from under or over producing oxygen. None of the necessary controls has been developed; therefore, these dual-purpose materials were dropped from further consideration.

Of the remaining two materials, only lithium hydroxide (LiOH) has a history of proven development culminating in manned spaceflight usage. Additionally, lithium oxide (Li_2O) is largely undeveloped due to unavailability of the material. This scarcity resulted in a large effort to develop LiOH which has been very successful. Therefore, LiOH is considered to be the developed chemical absorbent of choice.

LiOH Bed Sizing

For design purposes, we will consider the LiOH CO_2 removal efficiency to be that of the Apollo PLSS which is 32%. This apparently low value is due to the fact that the total system volume is very low, approximately 56,600 cm^3. Therefore, any slight decrease in the CO_2 absorption rate increases the partial pressure greater than allowable and thereby causes bed failure by definition.

Theoretical CO_2 removal may be calculated from the stoichiometric equation.

$$2\ LiOH + CO_2 \longrightarrow Li_2CO_3 + H_2O$$

This equation states that 2 moles of LiOH theoretically will immobilize 1 mole of CO_2 or ~~21.8~~ 47.88 Kgm of LiOH reacts with ~~20~~ 44.01 Kgm of CO_2 for a theoretical ratio 495 gms LiOH (gm) CO_2. Since we are predicating a 32% efficiency, this ratio becomes 1.09/0.32 or ~~1.54~~ 3.64 Kgm of LiOH/lb (Kgm) CO_2. Thus for a mission of 0.535 Kgm of CO_2, we require ~~1.54~~ 3.64 x 0.535 or 1.82 Kgm of LiOH.

this guy needs help!...

Noxious Odors and Trace Contaminants

Noxious odors and trace contaminants such as aromatic and mercaptan compounds have been shown to be adequately controlled using activated charcoal. The basis of control for these compounds is to maintain the total concentration at a level commensurate with physiological comfort and safety. A literature survey revealed the contaminants and accompanying generation rates shown in Table VI. Also shown are the toxicological groups that each constituent belongs to.

The charcoal bed sizing procedure used was as follows. First, a determination was made to see which contaminants could be controlled by ordinary activated charcoal as is done in the Apollo PLSS. It was found that all components except two could be adequately controlled in this manner. These two are hydrogen fluoride and ammonia. They may be chemi-sorbed by adding approximately 10 grams each of 10% phosphoric acid impregnated charcoal for ammonia and 2% potassium hydroxide impregnated charcoal for hydrogen fluoride. These are commercially available as Barneby-Cheney type 213 and type CH respectively.

TABLE VI
TRACE CONTAMINANT GENERATION RATES

Contaminant Name	Average Generation Rate	Space Maximum Allow. Concentration	Toxicological Group
	gm/hour	PPM(Vol.)	
Ammonia	1.59×10^{-3}	85	Irritant
Benzene	1.59×10^{-3}	14.8	Narcotic
Carbon Monoxide	4.36×10^{-5}	56.5	Blood Poison
Cyclohexane	3.18×10^{-5}	79	Narcotic
Dioxane	1.59×10^{-5}	21	Irritant-Poison
Ethanol	1.59×10^{-5}	78	Narcotic
Formaldehyde	1.59×10^{-5}	2.9	Irritant
Hydrogen	3.09×10^{-4}	30,600	Asphyxiant
Hydrogen Fluoride	4.54×10^{-5}	0.22	Irritant
Hydrogen Sulfide	6.8×10^{-7}	4.24	Irritant
Methane	2.72×10^{-3}	51,400	Asphyxiant
Methanol	1.59×10^{-5}	8	Irritant-Narcotic
Methylene Chloride	1.59×10^{-5}	79	Narcotic
Ozone	1.59×10^{-6}	0.15	Irritant
Sulfur Dioxide	1.59×10^{-5}	2.9	Irritant
Tolvene	1.59×10^{-4}	79	Poison-Narcotic

Oxygen Loop Flow Rate

The oxygen loop flow rate was determined by using Apollo EMU manned test data.* For these tests, an average metabolic rate of 400 Kcal/hour was required. The oxygen loop flow was required to prevent inspired CO_2 concentrations in access of 7.6 mm Hg and to prevent visor fogging. The data showed that a flow rate of 147 liters per minute was adequate for the above noted metabolic rate. The lower average metabolic rate of the Integrated EVA system would seem to allow a somewhat lower flow rate than the Apollo EMU valve. However, the peak metabolic load of 1000 Kcal/hour requires that the minimum flow be increased to 158 liters per minute.

Next, a study was conducted to determine the optimum prime mover for the oxygen loop flow. Three candidate concepts for supplying the necessary power to provide 158 liters per minute at a suit pressure of 352 gms/cm^2. These were: Use of an ejector nozzle in conjunction with the make up flow from the high pressure oxygen supply, Use of a turbine to drive a fan, again using the high pressure oxygen make up flow, Use of the present Apollo Portable Life Support System (PLSS) battery powered fan. The results of the study indicate that the ejector and turbine concepts can not provide the required flow using the make up flow of 0.128 Kgm/hour.

The required flow amplification for an ejector is $\frac{4.63 \text{ Kgm/hr}}{0.128 \text{ Kgm/hr}} = 36$ at a nominal system pressure ratio of 1.036. Figure 35 is a curve indicating the upper performance limit of single nozzles. It shows that the maximum flow amplification at a Δ P/Ps is 6.4 which is approximately 18% of the required factor of 36. This means that an ejector could not provide the required flow without decreasing the flow amplification to 6.4. To do this, the system make up flow of 0.128 Kgm/hour would have to be increased to 0.74 Kgm/hour. This would result in a system weight and volume increase of 9.1 Kgm and 3110 cm^3 assuming the fan and ejector have equal weight and volume.

The next system considered was a turbine driven fan assembly. The turbine is driven by the oxygen make up flow which averages 0.128 Kgm/hour. This low flow requires a ΔP of approximately 7.04 Kgm/cm^2 for even a 100% efficient turbine. At this ΔP, however, the turbine specific speed would be about 0.27 which results in figure 36. To raise the efficiency, the specific speed must be increased. The formula shown in figure 36 indicates that the only variable that can be changed is flow. This can be accomplished by venting a portion of the make up flow overboard, however, the same weight and volume penalties as those incurred with the ejector arise.

The Apollo PLSS fan-motor assembly performance indicates that at a system pressure of 352 gms/cm^2, a flow of 158 liters per minute will be provided at the design point of 16.5 volts d.c. as shown in figure 37 and 38. This system has two distinct advantages over the ejector and turbine systems; it is developed, and it is the lightest. Its major disadvantage over the other two systems is that an electrical component is in contact with the oxygen loop and special precautions must be taken to preclude an electrical fire. Table VII summarizes the results of this discussion.

*Hamilton Standard Test Report, SVHSER 4021 dated 20 May, 1966

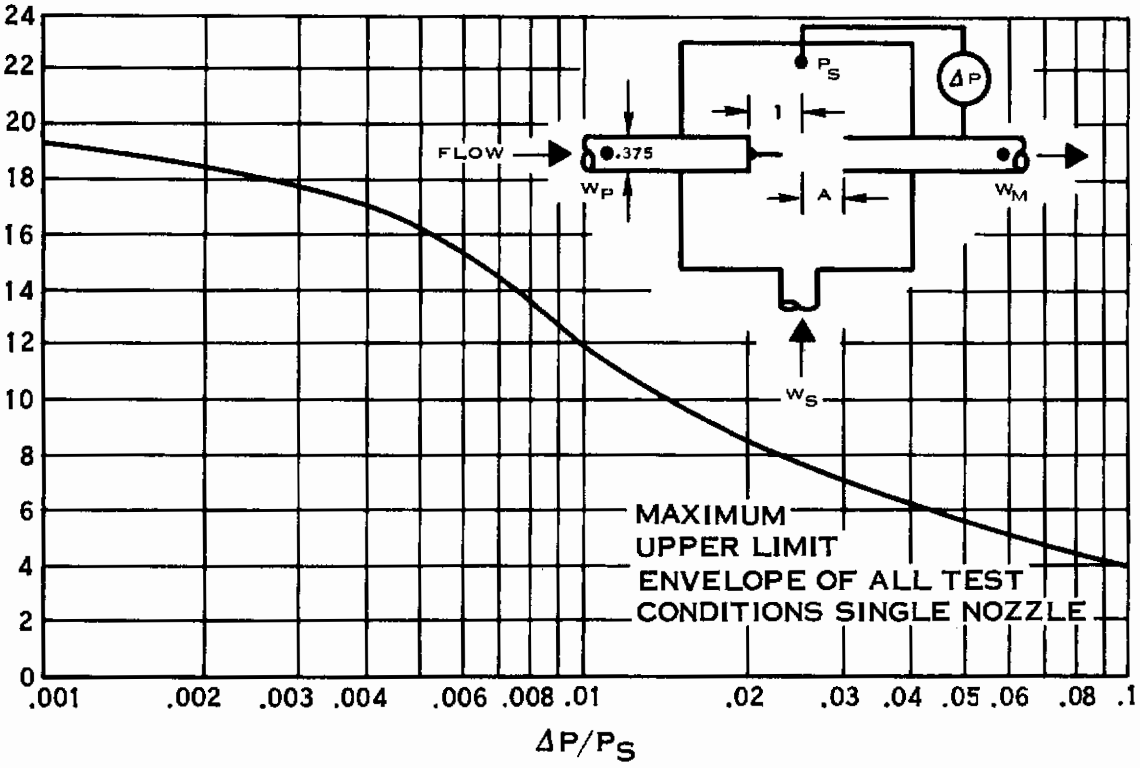


Figure 35. Ejector Nozzle Performance

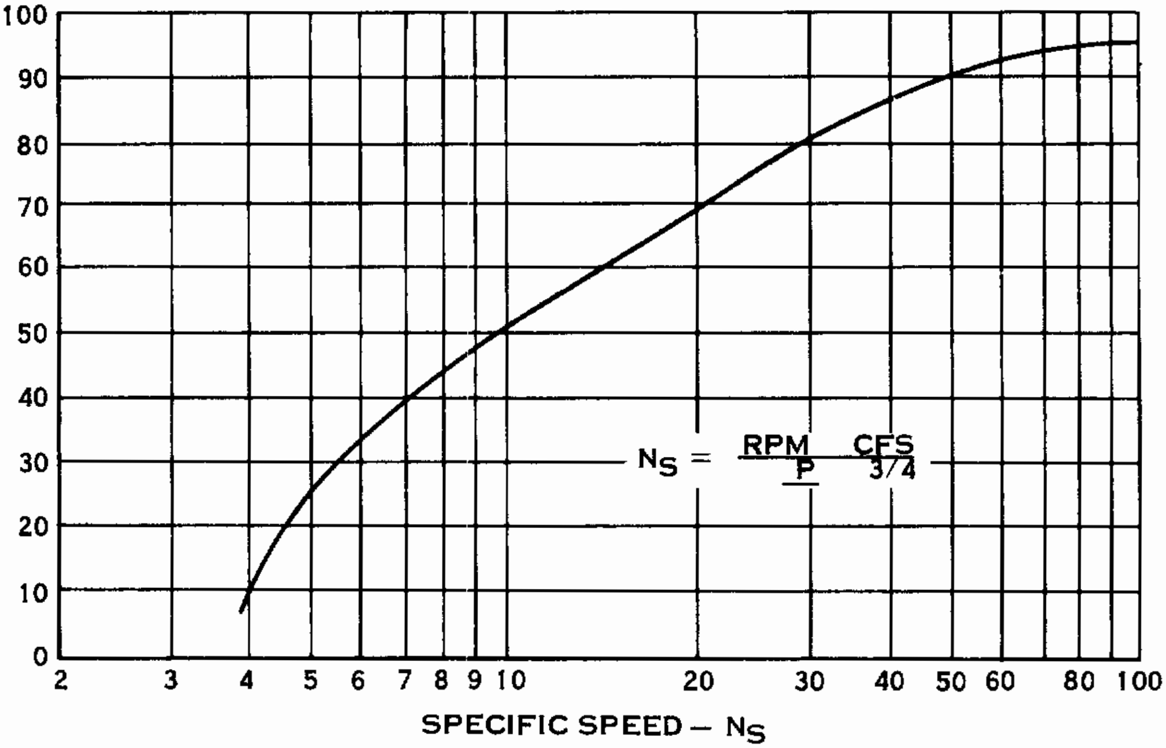


Figure 36. Turbine Efficiency vs Specific Speed

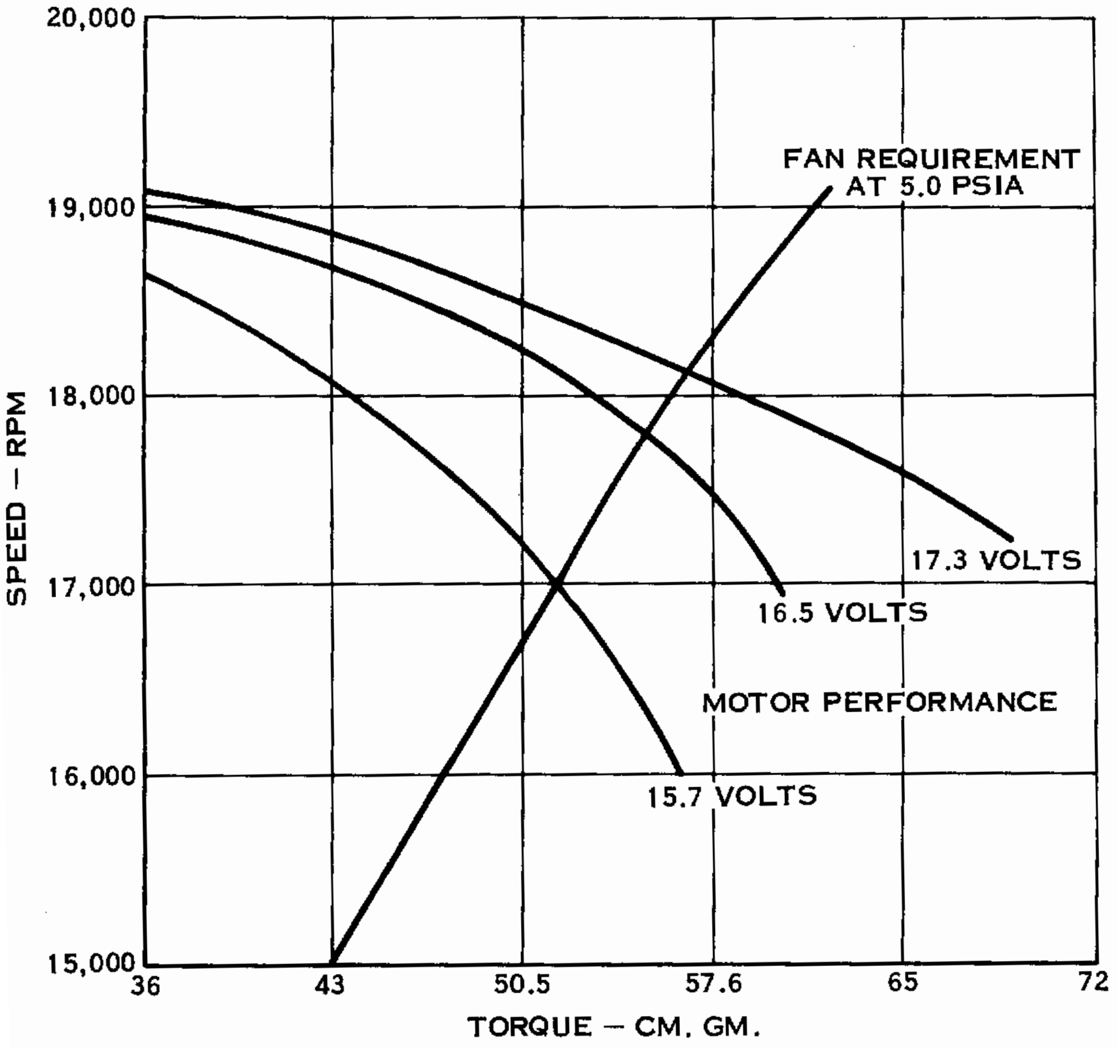


Figure 37. Apollo PLSS Fan & Motor - Speed vs Torque

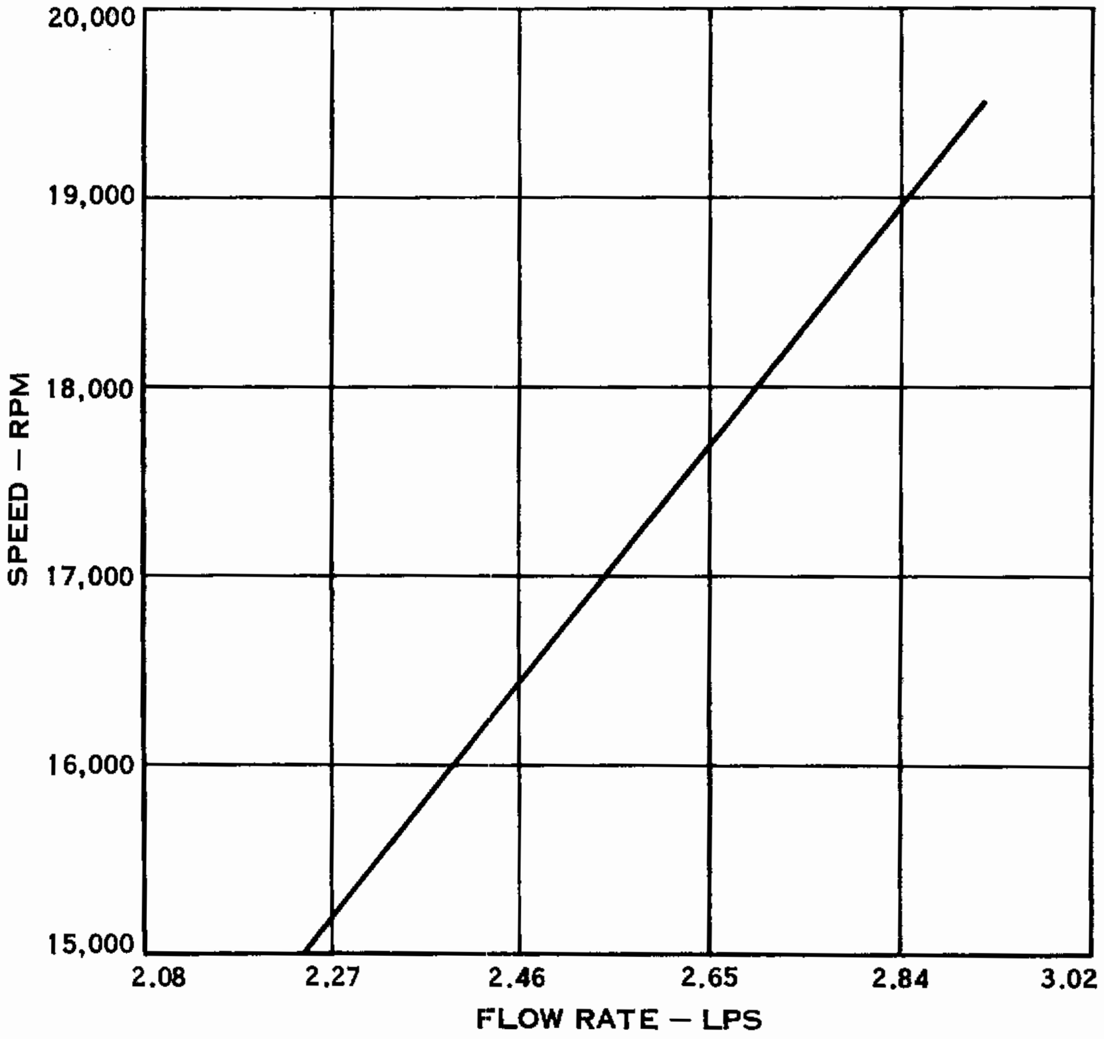


Figure 38. Apollo PLSS Fan-Motor Assembly Flow Rate vs Speed 352 gm/cm^2

TABLE VII
GAS LOOP PRIME MOVER SUMMARY

Prime Mover	Safety	Volume	Weight	Develop Status	Total*
Gas Ejector	1	3	3	3	10
Turbine Driven Fan	1	3	2	4	10
Battery Driven Fan	2	1	1	2	6

*Lowest is Best

Legend
1-Excellent
2-Good
3-Fair
4-Poor

These results indicate that the Apollo PLSS battery powered fan-motor assembly is the prime mover of choice.

Humidity Control

Water vapor entering the gas stream from the astronaut's respiration and evaporated perspiration as well as the water produced by the CO_2 removal reaction in the LiOH canister must be removed. At the design point metabolic rate of 375 Kcal/hour the total quantity of water that must be removed is 233 gm/hr including the 100 gm/hr perspiration taken up by the gas stream. In addition to this average metabolic rate of 375 Kcal/hr there are four 10-minute periods at 1000 Kcal/hr. The water separator must therefore be capable of handling the 348 gm/hr slugs of water generated during these peak loads. Table VIII provides a breakdown of the various water vapor sources contributing to these design loads. To remove this water vapor and produce a suit inlet dew point of 10 C, the arrangement shown in figure 39 will be used.

At the sublimator inlet, the gas stream temperature is 74 C and has a dew point of 30 C. While traversing the sublimator, the hot moist gas stream is cooled to 10 C, thus reducing the dewpoint to 10 C. The water vapor condenses and appears as entrained droplets in the sublimator exit gas stream. If this liquid water is not removed from the gas stream, it will be carried into the helmet where visor fogging and discomfort to the astronaut would occur due to the high humidity.

Figure 40 gives a sectional view of a typical water separator of the type to be used in the IEVA suit life support system. It is an impingement separator which has been designed to operate under conditions of zero gravity. In operation, the water separator directs the gas stream, with its entrained water, through a rather tortuous path. The entrained droplets, although traveling at a slightly slower speed than the gas, have a larger amount of momentum, causing them to have a greater resistance to a change in direction; hence, they impinge upon the separator walls.

On earth the water would collect in the bottom and drain off, but under zero g conditions some artificial means of collection and drainage must be used. In this separator, the walls are composed of nylon felt wicking. When the water droplets impinge on the nylon felt, they are adsorbed and transferred to the drainage port by means of capillary action. The dacron felt disk in the upper part of the drainage port has a greater affinity for water (better hydrophile) than the nylon. This enables it to pick up the water from the nylon and transfer it to the port assembly. The port is connected by a line to the outer wall of the feedwater reservoir. As the water is used up by the sublimator, the reservoir's diaphragm collapses creating a lower pressure in the drainage line which draws the separated water from the dacron felt pads and transports it to the reservoir.

This water separator is a simple reliable device. It has no moving parts nor does it require electrical power to operate. It has a steady state design capability of 4.15 cc/min, and can easily handle, for short periods, our expected peak load of 5.8 cc/min.

TABLE VIII
IEVA WATER VAPOR SOURCES

H_2O Source	Steady State (375 Kcal/hr) (gm/hr)	Peak (1000 Kcal/hr) (gm/hr)
1. Respiration	50	104
2. Perspiration	100	100
3. LiOH Reaction	55	144
Total H_2O Flow (gm/hr)	205	348
H_2O Separator Capacity (gm/hr)	249	480

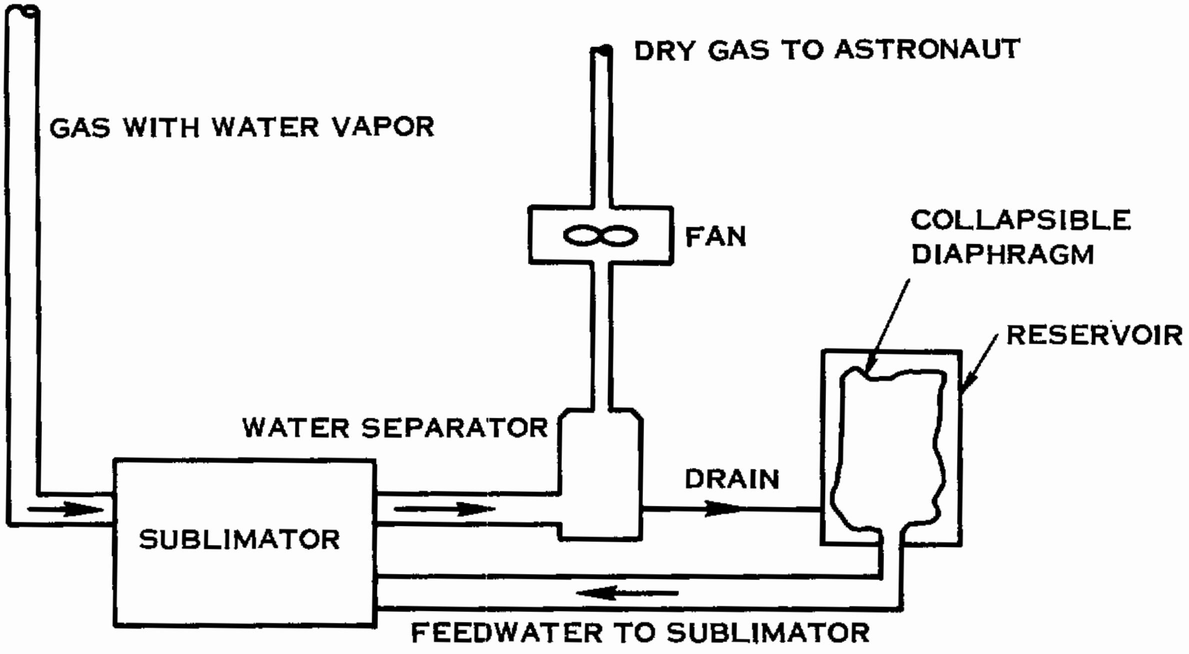


Figure 39. Humidity Control System Schematic

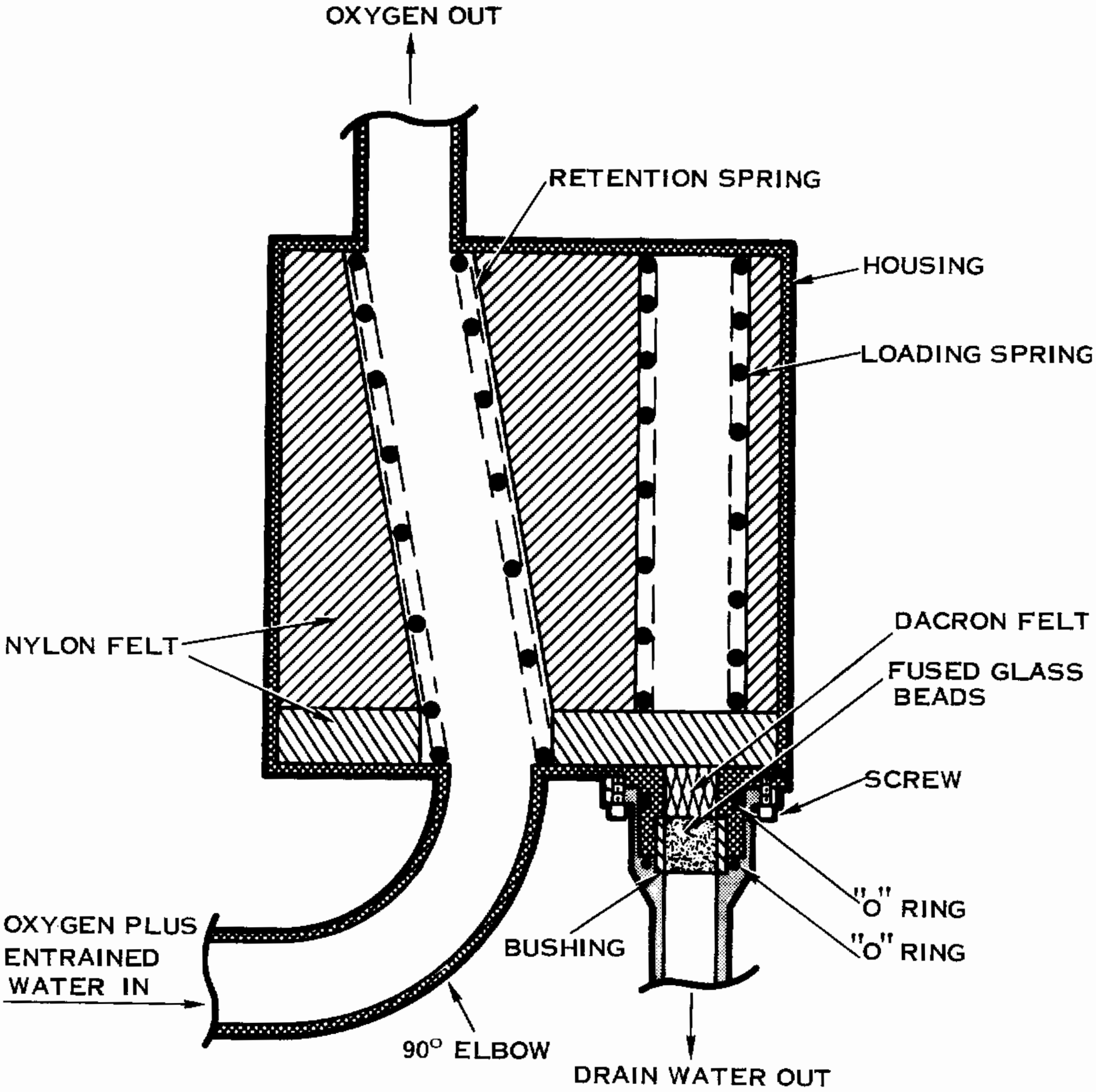


Figure 40. IEVA Water Separator Schematic

Thermal Control

The IEVA system is a heat producing system. The crewman produces heat via his metabolic activity and all electrical components produce heat due to their inefficiencies. Furthermore, the entire system absorbs heat from the sun at the average rate of 62.5 Kcal/hour. Figure 1 shows the magnitude of these various heat sources.

There are two major problems associated with the control of this thermal load;
(1) collection and, (2) rejection.

Collection

It is a system requirement that both liquid and gas cooling systems be used with a thermal collection rate ratio of approximately 80/20. Therefore, a liquid cooling garment (LCG) will be used to collect the excess metabolic heat from the crewman's skin. Figure 41 shows the relationship of LCG performance to skin temperature and subject comfort thresholds. To ensure a constant heat transfer, the coolant fluid (water) is circulated in a closed loop through a heat exchanger by a positive displacement pump developed for the Apollo PLSS. This is shown schematically in figure 3.

Rejection

Two methods of rejecting the excess heat picked up by the water transport loop were studied.

- Evaporation
- Radiation

Evaporative cooling may be accomplished through the use of a porous plate sublimator developed for use in the Apollo PLSS. Operation of this device is shown schematically in figure 42. Expendable water is frozen by lowered pressure through a porous plate. The ice layer thickness is then proportional to the heat flux from the transport water and gas loops. This device weighs approximately 3.2 Kgm and occupies 1,640 cm^3. It is fully developed and will cool both the liquid and gas loops.

Radiation panels could also be used to reject heat to space. The controlling relationship for this operation may be expressed as follows:

$$Q = F A e \delta (T_1^4 - T_2^4)$$

where Q = Heat Rejected
F = Form or View Factor
A = Panel Area
e = Emissivity
δ = Boltzmann's Constant
T_1 = Panel Temperature
T_2 = Radiation Sink Temperature

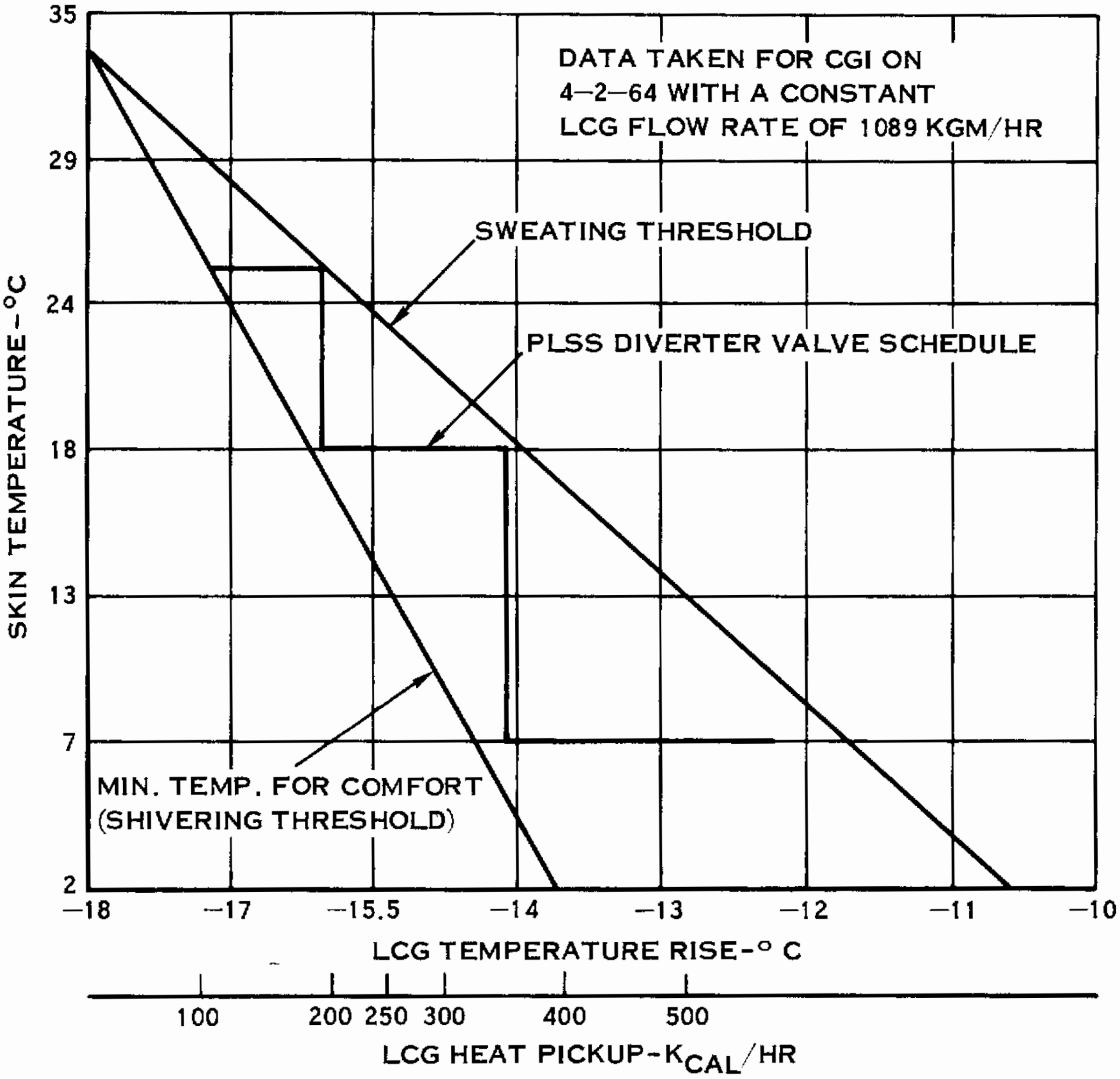


Figure 41. Liquid Cooling Garment Performance

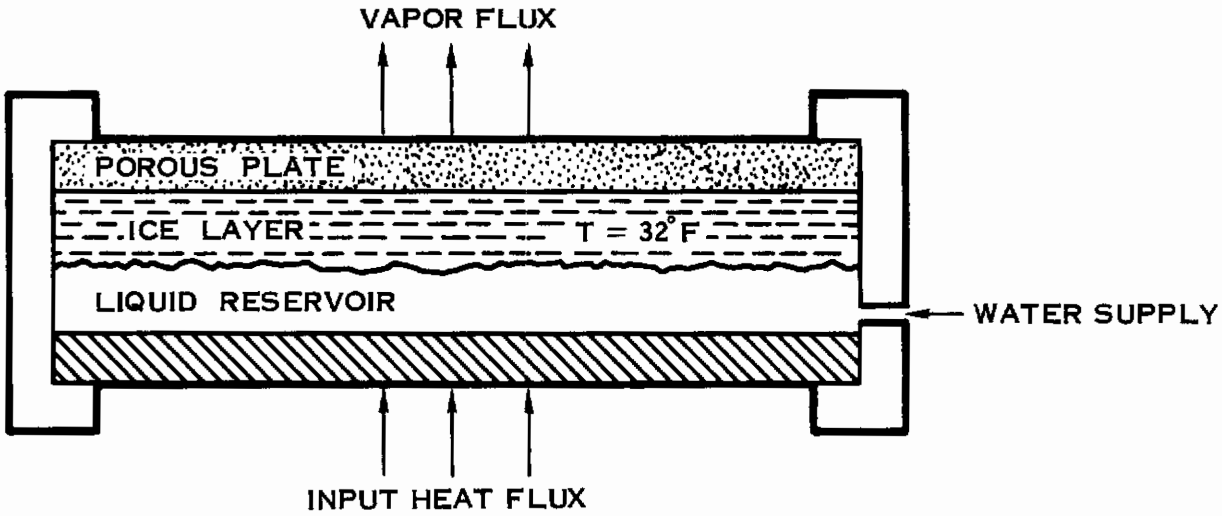


Figure 42. Porous Plate Sublimator Operation

Therefore the panel area required to reject a given amount of heat may be easily calculated. The area required is greater than 1.5 meter ^{2} under ideal conditions for average metabolic conditions. This is obviously an unworkable scheme from a weight and volume standpoint of the panel alone, not to mention the controls required to maintain panel orientation.

Power Supply

The IEVA life support system has a power requirement of approximately 160 watt-hours, 40 watts/hour for a four hour mission. This power must be supplied at a constant rate with battery voltage and amperage remaining constant throughout the entire mission. The two problems to be solved are: (1) what power source is best, the (2) should the power supply be rechargable.

Source

As a possible source for this power, the present Apollo Portable Life Support System (PLSS) battery was considered. This power source is especially attractive since, it is specifically designed to power the fan and pump assemblies. This battery was designed to provide 240 watt-hours and consists of 11 series connected PM5-(13) type cells (Yardney Silvercel). This capacity will satisfy the system power requirement and provide adequate margin for future growth such as communications, sensors, and displays. The battery, with its present case, occupies approximately 1410 cm^3 and weighs 2.35 Kgm in its activated state. Silveroxide and zinc are employed as the electrodes. The electrolyte is a 40% solution of potassium hydroxide. The battery produces electrical power by means of the following chemical reaction:

$Ag + Zn(OH)_2$	$AgO + Zn + H_2O$
discharged	charged

One of the battery's most interesting features is its high output per unit weight or volume. Figure 43 presents a comparison of various types of batteries with respect to weight-to-power ratios. The zinc-silver oxide battery has an obvious advantage in this respect. The "PM" cells are capable of quick activation and high rates of discharge; and although the battery musk soak for four hours after filling, it has good power retention, maintaining 50% of its charge after six months at 26.6°C. Power retention is improved with decreasing storage temperatures down to -18°C. For these reasons this type of battery is well suited for its present space application.

Recharge

Limiting its use in more commercial applications are its relatively high cost and limited recycle capability. It is this latter feature that is of particular interest in examining the battery for use in the IEVA suit life support system. Although the battery is only capable of a limited number of cycles, it can be recharged over 100 times, and the question of whether the LSS battery should be replaced or recharged arises.

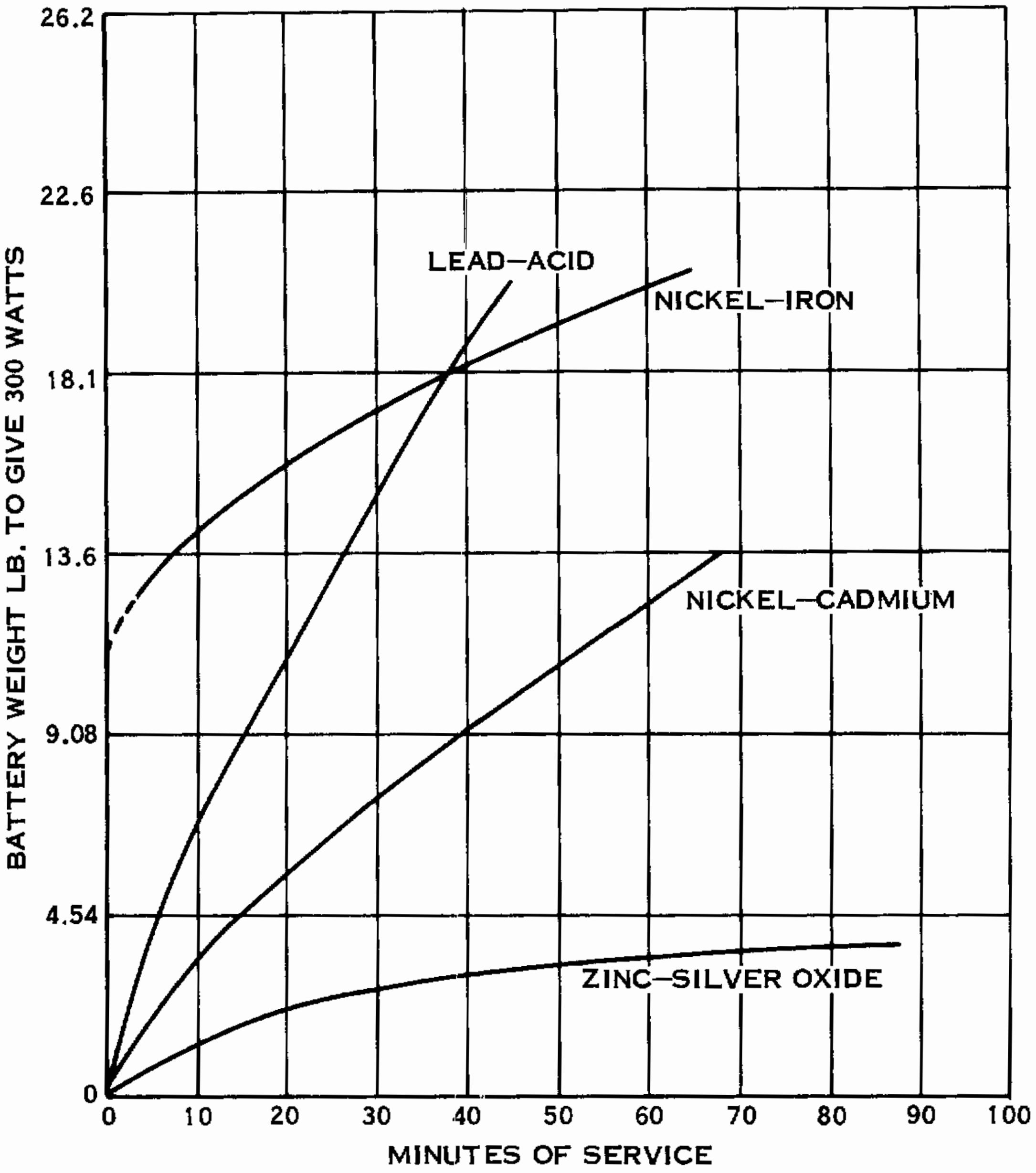


Figure 43. Performance of Various Power Supplies

There are two methods of recharging the zinc-silver oxide battery; (1) the constant current method which is the faster of the two but requires more attention and constant adjustment, and (2) the modified constant potential method which, although slower, requires less personal attention and less complex equipment. Figure 44 presents data on several discharge-charge cycles run at Hamilton Standard on the Apollo PLSS battery using the constant current method. It can be easily seen that even with this faster recharge method, it takes 14-16 hours to achieve reuse capability. This eliminates the possibility of EV recharge of the battery. Several additional factors also contraindicate the feasibility of recharging the batteries in the spacecraft.

To achieve in-cabin recharge capability, additional equipment and power will be required as well as the time used by a crewman in setting up and monitoring the battery during recharge. Because of the time for recharge, provision for recharge of more than one battery at a time should be made, thereby increasing equipment weight even more. Additionally, each recycle of the battery lowers its reliability as shown in figure 45 which in turn lower the system reliability and compromises crewman safety.

In conclusion, the Apollo PLSS battery will be the power supply for the IEVA suit LSS. The battery will be used on a replace rather than recharge basis due to long recharge times and a decrease in battery reliability with number of recharges.

Expendables Trade Study

The expendables trade study is a comparison of mission expendables (oxygen, water, power, and LiOH) weights and volumes for various mission times at specified average metabolic rates. It was performed during the early months of this contract when the requirements for a two (2) hour mission contingency and an average metabolic rate of 500 Kcal/hour existed. These requirements have since been deleted, however, the results of the study are included as they may benefit other Air Force programs. The study was conducted in two parts. The first part compares weight and volume for four vs six hour missions, while part two compares these parameters as a function of metabolic rate. The entire study is summarized in Table IX which gives system weights and volumes for missions from two to eight hours and for metabolic rates from 300 to 500 Kcal/hour.

The design mission length is four hours, however, all Life Support System (LSS) expendables must include a two hour contingency per paragraph 8 of the work statement. The LSS must in effect be designed for a six hour mission at an average metabolic rate of 500 Kcal/hr. This additional two hour contingency requirement results in component weight and volume penalties. Table X compares the system expendables for four and six hour missions.

In addition to the individual differences of Table X, the total life support system weight will increase by a factor of about 25% from approximately 36.25 kg to 45.36 Kg. This system weight increase will be accompanied by a 20% volume penalty above a four hour mission volume of 31,800 cm^3. With improved packaging density, however, the system envelope volume is expected to increase by only 10 to 15%.

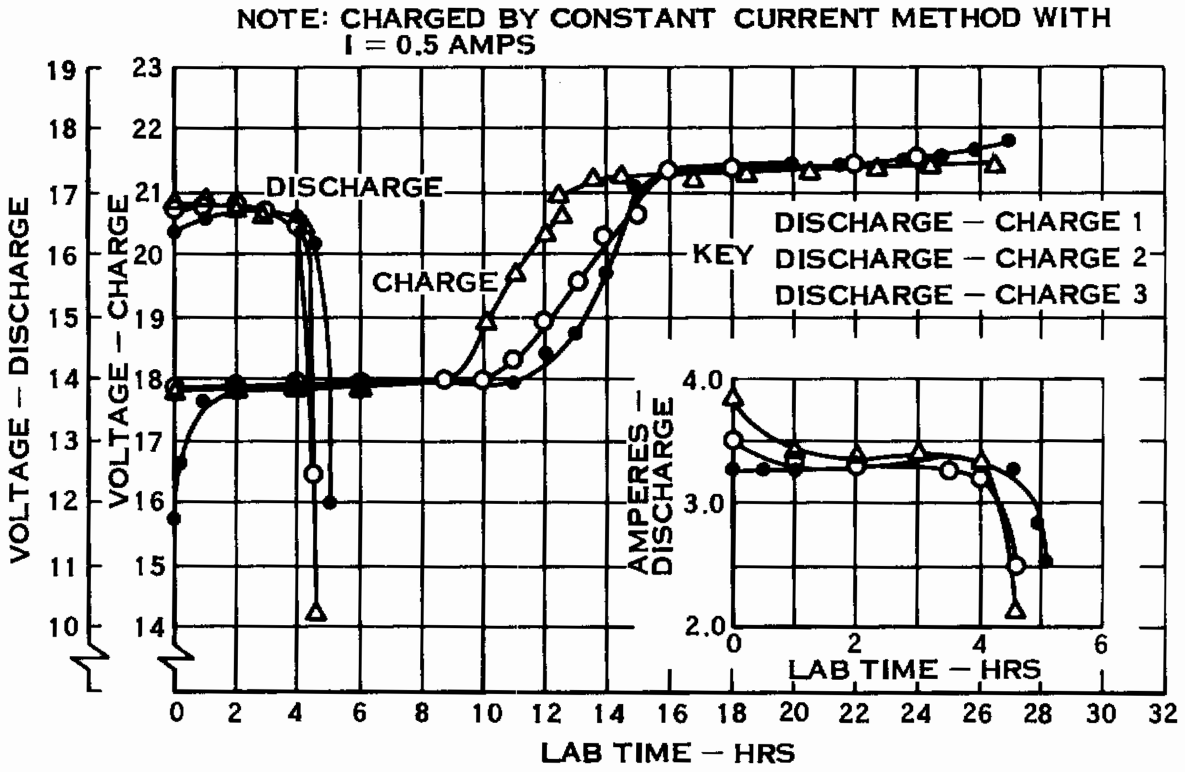


Figure 44. PLSS Battery Performance

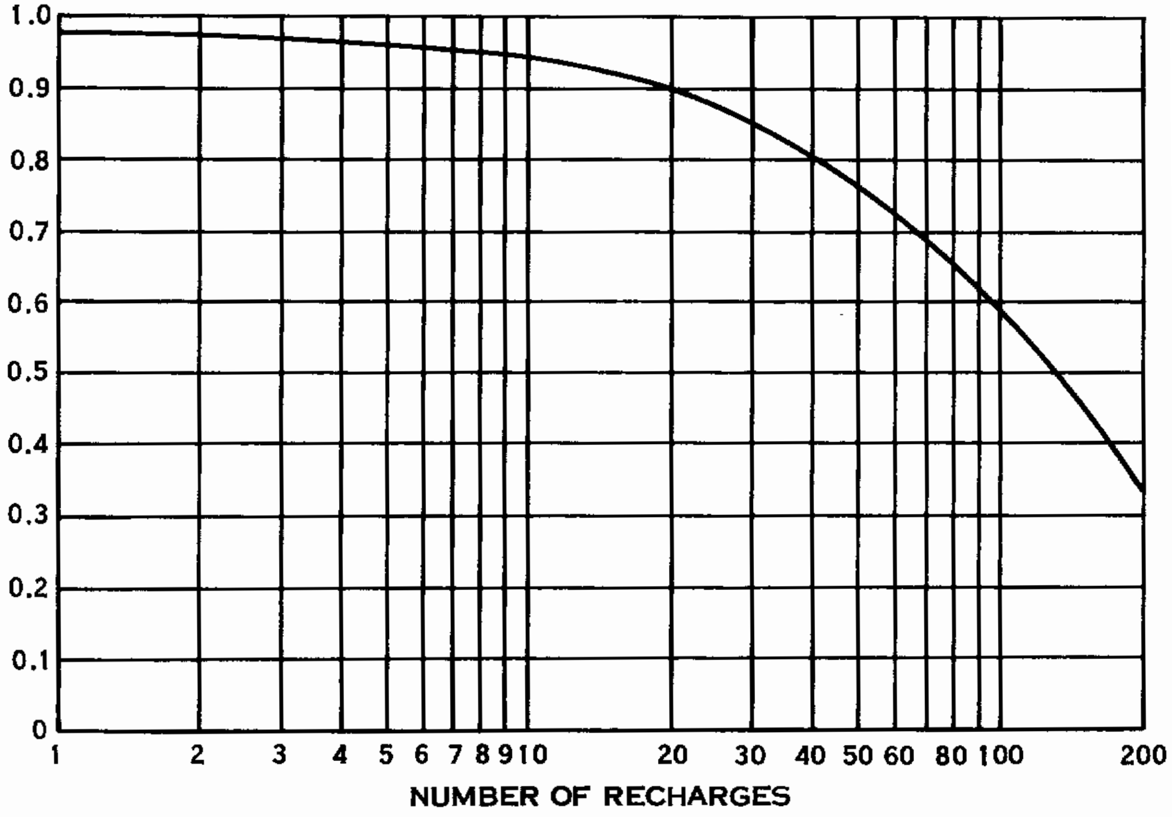


Figure 45. Apollo PLSS Battery Reliability vs Number of Recharges

TABLE IX
SYSTEM WEIGHT AND VOLUME VS. MISSION TIME AT VARIOUS METABOLIC RATES

Metabolic Rate KCal/Hr.	Mission Time (Hrs.)	2	4	6	8
300	Wt. Kg	7.58	14.24	20.45	27.50
	Vol. cm^3	5,540	11,080	16,150	21,560
375	Wt. Kg	9.19	17.25	25.40	33.25
	Vol. cm^3	6,690	13,280	19,850	26,580
450	Wt. Kg	10.78	20.20	29.60	39.00
	Vol. cm^3	7,910	15,780	23,610	31,450
500	Wt. Kg	11.83	22.25	32.45	42.75
	Vol. cm^3	8,640	17,250	25,900	34,550

TABLE X
IEVA LSS COMPONENT WEIGHTS, VOLUMES, AND CAPACITIES

		Mission Time					
		4 Hrs.			6 Hrs.		
Component		CM^3	Kg.	Kg.	CM^3	Kg.	Kg.
OXYGEN BOTTLE	Volume	1480			2220		
	Weight		2.26			3.74	
	O_2 Capacity			0.66			1.00
LiOH CANISTER	Volume	7260			11050		
	Weight		4.31			6.35	
	LiOH Cap.			2.40			3.60
FEEDWATER RESERVOIR	Volume	7660			11350		
	Weight		5.43			8.16	
	H_2O Cap.			4.58			7.02
BATTERY	Volume	980			1300		
	Weight		1.95			2.45	
	Watt-Hrs.			160			240
TOTALS	Volume	17390			25950		
	Weight		13.98			20.70	

Mission Length Effects

The two hour contingency requirement results in effects on the other evaluation criteria as well. The basic reason for the additional two hours is to afford the astronaut a 50% time safety factor and thus increase the probability of a safe return to the spacecraft. This, however, is the only criteria that appears to be favorably affected. Except for several criteria, such as suit wear, which do not appear to be affected in either direction, nearly all other design criteria suffer some penalty because of the 50 percent time safety factor. A list of these criteria and how they are affected is given in Table XI.

Mobility, the degree to which movement is free and unhampered by the suit system, will definitely be limited by the increased volume of the hard torso area housing the life support system. There will be more surface area and larger protrusions around which the astronaut must work. Use of an extravehicular maneuvering unit will also be more difficult due to increased volume and inertia effects.

Comfort, don/doff ease, and stowage are all adversely affected by the increased volume and mass. The bulkiness which results from the added volume and the increased component size will increase the astronaut's awareness of his suit and may possibly produce areas of discomfort. Additionally, the larger suit will be more difficult to don and doff while the larger components could prevent the use of several entry/closure techniques. Stowage capability is also hampered due to the increased bulk and additional area.

Because of the two hour contingency, the expendables replacement bottles and canisters will also be taking up additional space and weight compared to their counterparts for a four hour mission. With the additional size of the equipment and life support requirements, replacement of the components and recharge of the water reservoir (and discharge of the accumulated water from the separator) will take additional time and require additional effort.

Figures 46 through 49 show the effect of mission length on oxygen, LiOH, feedwater, and power at 500 Kcal/hour. Figure 50 summarizes the entire system weight and volume changes as a function of mission length.

Metabolic Rate Effects

Increased oxygen usage, additional CO_2 exhaled, and of course, greater metabolic heat are all a result of increased physical activity. The growth effect of these physiological parameters on system expendables for a six hour mission is indicated on figure 51, which plots the weights of O_2, LiOH, and sublimator feedwater against increasing average metabolic rate for a six hour mission. System power requirements are virtually unaffected since the operation of electrical equipment is independent of metabolic rate.

The extra expendables are, however, only a part of the penalty that must be paid. Heavier and larger containers to store these expendables will also be required.

TABLE XI
EFFECTI OF 2 HOUR CONTINGENCY ON DESIGN CRITERIA

Priority	Criteria	Impaired	Unaffected	Improved	
1	Safety			X	Safety is the basis for having the 50% time safety factor. The propability of the astronaut's safe return is greatly enhanced.
2	Mobility	X			The effect on mobility due to the increased volume of the suit should be considerable, especially in the frontal plan.
3	Volume	X			The volume penalty will be approximately 20% which adversely affects many of the other criteria.
4	Weight	X			The system weight will increase nearly 25%, due mostly to increased LSS component size and capacity.
5	Reliability	X			Because the reliability is time dependent, the system reliability decreases with increased mission length, assuming failure rate is constant.
6	Comfort	X			Because of increased bulk, suit awareness will be increased and greater discomfort will occur.
7	Wear		X		Although contact with other objects may increase with the greater volume, wear is not expected to be greatly affected.
8	Don/Doff	X			The astronaut should encounter greater difficulty donning and doffing the larger suit.
9	Stowage	X			Increased weight and volume due to the 2-hour contingency will make stowage of the suit more difficult.

TABLE XI
EFFECT OF 2 HOUR CONTINGENCY ON DESIGN CRITERIA (CONT)

Priority	Criteria	Impaired	Unaffected	Improved	
10	Recharge	X			Replacement or recharge of the larger components will be more difficult and time consuming.
11	Maintainability		X		These three criteria are more dependent on system design than system size.
12	Start/Stop Ease		X		
13	Self-Monitoring		X		

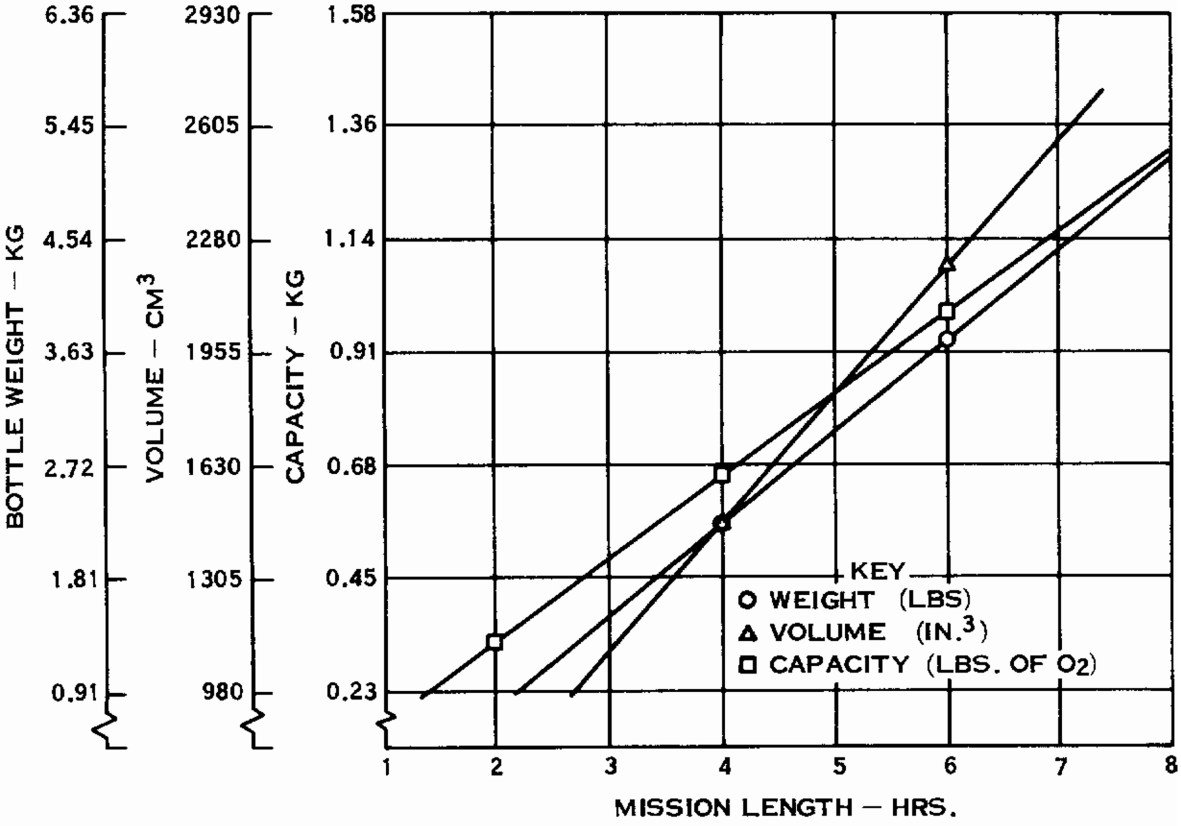


Figure 46. Oxygen Bottle Parameters vs Mission Length

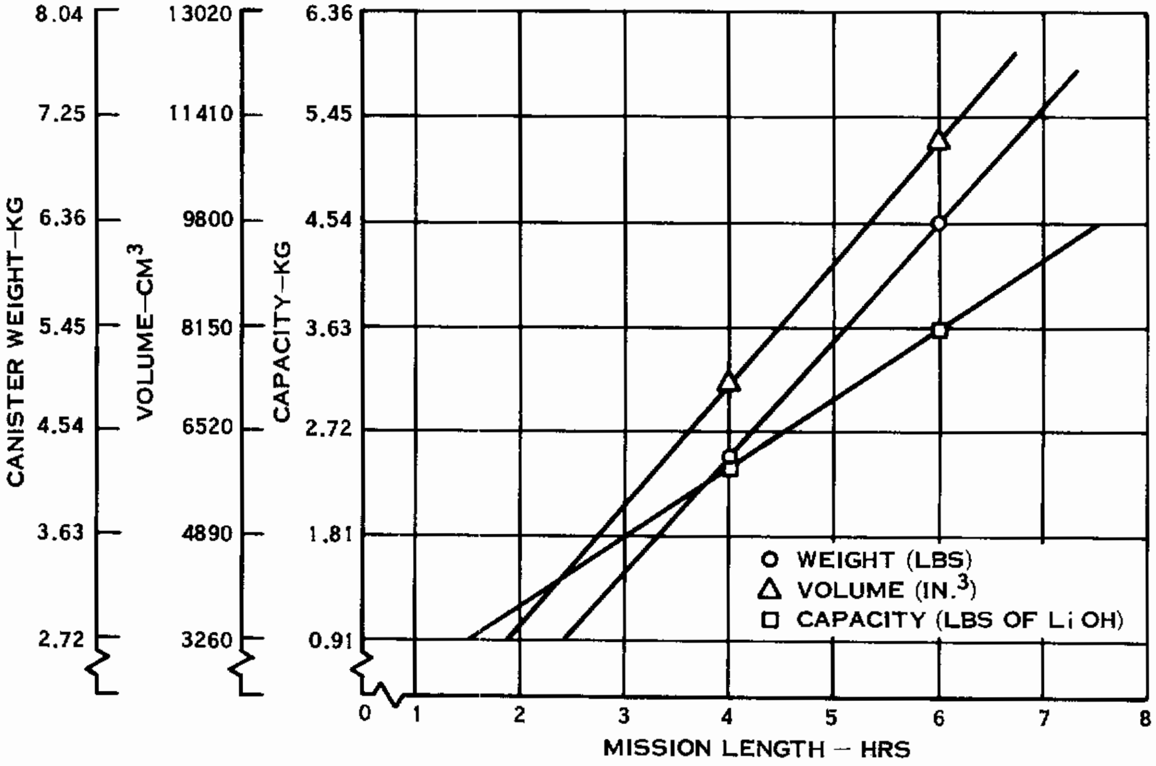


Figure 47. LiOH Canister Parameters vs Mission Length

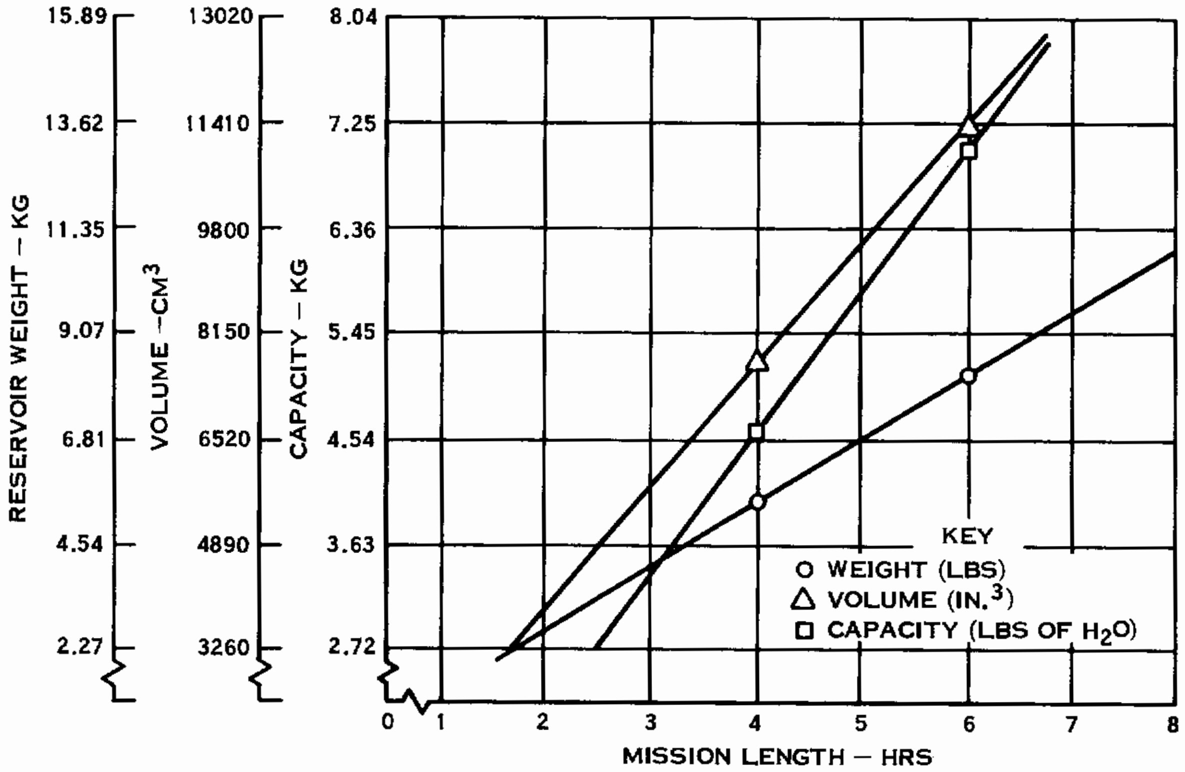


Figure 48. Feedwater Reservoir Parameters vs Mission Length

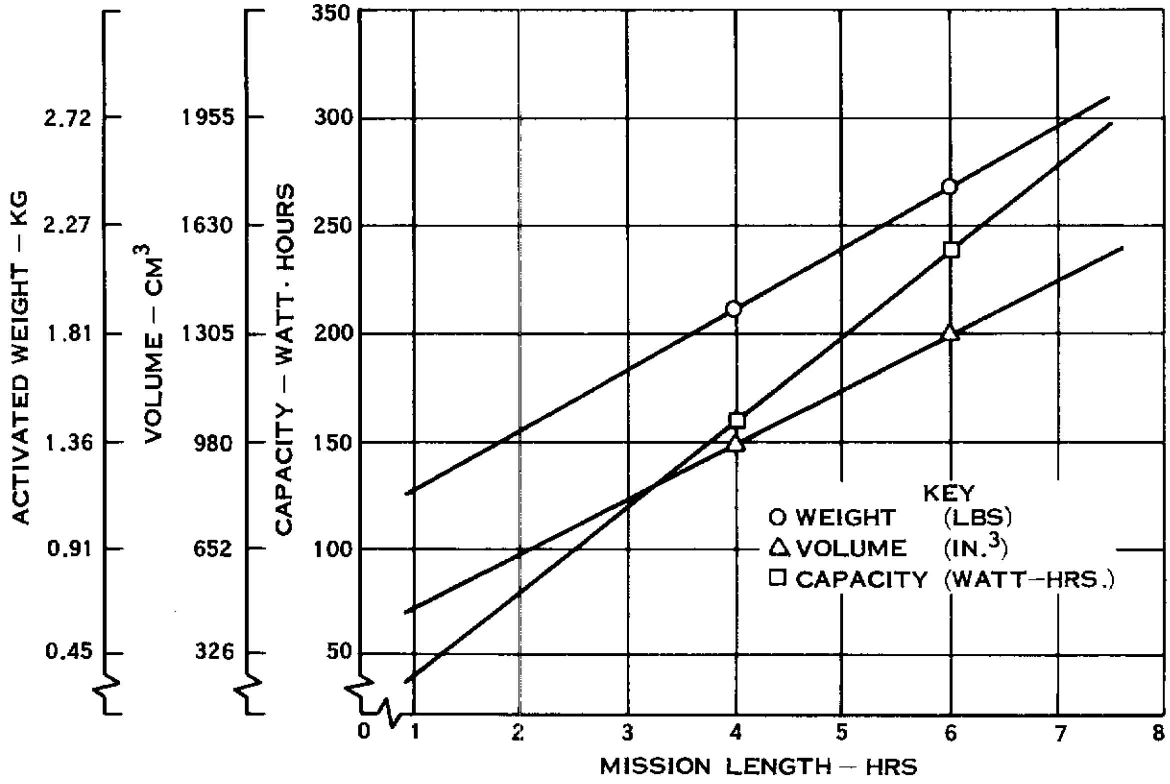


Figure 49. Battery Parameters vs Mission Length

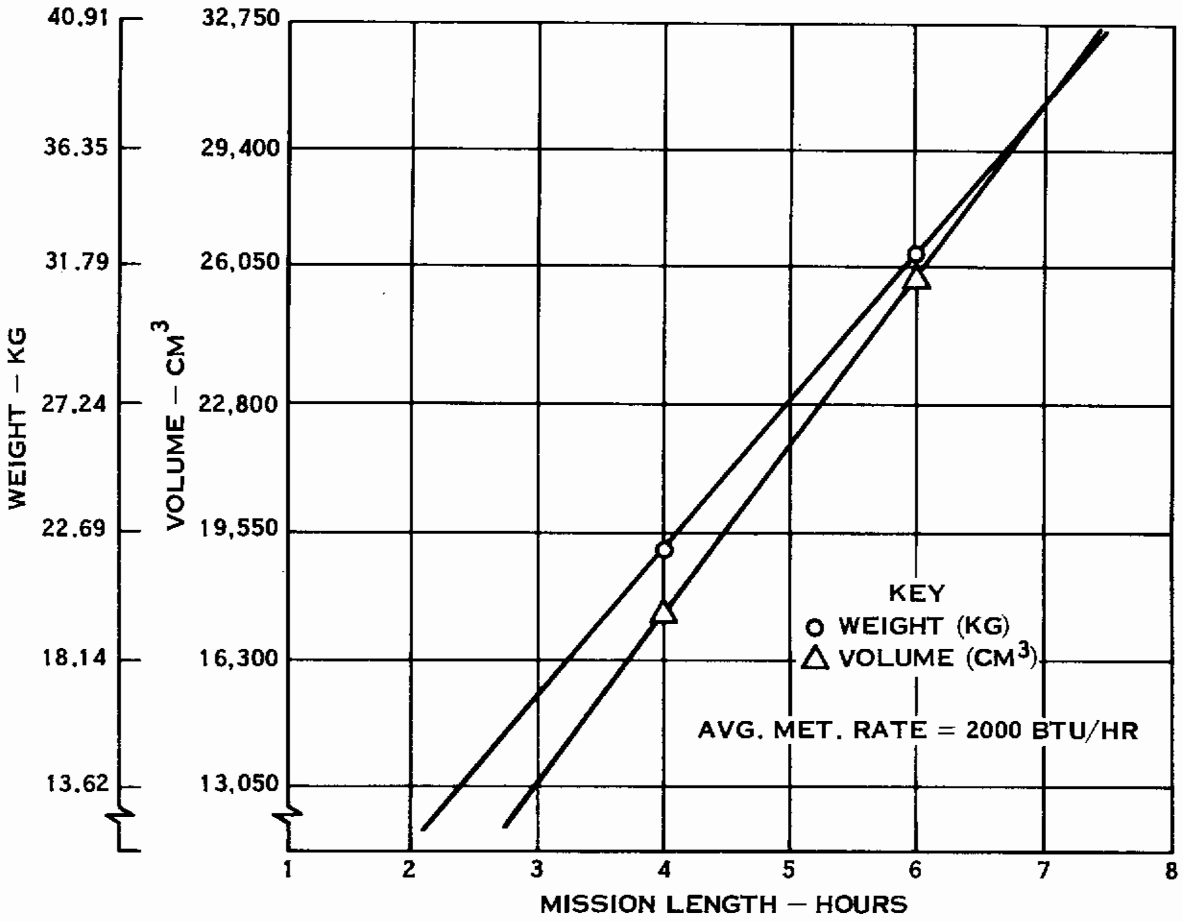


Figure 50. Total LSS Parameters vs Mission Length

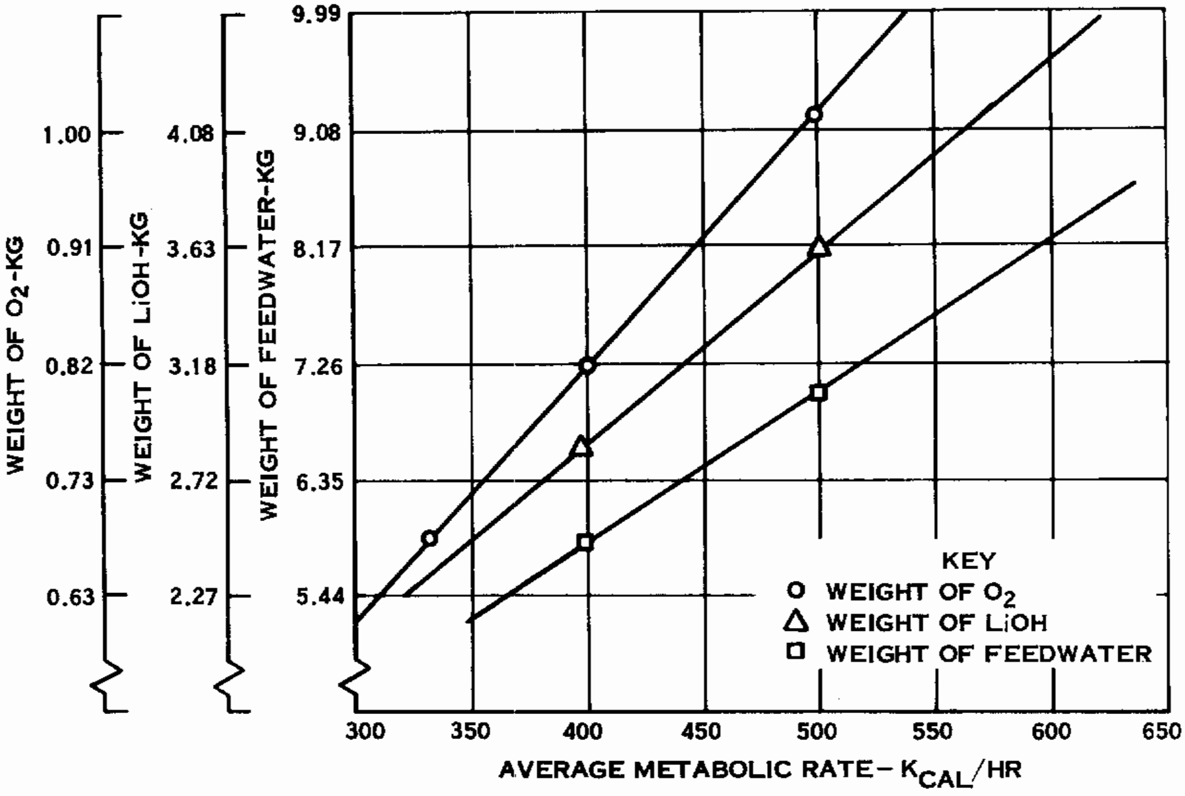


Figure 51. Expendable Weights vs Avg. Metabolic Rate

Figures 52 and 53 present in graphical form, the weight and volume increases for the oxygen bottle, LiOH cannister, and feedwater reservoir due to increased metabolic rate for a six hour mission; figure 54 gives the total weight and volume penalties resulting from the three components. Each component realizes a 20 to 33 per cent increase in weight due to the greater metabolic rate. Total component weight increases 3.74 Kg or approximately 25 per cent more than their weight of 14.51 Kg at 400 Kcal/hour. The system volume penalty is also quite large; an extra 4890 cm^3 above the 19750 cm^3 required for a 400 Kcal/hour rate will be needed for the larger system.

Expendables Package Latch Study

Expendables package latch is a mechanism which is used to retain the package during a mission. This latch is operated by the suited crewman during extravehicular recharge procedures. Due to the complex requirements that such a mechanism must satisfy and the multiplicity of devices that could possibly do the job, a study was performed.

Study Ground Rules

Before assessing whether a given concept would perform properly, a set of ground rules had to be established. These ground rules are, in essence, design requirements by which the concept must be judged. The device must meet the following:

- Be within the suit envelope
- Be invulnerable to bind-up due to expansion and contraction of the LOH canister
- Have an automatic locking feature upon package engagement
- Provide visual and tactile indication that the expendables package is locked in place
- Require two separate motions to unlock
- Automatically rearm itself when the expendables package is removed.
- Stay in the disconnect position so both hands can be used to remove the expendables package
- Have a maximum installation load of 40 pounds.
- Be visible as well as accessible
- The latch may be returned to the locked position from the unlocked position without package disengagement.

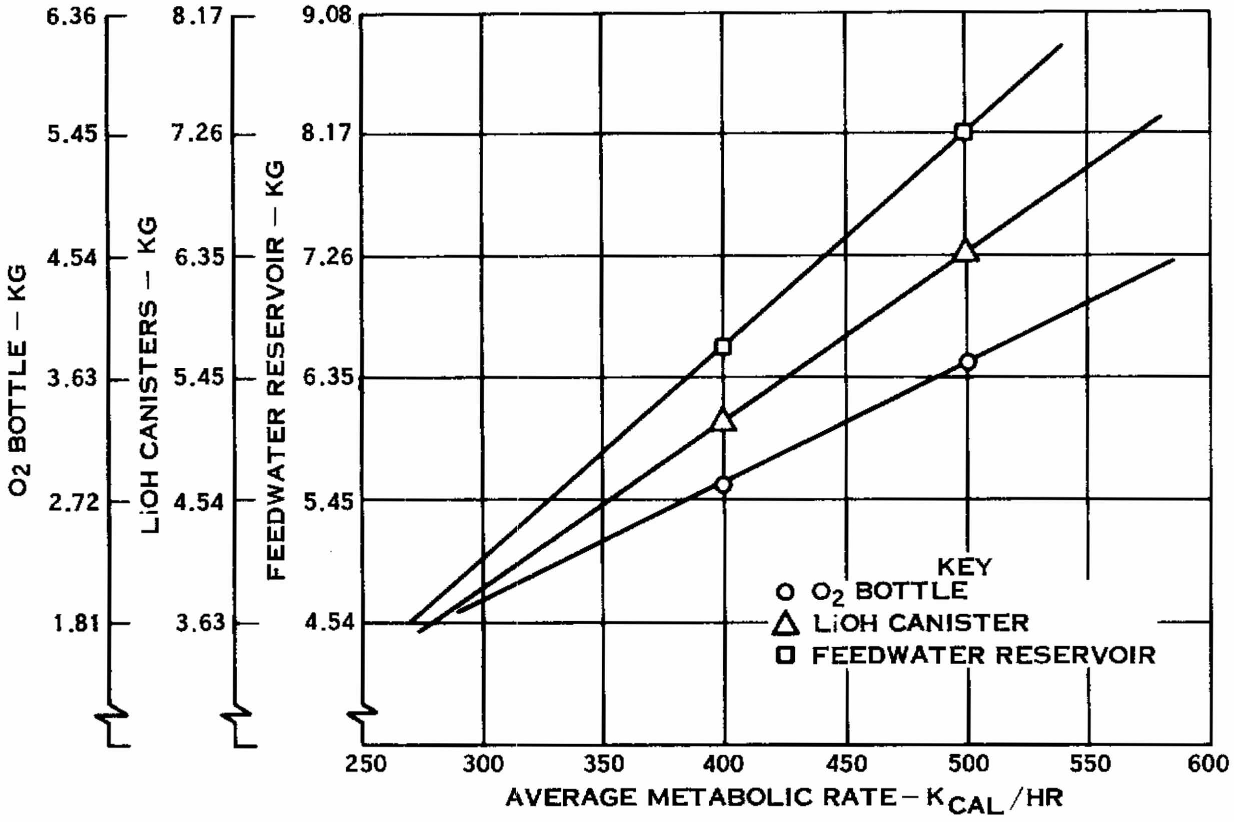


Figure 52. Expendable Components Weights vs Metabolic Rate

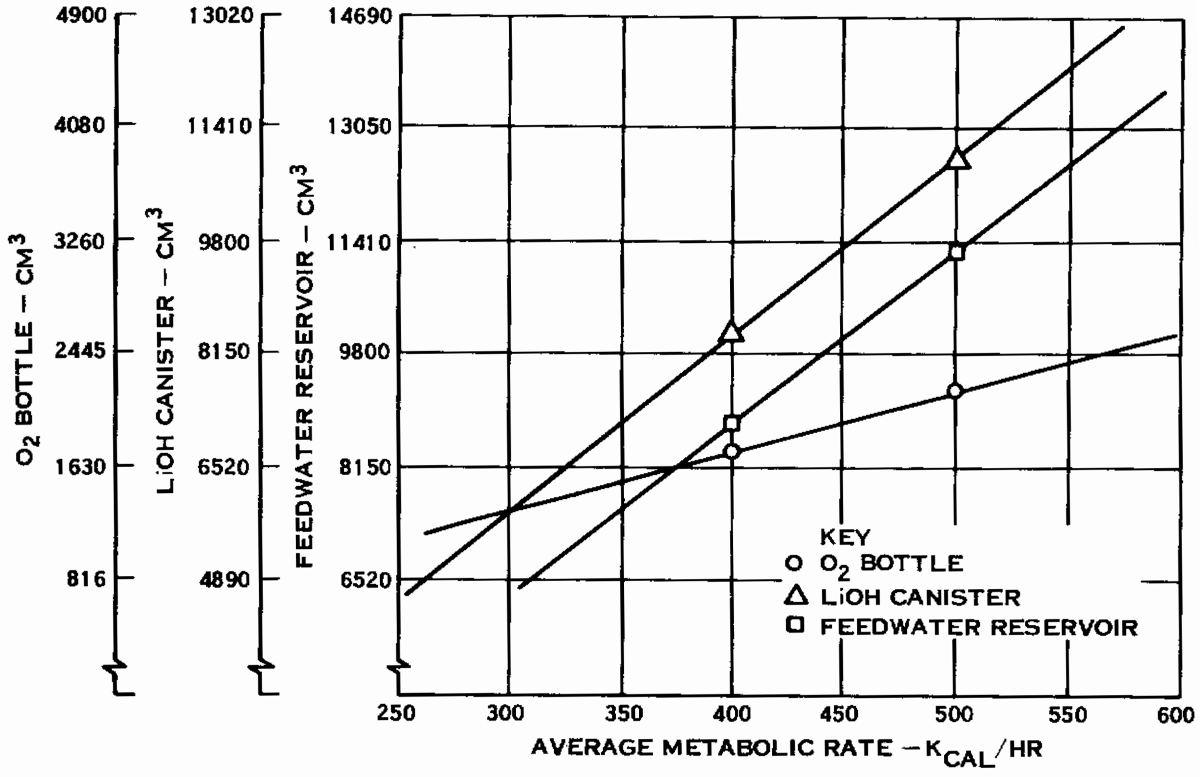


Figure 53. Expendables Components Volumes vs Metabolic Rate

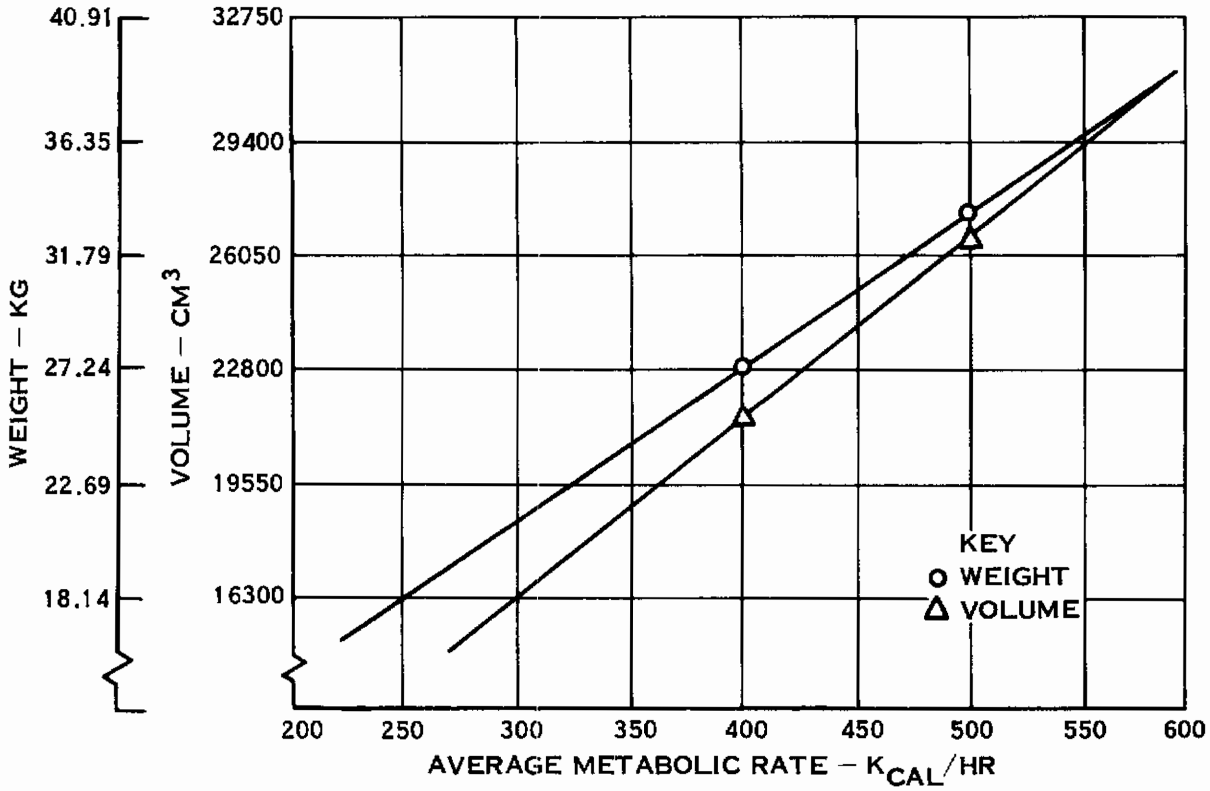


Figure 54. ECS LSS Total Expendables and Components

Concepts

Eight concepts were considered as candidates for the system. These were:

- Bolt-on
- Strap
- Clamp
- Overcenter Toggle
- Door Lock
- Cam Lock
- Wing Nut
- Pawl Latch

A brief description of each of these concepts follows.

Bolt-on

The expendables package is held on with nuts and bolts. A wrench would be required to remove the package. See figure 55.

Strap

A strap of velcro, elastic, or metal with a spring clip is used to hold the package in place. See figure 56.

Clamp

Four to six "suit case" type clamps are used to retain the expendables. See figure 57.

Overcenter Toggle

Latching of the expendables package is achieved by locking levers at the top and bottom of the package. These levers are connected to an overcenter toggle which holds the levers in the locked position. See figure 58.

Door Lock

This concept uses a door lock mechanism as the expendables package latch. See figure 59.

Cam Lock

A cam is mounted on the LiOH canister with an actuating handle. This cam engages a bayonet protruding from the water reservoir to make the lock. See figure 60.

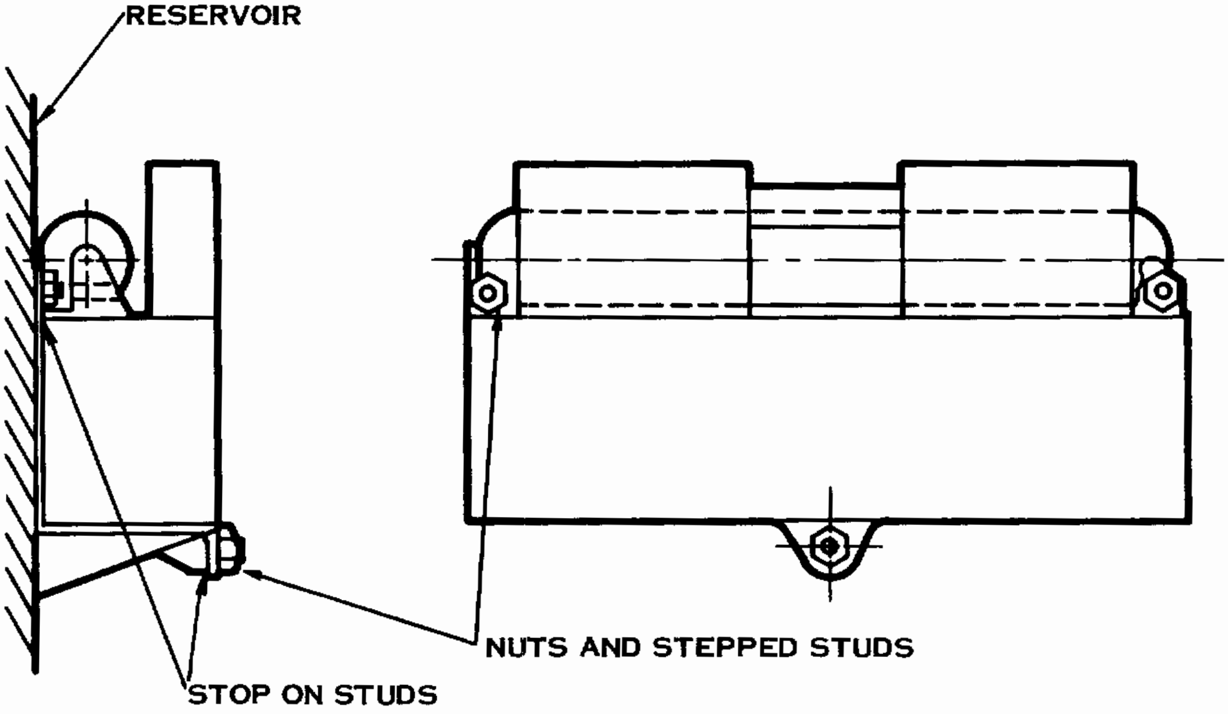


Figure 55. Expendables Package - Bolt-On Concept

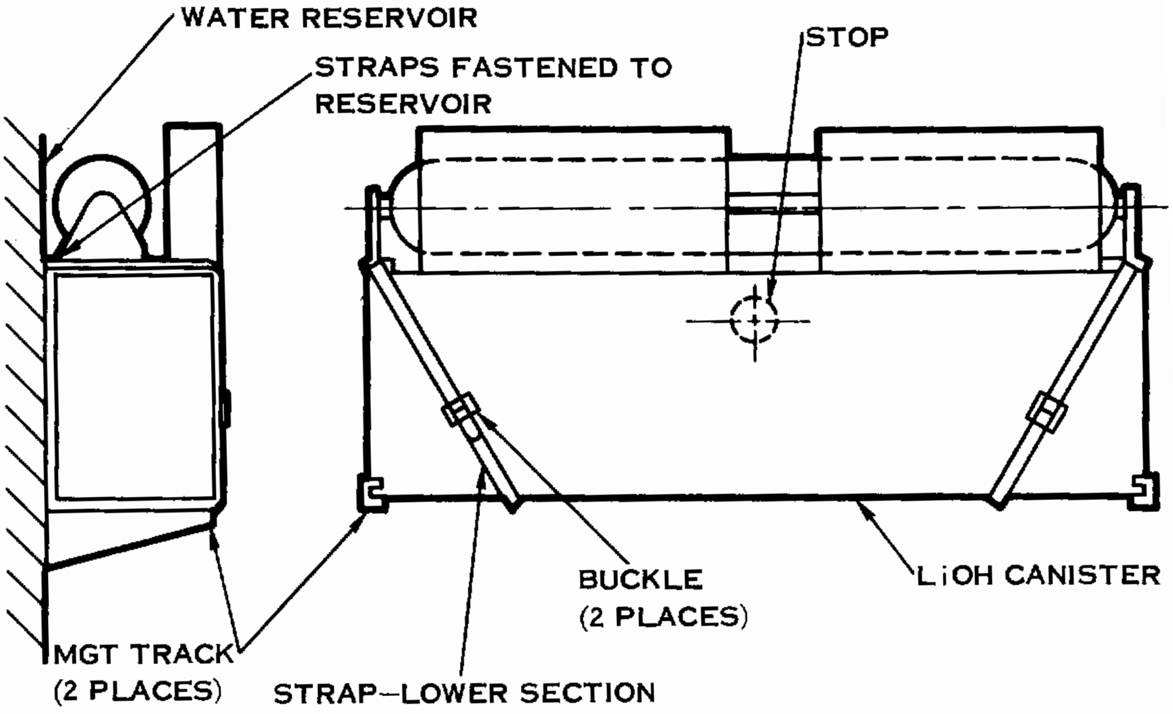


Figure 56. Expendables Package - Strap Concept

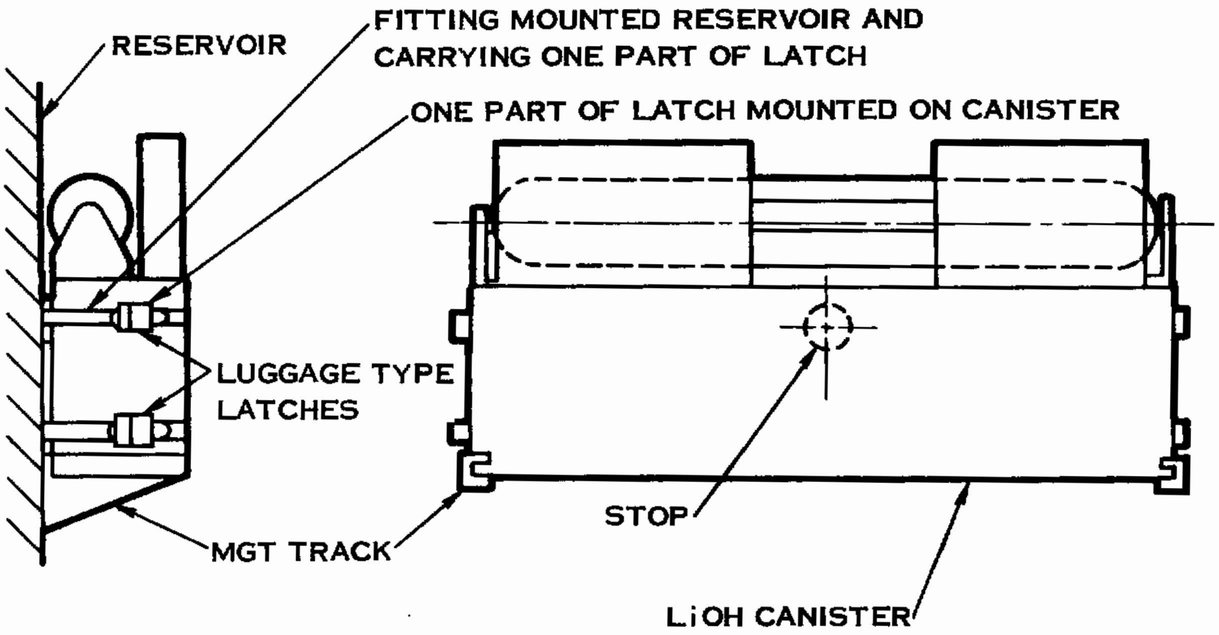


Figure 57. Expendables Package - Clamp Concept

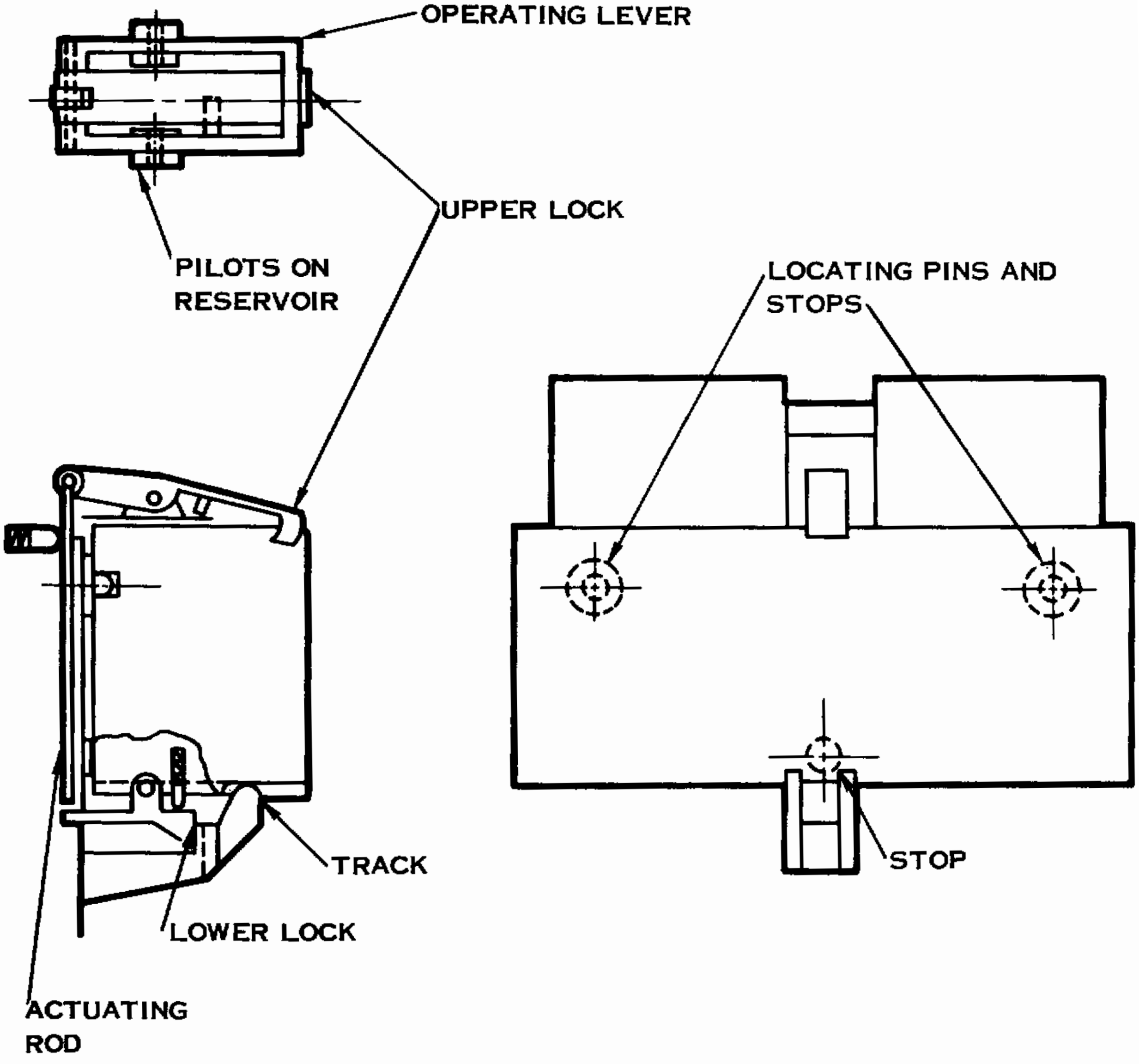


Figure 58. Expendables Package - Over Center Toggle Concept

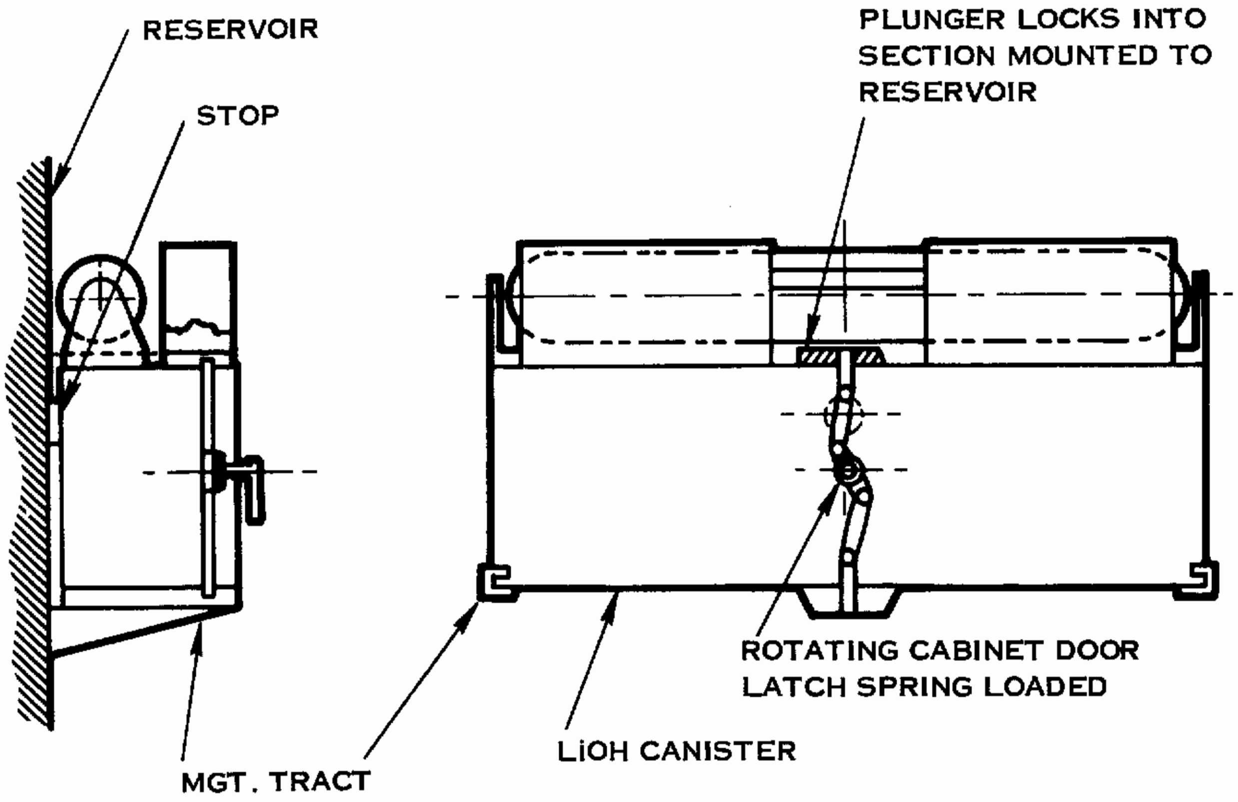


Figure 59. Expendables Package - Door Lock Concept

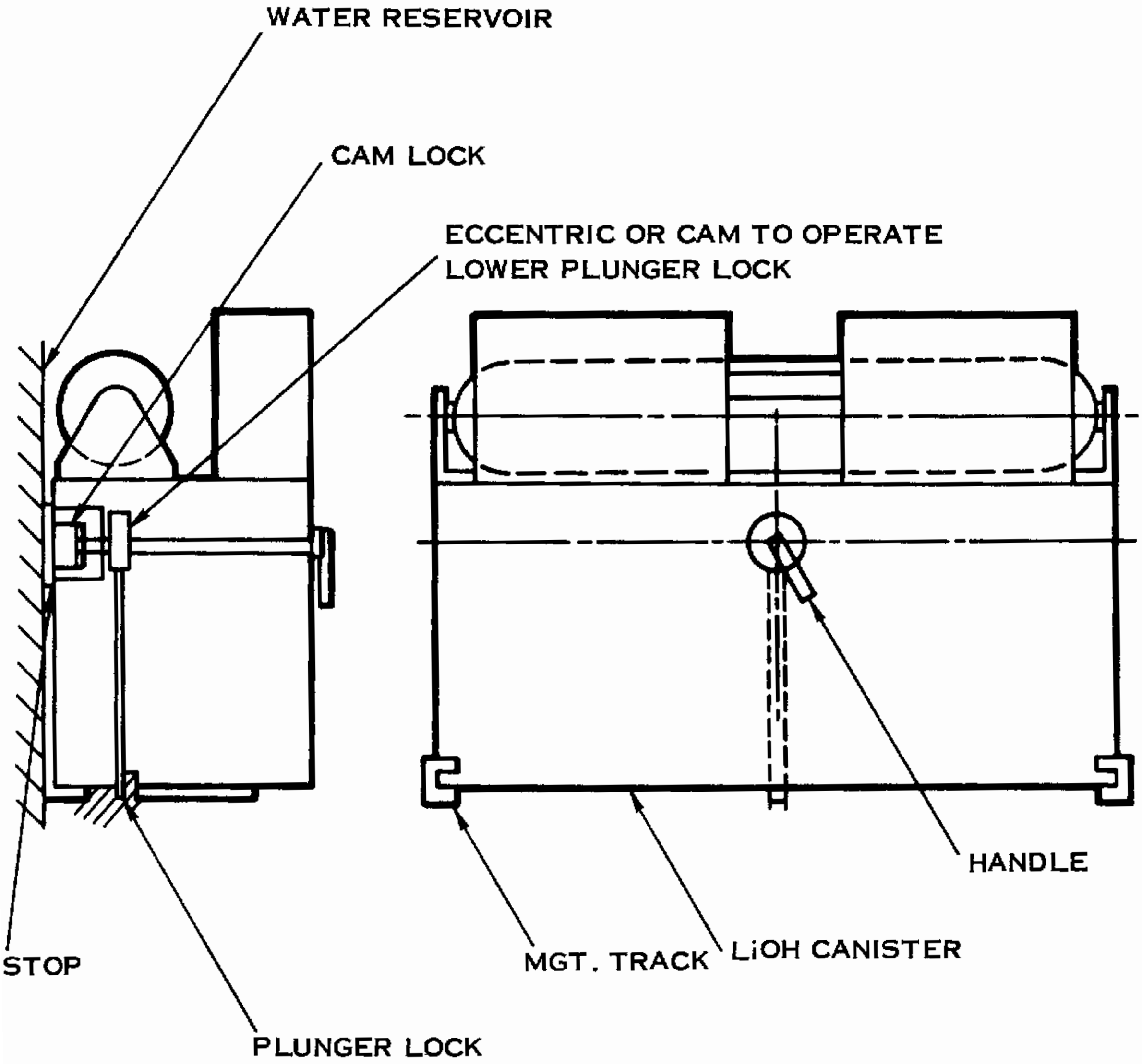


Figure 60. Expendables Package - Cam Lock Concept

Wing Nut

The expendables package is held in place by a wing nut screwed on to a threaded shaft mounted on the water reservoir. See figure 61.

Pawl Latch

This concept consists of two parts, a lock and a disconnect. The lock consists of a pawl and a chamfered plunger which accomplish the retaining action. The disconnect is comprised of two levers and an indicating rod. These provide the disconnecting and status indicating functions. See figure 62.

Concept Evaluation

Each of the concepts was evaluated against the ground rules previously delineated. This evaluation is summarized in Table XII. Since the pawl latch is the only concept which meets all criteria, it was chosen as the IEVA expendables package latch.

Emergency Return

The Integrated EVA suit system must provide a 15 minute return capability in the event of an emergency. This requirement is interpreted to mean that some backup means of life support must be provided for any single failure other than catastrophic pressure rupture. The following components may fail, resulting in loss of the crewman if not corrected.

- Battery
- Fan
- Pump
- Sublimator
- O_2 regulator or bottle
- LiOH Canister
- Leakage or Relief Valve

A failed battery will result in the loss of the fan and pump. Loss of the fan means that the ventilation gas flow will cease. Figure 63 shows how the concentration of CO_2 in the helmet will increase with time at an assumed metabolic rate of 375 Kcal/hour. It is clear that some means of CO_2 control is required. Thermal control would be lost also, due to pump stoppage, but this is a long term effect (10-20 minutes) compared to that of CO_2 buildup. Battery failure control is provided by means of an emergency battery which will operate the fan and pump for 15 minutes minimum. The main battery is switched out of the circuit and the emergency battery turned on with a similar switch.

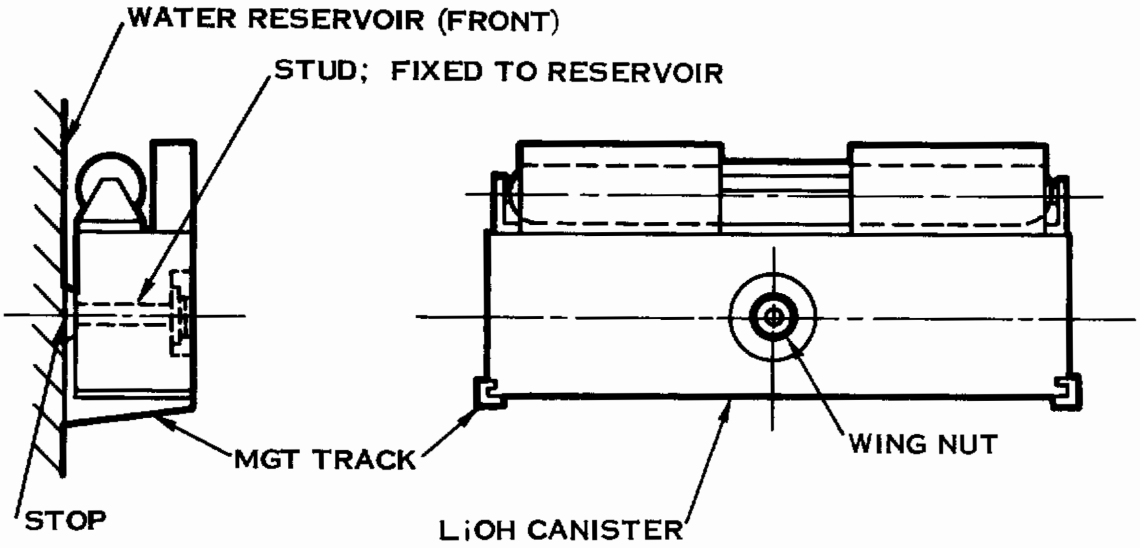


Figure 61. Expendables Package - Wing Nut Concept

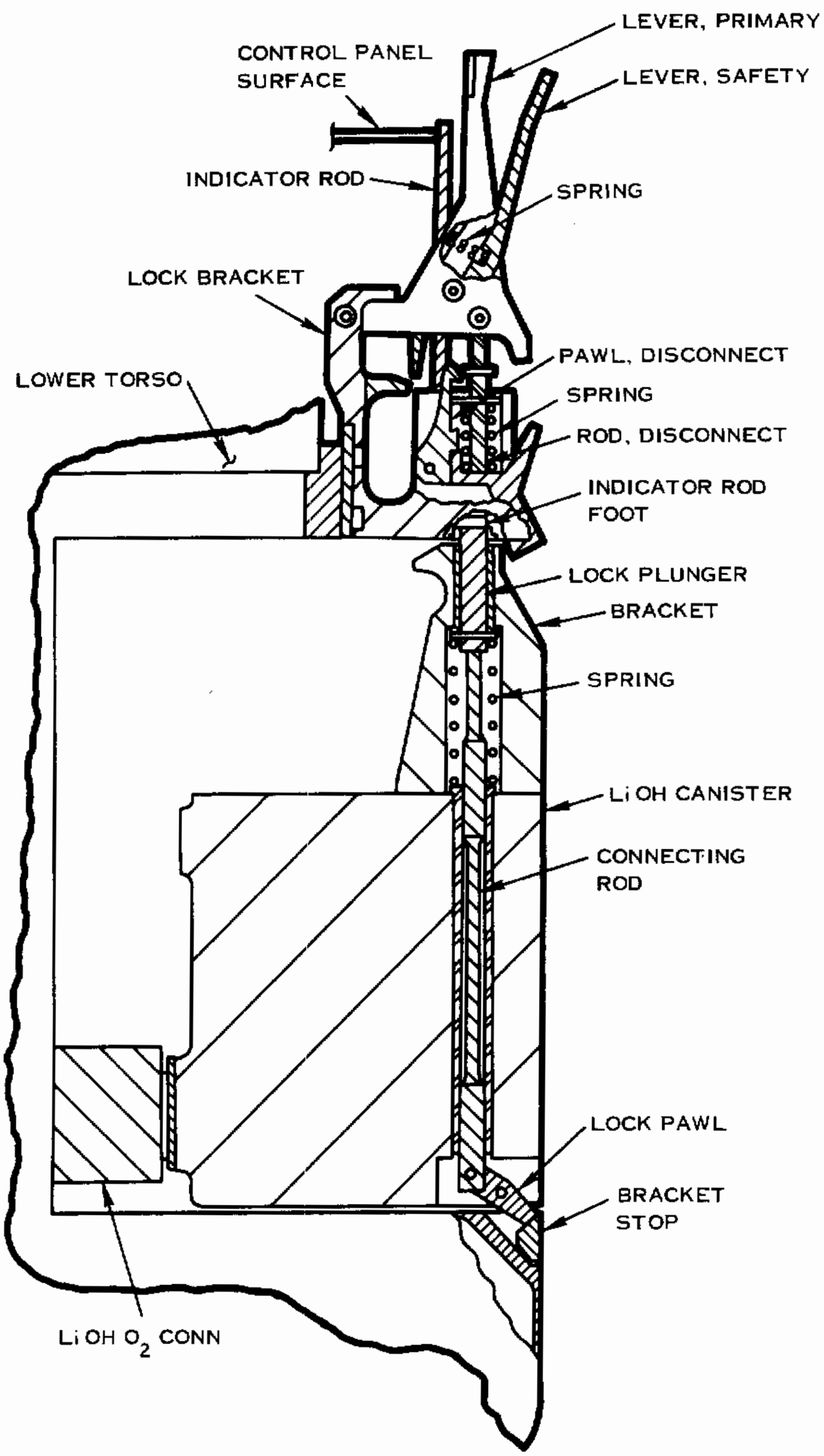


Figure 62. Expendables Package - Pawl Latch Concept

TABLE XII
EXPENDABLES PACKAGE LATCH STUDY SUMMARY

	Within Suit Envelope	Free of Bind-up	Automatic Locking	See & Touch Locked	Require Two Motions	Automatic Re-arming	Hold Disconnect Position	40 Lb. load Installation	Visible & Accessible	Return to Lock Position	Total
Bolt-on	1	1	0	0	1	0	1	1	0	1	6
Strap	1	1	0	0	0	0	1	1	0	1	5
Clamp	1	1	0	0	0	1	0	1	0	1	5
Overcenter Toggle	1	1	0	0	1	0	1	1	1	1	7
Door Lock	1	1	1	0	1	1	1	1	0	0	7
Cam Lock	1	1	0	0	0	0	1	1	1	0	5
Wing Nut	1	1	0	0	0	0	0	1	0	0	3
Pawl Latch	1	1	1	1	1	1	1	1	1	1	10

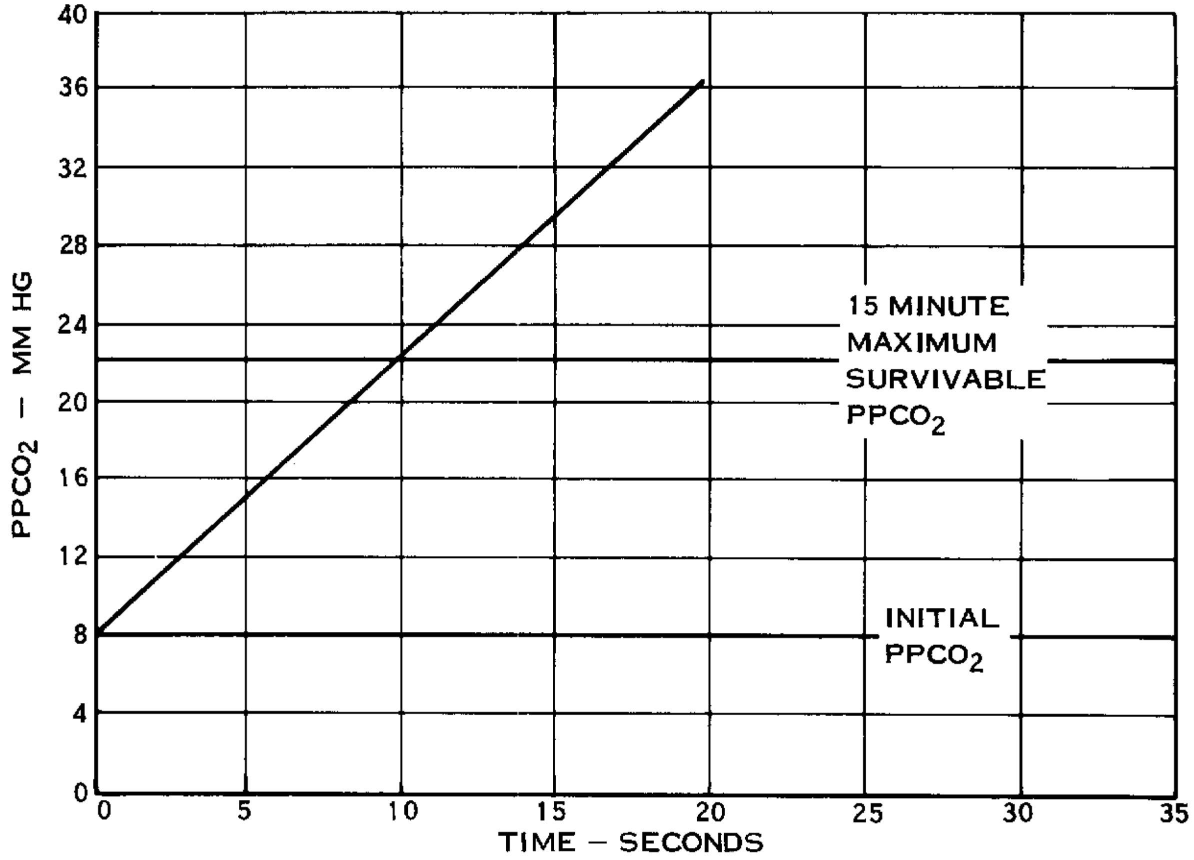


Figure 63. Helmet $PPCO_2$ vs Time at Zero Flow

A failed fan requires the same CO_2 control as a failed battery. However, ventilation must be provided by other means. The simplest and most effective is a gaseous O_2 flush flow to the helmet which scavenges the CO_2 produced and is then dumped overboard. Figure 68 shows the O_2 flow required to maintain the helmet potential pressure CO_2 at 15.0 mm Hg or less at a metabolic rate of 500 Kcal/hour. This flow of 2.1 Kgm/hour will, of course, maintain the partial pressure CO_2 at 15.0 mm Hg during LiOH canister and O_2 regulator failure conditions also.

In the event of a pump failure, the pump would be switched out of the electrical circuit immediately upon detection. However, the crewman would not experience discomfort until his skin temperature rose above the sweating threshold, see figure 41. In this case, he would activate the emergency O_2 system with the intention of using the latent heat capacity of the gas stream. Table XIII below shows the heat into and out of the crewman during a 15 minute period at 375 Kcal/hour and compares the net result with the allowable heat storage value.

TABLE XIII

CREWMAN HEAT BALANCE DURING A 15 MINUTE EMERGENCY RETURN

Heat in Kcal			Heat out Kcal		
Metabolic	-	94	Gas Stream Sensible	-	3
Heat Leak	-	15.6	Gas Stream Latent	-	18.8
			LCG Sensible	-	9.4
TOTALS		109.6			31.2

Heat = 78.4 into the crewman

Since the maximum allowable heat storage in the body is 110 Kcal, this emergency system is adequate compensation for loss of thermal control by either pump or sublimator failure.

The O_2 regulator may fail in the open or closed position. If the regulator fails open, the maximum flow of 1.66 Kgm/hour will cause the suit relief valve to open.

The relief valve will stay open until the primary O_2 bottle is depleted. At this point, the relief valve will reseat and the crewman can actuate the emergency O_2 system for 15 minutes of operation. This same sequence of events would take place if the relief valve failed open. If the regulator fails closed, the suit pressure will decrease with time due to removal of oxygen for metabolic needs and system leakage. Figure 64 shows the decrease of suit pressure vs time under these conditions. The minimum survivable partial pressure of oxygen is reached in only 2.75 minutes. Therefore, a make up oxygen source and a regulator are required to maintain suit pressure. This regulator must also provide the required CO_2 purge flow of 2.11 Kgm/hour. The emergency O_2 regulator will control system pressure to 316 ± 14.1 gm/cm^2 psig.

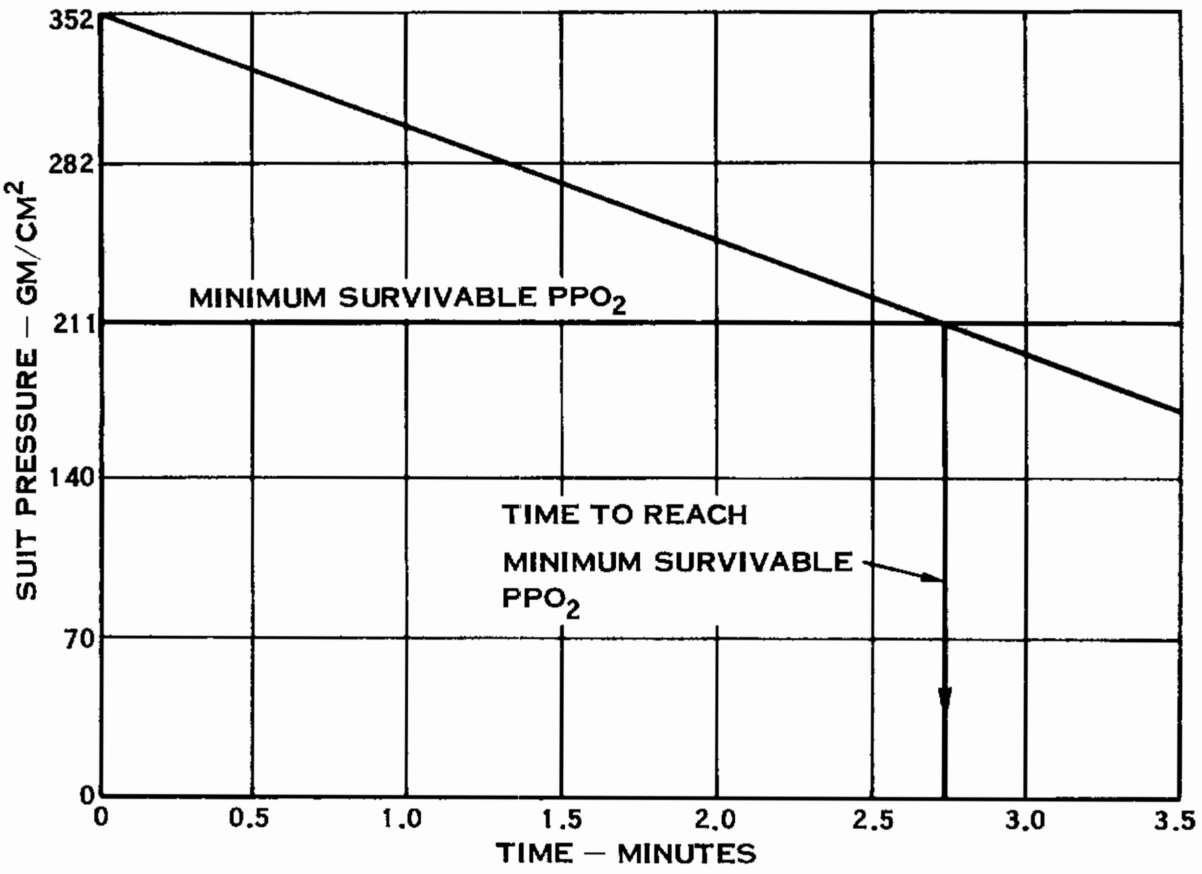


Figure 64. Suit Pressure vs Time

We have seen that a regulated 527,000 gm/cm^2 emergency O_2 supply and emergency battery are sufficient to provide a 15 minute return capability for the crewman in the event of any single failure other than catastrophic pressure rupture. It should be noted that the system as defined will provide protection for leakage rates up to 2.11 Kgm/hour or 78 liters/second at 352 gm/cm^2. However, one additional problem remains to be solved. The flow rate required, 2.11 Kgm/hour, causes the gas stream to cool isentropically as it leaves the bottle. This condition is further aggravated by the fact that free convection in zero gravity is nil. This eliminates even the bottle wall as a heat source without special provisions. Finally, expansion through the regulator cools the gas still further, even to the point of liquification. Liquid oxygen may be precluded by keeping the minimum bottle pressure above 53,000 gm/cm^2. However, as figure 65 shows, the bottle and regulator outlet temperatures may reach minimums of -118°C and -182°C. Figure 66 shows these same parameters as a function of time. These gas temperatures are sufficient to freeze and crack the regulator seals causing regulator failure plus causing great discomfort, injury, or even death to the crewman. Test data on the regulator indicates a minimum operating gas temperature of -40°C while humans are uncomfortable at inlet gas temperatures below 0°C. Therefore, it was ruled that the emergency system had to meet those two gas temperature criteria. The average gas temperature into the regulator is:

$$-118 + \frac{18 - (-118)}{2} = -51\text{C}$$

The heat required to raise the gas temperature to -40°F (-40°C) is

$$\begin{aligned} Q &= W\ Cp\ \Delta T & W &= 526\ \text{g} \\ &= (526)\ (.22)\ (6.7) & Cp &= 0.22\ \text{cal.}\ g^{-1}\,{}^{\circ}C^{-1} \\ &= 1.3\ \text{Kcal} & \Delta T &= 6.7^{\circ}\text{C} \end{aligned}$$

The heat available from the bottle shell may be estimated as follows:

$$\text{gm } O_2 \text{ required} = \frac{4.65}{4} = 526\ \text{g}$$

$$\text{Kgm bottle/lb } O_2 = 2.27\ \text{Kgm}$$

$$\text{mass of } O_2 \text{ bottle} = 526\text{g} \times 2.27\ \text{Kgm} = 2.64\ \text{Kgm.}$$

$$\begin{aligned} Q &= (2.64)\ (0.11)\ (27) \\ &= 12.7\ \text{Kcal} \end{aligned}$$

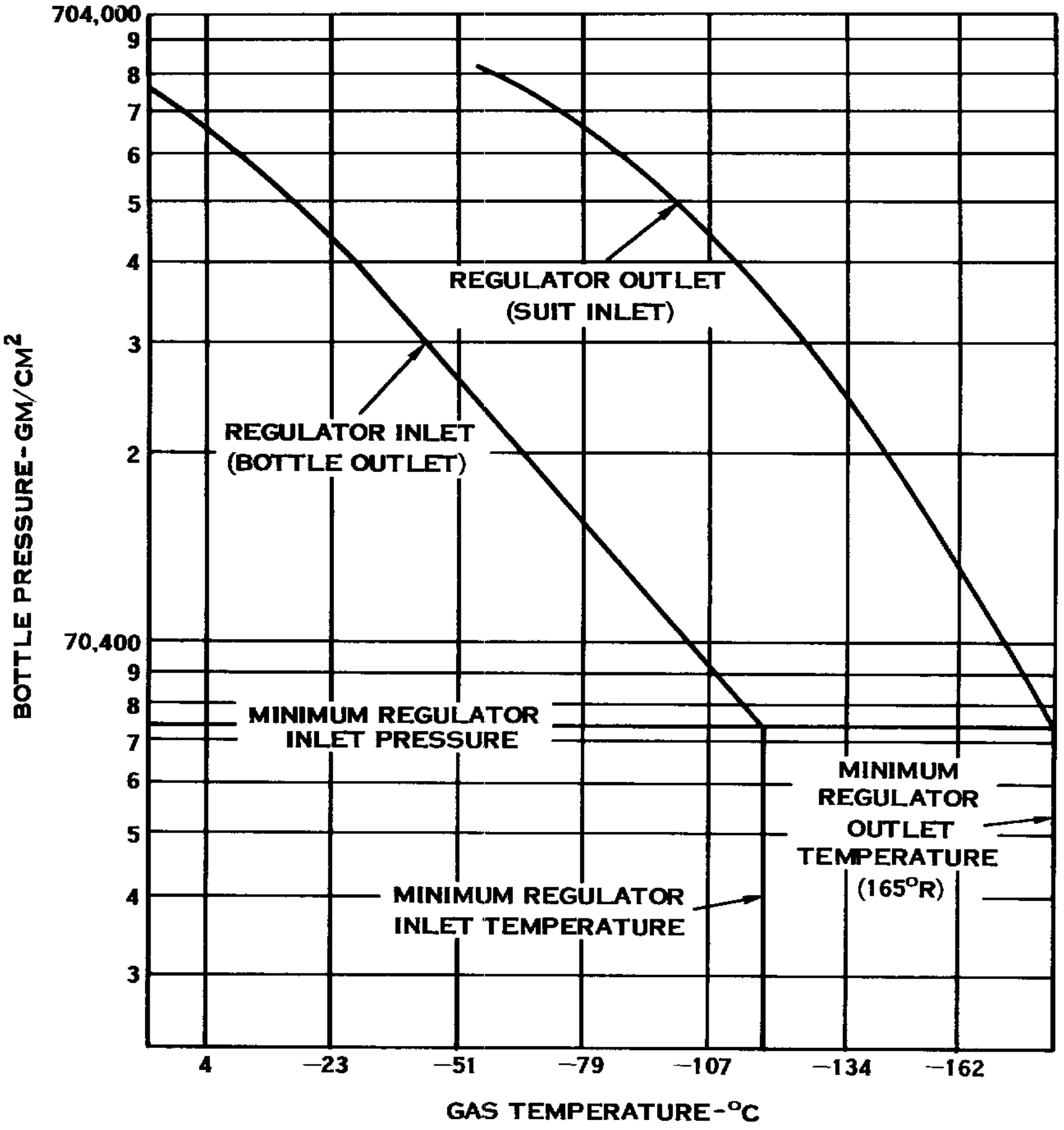


Figure 65. Emergency Return System Gas Temperature vs Bottle Pressure

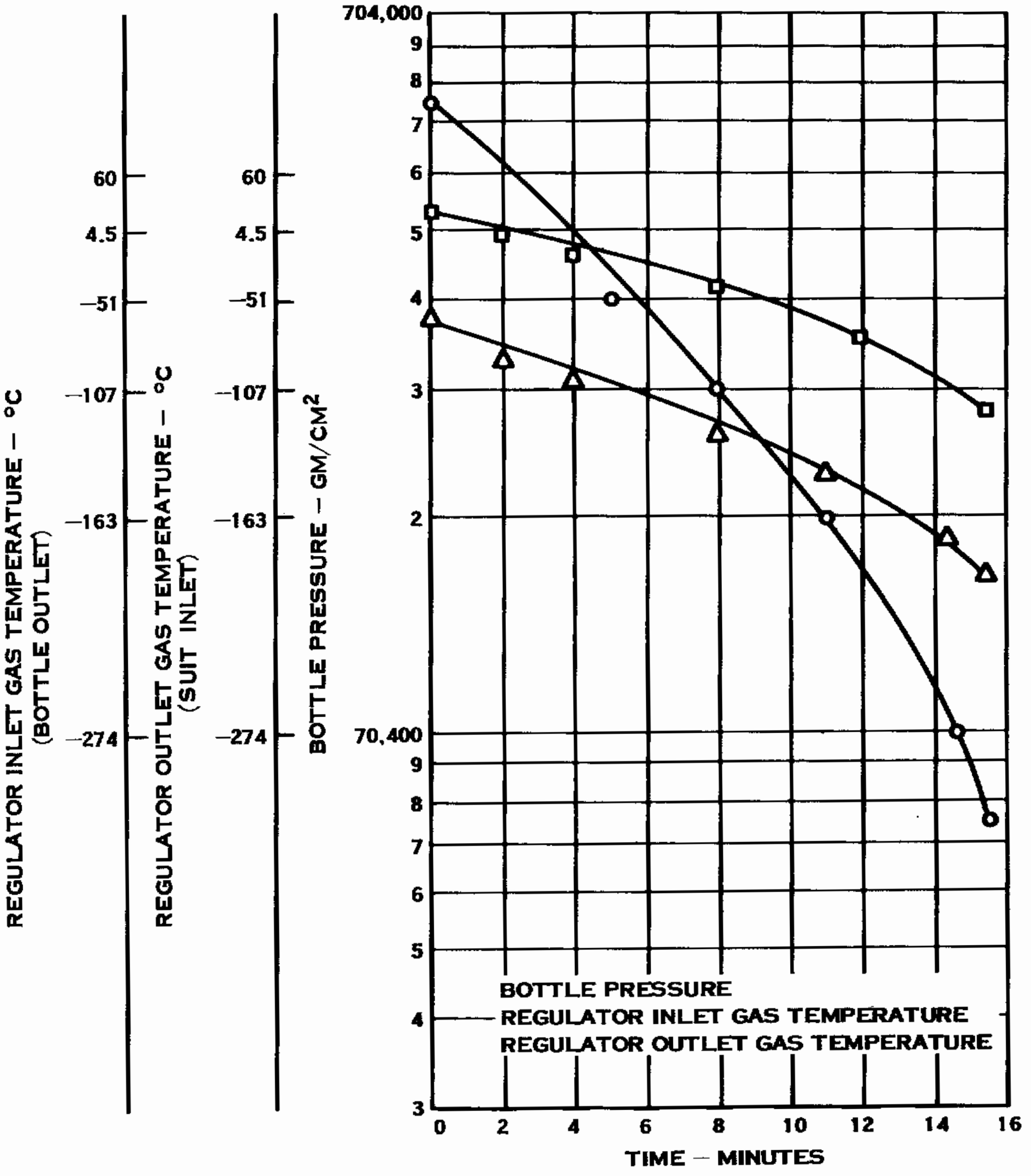


Figure 66. Emergency Oxygen System Gas Temperature vs Time

Experience has shown that the heat pickup efficiency of tubes brazed to the bottle surface is 25% to 50%. Assuming the conservative 25% value, 12.7 Btu(3.17 Kcal)are available, which is more than adequate for maintaining the -40°C minimum regulator inlet temperature. At this point, some means of alleviating the effect of the 83°C ΔT due to expansion through the regulator must be found. The heat required to maintain a regular outlet temperature of 0°C is 14.65 Kcal. The methods of supplying this amount of energy to the gas stream that were investigated were:

- Use the thermal storage of the bottle and surrounding structure by brazing the tubing to them. We are already using (5.1/12.7) (100) or 40% of the available energy from the bottle shell, leaving 12.7-5.1 or 1.9 Kcal for warming of the regulator exit stream. Therefore, 14.65 - 1.9 or 12.7 Kcal additional are required. The mass of structure required to supply this amount of energy at 16.7°C ΔT and 25% efficiency is:

  $$W = \frac{Q}{Cp\ \Delta T\ (.25)} \qquad \frac{12.7}{(0.11)\ (20)\ (.25)}$$

  $$= 28.0 \text{ Kgm}$$

  At this time, the system contains approximately 5 lb of structural metal. Therefore, this method was considered unfeasible.

- Use the transport water loop in a liquid gas heat exchanger. The transport loop water temperature is 10°C at its coldest. In 15 minutes, the loop can give up 12.7 Kcal and lose less than 0.55°C. Because of the low heat transfer characteristics, 382 cm of heat exchanger tubing will be required. The heat exchange tube is assumed to be .635 cm OD gas tubing inside 2.54 cm OD water tubing. This represents a volume increase of 1935 cm^3. Because of this large volume requirements, it was decided to pursue other concepts.

- Use a battery and electrical gas heater. A review of the possible emergency situations reveals that the emergency battery is never required at the same time as the emergency O_2 supply. The battery capacity is 16 watt-hours or 13.65 Kcal. Therefore, a heater of 50.9/54.6 or 93% efficiency will do the job. A search of this type of heater revealed an Apollo PLSS derived component capable of satisfying the requirement. Minor design changes will have to be made since this heater was designed to accept gas from two bottles simultaneously. The total heater volume will be on the order of 328 cm^3. The foregoing facts dictate that this is the gas heater of choice for the IEVA suit.

To summarize, the emergency return system will provide crewman return capability for 15 minutes in the event of any single failure other than catastrophic pressure rupture. The system consists of an O_2 bottle containing .53 Kgm. of useable oxygen at 527,000 gm/cm^2, a regulator capable of providing 2.11 Kgm of oxygen per hour, and a 16 watt-hour battery.

Maneuvering Unit

The maneuvering unit is a device which the crewman would don during EVA for the purpose of moving about. A maximum total impulse of approximately 1135 kgm - seconds was specified. It is required that mounting provisions for this maneuvering unit be provided on the Integrated EVA suit.

Inquiries revealed that the fuel to be used is hydrazine. This fuel has a specific impulse of approximately 200 seconds (depending on chamber pressure). This means that the maximum force imparted to the man-suit system is 2500/200 or 5.67 kgm. This results in a maximum g-force of 12.5/300 or .042 g for a 136 kgm system. This is negligible compared to launch, abort, and ground test forces that the system may be required to withstand. Therefore, the mounts will be designed for ground test with a safety factor of 2.

The unit will attach to the bottom of the lower torso with a trapping assembly at the rear and a manually operated latch assembly in front. These attachment points will be located so as not to interfere with any life support or suit joint functions. Figure 67 indicates how these attachments might be made. This and other typical attachment schemes will be studied to determine the optimum approach as the detail design of the lower torso is finalized.

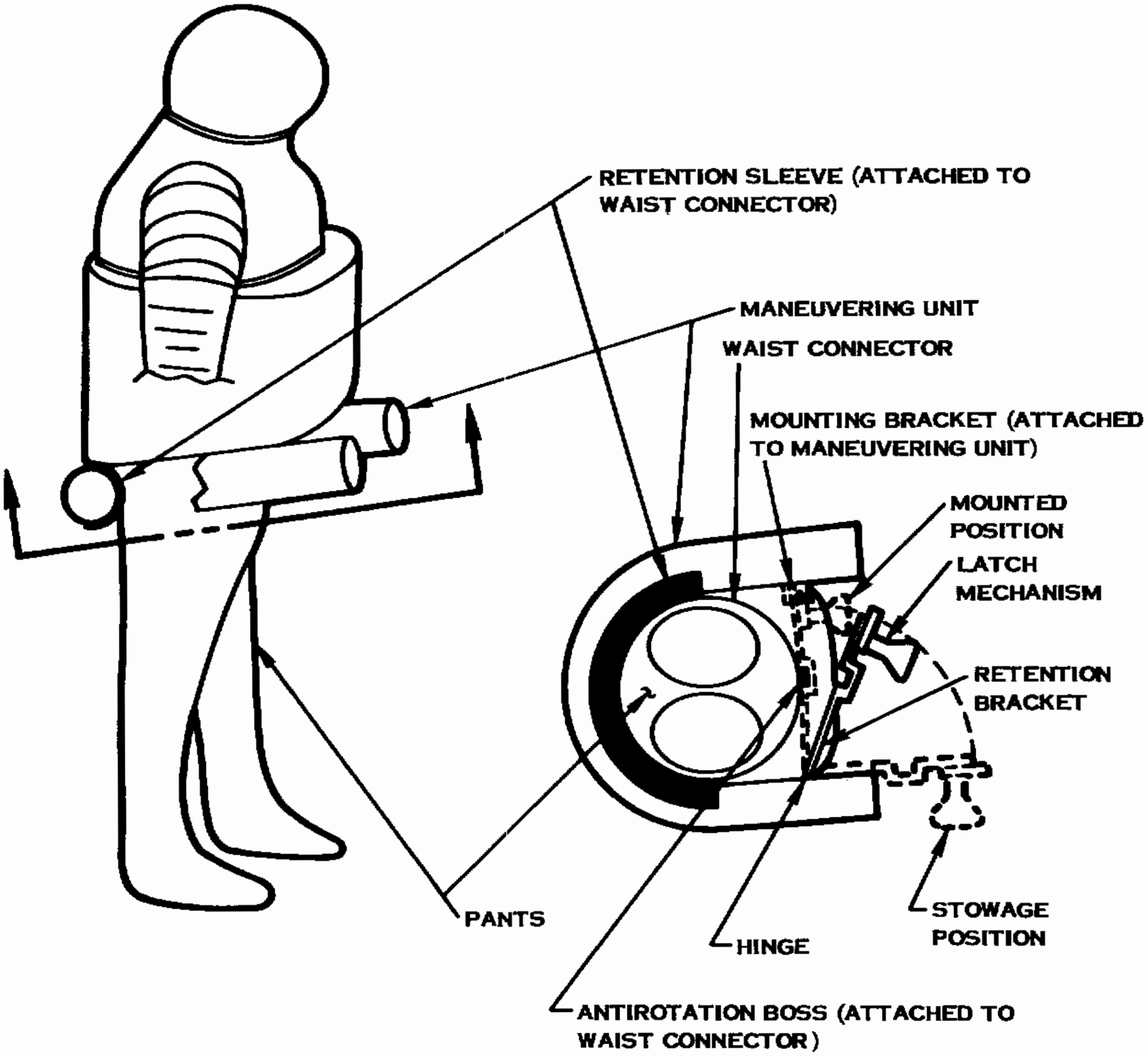


Figure 67. Maneuvering Unit Attachment Scheme

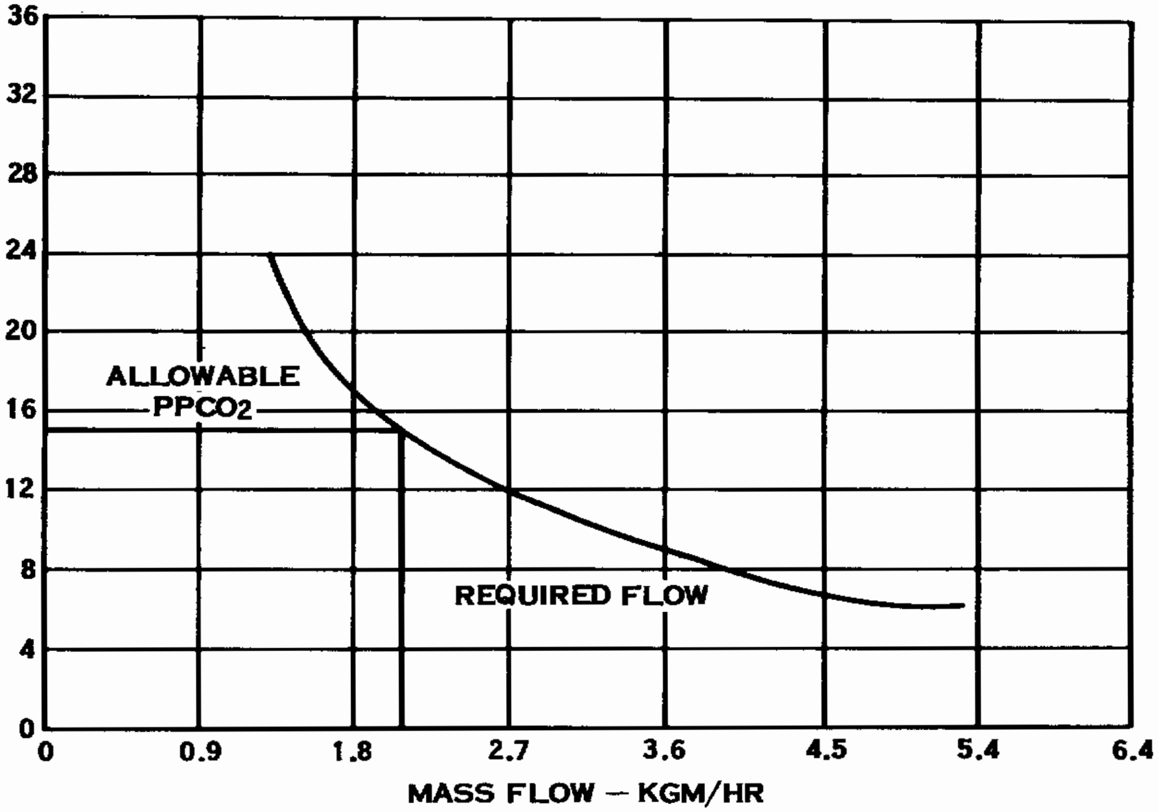


Figure 68. Helmet $PPCO_2$ vs. Gas Flow

SECTION IV

SYSTEM RELIABILITY PROGRAM

PROGRAM PLAN

The objective of the Reliability Program for the Integrated EVA Space Suit system is to determine the overall reliability of the whole suit and life support system concept. The reliability prediction for the suit and life support system is built-up from the performance probability relationships between the subdivided parts or elements of the suit and life support systems. A detailed examination will pinpoint those subdivided parts or elements which do not meet the necessary individual reliability level and thus enable effective corrective action to be taken to raise the system reliability level so that the overall reliability prediction will approach the desired goal of 0.999 as closely as possible.

In order to implement the program outlined in the foregoing paragraphs, a detailed method of assessing the reliability of the constituent elements has been developed in the form of a building block data collection system. This system will make available the collective knowledge of the elemental failure rates from related hardware being used in similar programs.

Using the foregoing as the starting point, a sound reliability model for the Air Force IEVA space suit can be evolved. The basic approach to the problem of reliability data collection is to insure establishment of the closest possible relationship to existing hardware of identical or similar design for which a reliability evaluation has been done. To achieve this relationship, a detailed IEVA Space and Life Support System parts list has been prepared and all items have been evaluated and separated into three (3) main categories; "as is", "modified" and "similar to." These categories in turn may be subdivided into nine (9) sections which are as follows:

- Apollo EMU parts used "as is"
- Apollo EMU parts used "modified"
- Apollo ECS parts used "as is"
- Apollo ECS parts used "modified"
- Apollo Space Suit Parts used "as is"
- Soft Space Suit Parts used "as is"
- Soft Space Suit Parts used "modified"
- IEVA Space Suit Parts "similar to"
- IEVA Life Support System Parts "similar to"

It should be noted that in the case of categories 8 and 9 which are for items specifically designed for the IEVA, they are in reality, "similar" to or based on existing designs and therefore can be related to those specific items to a determinable extent.

(Continued)

The procedure that is being followed in investigating, checking and establishing the reliability levels, is to correlate all the IEVA suit items to be used with those parts previously used on other programs. The relating evaluation with the greatest degree of confidence is "as is", then "modified" and finally "similar to". The parts list covering all items comprising the IEVA Space Suit has been issued to the respective reliability personnel for the relating programs. They will submit the pertinent reliability data for each particular part from their programs. The method of use, mounting, and connection of each part in the proposed IEVA design is being checked by the design group to insure that the "as is" parts are being used in the same manner as in the related programs that therefore the reliability data is applicable. In the case of modified items the IEVA Design Group has prepared an individual statement of the changes in the use, mounting and connection as well as the modification to the actual part. From this data the pertinent IEVA part is being re-evaluated for its changed reliability. Finally, in the case of items designed for the IEVA which, in essence, are "similar to" existing designs, a detailed description and design source statement will be prepared by the designer responsible. This statement will give the details necessary to that each of these IEVA "new parts" can have their reliability ascertained based on the "similar to" relationship. Thus, by the means outlined above, a reliability accessment, based on established programs is being evolved for this IEVA Space Suit and Life Support System study.

When the foregoing method of placing all the items comprising the Space Suit and Life Support System in the three (3) categories of identification is finished, the quantitative reliability assessment work will be performed. In general, the two main approaches outlined in the paragraphs below will be followed.

- First, where a comparable previous use exists, either at component or at piece part level, the following steps will be taken to establish the reliability of the IEVA item.

    1) A statement of performance and structural margins from previous uses is prepared which will be the basis of the predicted reliability level of the IEVA item.

    2) In the course of performing the work outlined above, any Failure Effects Analysis will be checked to see if the item in question had development or use failures. Also, applicable Reliability Data Reports will be checked using NASA or Air Force item numbers for reference. From this data the cause of any particular failure and any corrective action taken will be ascertained. Proper allowance will be made for this in the reliability assessment modification for the IEVA item.

- Secondly, where no applicable previous use is found to exist either at the component or at piece part level, a more elaborate procedure will be necessary. The following steps will be taken to insure the validity of the IEVA reliability prediction by building it up from the reliability of the basic pieces or parts.

  1) A synthesis of the reliability data for similar pieces or parts will be performed to build-up reliable preductions for a given IEVA item.

  2) The next step is to analyze the performance and structural margins. An estimate of the performance model will be made and from this, a failure effects analysis will be prepared.

  3) The third step is to then record the needs for special development test and/or back-ups to ensure a sufficiently high reliability.

By means of the foregoing program a valid overall reliability preduction for the IEVA Space Suit and Life Support System will be made.

SUMMARY

The Combined Hard Torso and the Soft Arms and Pants Complete Suit with the Integrated Life Support System for the 4-hour Extravehicular Mission was found to have an overall reliability of 0.99947.

Method

The IEVA was separated into two parts, the Space Suit with its Hard Torso, and the Life Support System. Then each component was related to either the Apollo or the MOL Space Suit and the Apollo PLSS (Portable Life Support System) or OPS (Oxygen Purge System).

This is done in each case for one of three degrees of relating, i.e., 1) "as is" or used without any significant change from existing hardware; 2) "modified" that is existing hardware altered in details only; and 3) "similar to" covering those items which are extensively redesigned but which have a similar functional concept for the design used on other programs.

In addition to the three grades above, the quality of the relating reliability data was evaluated and arranged in classes.

IEVA Component Failure Rates Established

The following summary sheets show the Probability of Failure of all components of the IEVA in accordance with the three (3) grades or degree of relating and the three (3) levels of quality of reliability data.

Method of Calculating Reliability Numbers

Two formulas are recognized for the calculation of Reliability from failure rate data.

1) $R = e^{-\lambda t}$
2) $R = 1 - \lambda t$

Where: R = Reliability number
e = Exponential Function
λ = Failure rates per-million hours
t = hours of actual use

Unless there is a real need for very accurate results and also the reliability number is less than 0.90 use of formulae 1) is not justified and a check into the tables of the exponential function e shows that the error, in this case, will be relatively insignificant.

The following pages summarize the IEVA component failure rates and reliability valves.

SUMMARY OF FAILURE RATES FOR COMPONENTS

A. COMPLETE SPACE SUIT

100 HARD SUIT PART				Failure Rate
I.	110	Helmet	--	1.12×10^{-6}
	111	Vent Duct	0.28×10^{-6}	
	112	Neck Ring	0.08×10^{-6}	
	113	Purge Port	0.40×10^{-6}	
	114	EV Visor	0.16×10^{-6}	
	115	Pressure Shell	0.20×10^{-6}	1.12×10^{-6}
II.	120	Upper Torso	--	19.28×10^{-6}
	121	Pressure Shell	1.80×10^{-6}	
	122	Neck Ring	4.00×10^{-6}	
	123	Arm Connector	9.20×10^{-6}	
	124	Vent System	0.92×10^{-6}	
	125	Entry Connector (upper half)	3.36×10^{-6}	19.28×10^{-6}

SUMMARY OF FAILURE RATES FOR COMPONENTS (Continued)

				Failure Rate
III.	130	Lower Torso	--	65.16×10^{-6}
	131	Maneuvering Unit Attachment	0.00×10^{-6}	
	132	Control Panel	6.00×10^{-6}	
	133	Expendables Pack Retention Mech.	8.00×10^{-6}	
	134	Entry Connector	3.36×10^{-6}	
	135	Pants Connector (Upper half)	6.80×10^{-6}	
	136	Lower Pressure Shell with Integral Feedwater Reservoir	3.00×10^{-6}	
	137	Back Cover	0.00×10^{-6}	
	138	Expendables Package Cover	18.00×10^{-6}	65.16×10^{-6}
	300 SOFT SUIT PART			
IV.	310	Thermal Meteroid Garment	--	110×10^{-6}
	311	Jacket	38.00×10^{-6}	
	312	Pants	28.00×10^{-6}	
	313	Boots	11.60×10^{-6}	
	314	Mittens (Gloves)	27.20×10^{-6}	
	315	Hood	5.20×10^{-6}	110×10^{-6}
V.	320	Liquid Cooling Subsystem	--	10.60×10^{-6}
	321	H_20 Conn. (LCG Half)	1.00×10^{-6}	
	322	Liquid Cooling Garment	9.60×10^{-6}	10.60×10^{-6}
VI.	330	Arms	--	77.16×10^{-6}
	331	Shoulder Joint	27.20×10^{-6}	
	332	Wrist Sizing Panel	0.04×10^{-6}	
	333	Upper Arm Bearing	5.92×10^{-6}	
	334	Elbow Joint	9.60×10^{-6}	
	335	Wrist Disconnect	4.80×10^{-6}	
	336	Wrist Joint	4.80×10^{-6}	
	337	Glove	18.40×10^{-6}	
	338	Vent System (Arms only)	0.48×10^{-6}	
	339	Wrist Transition	5.92×10^{-6}	77.16×10^{-6}

SUMMARY OF FAILURE RATES FOR COMPONENTS (Continued)

				Failure Rate
VII.	340	Parts	--	45.88×10^{-6}
	341	Parts Connector (Lower half)	6.80×10^{-6}	
	342	Hip Joint	29.40×10^{-6}	
	343	Ankle Sizing Panel	$.04 \times 10^{-6}$	
	344	Knee Joint	6.40×10^{-6}	
	345	Ankle Joint	2.40×10^{-6}	
	346	Soft Boot	$.16 \times 10^{-6}$	
	347	Vent System (Legs only)	$.68 \times 10^{-6}$	45.88×10^{-6}
100 HARD SUIT PART, COMPLETE				86.56×10^{-6}
I.	110	Helmet	1.12×10^{-6}	
II.	120	Upper Torso	19.28×10^{-6}	
III.	130	Lower Torso	65.16×10^{-6}	86.56×10^{-6}
300 SOFT SUIT PART, COMPLETE				243.64×10^{-6}
IV.	310	Thermal Meteroid Garment	110.00×10^{-6}	
V.	320	Liquid Cooling Subsystem	10.60×10^{-6}	
VI.	330	Arms	77.16×10^{-6}	
VII.	340	Pants	45.88×10^{-6}	243.64×10^{-6}
100 and 300 COMPLETE SPACE SUIT				330.20×10^{-6}
	100	Hard Suit Part, Complete	86.55×10^{-6}	
	300	Soft Suit Part, Complete	243.64×10^{-6}	330.20×10^{-6}
200 LIFE SUPPORT SYSTEM				
VIII.	210	Primary O_2 Subsystem		35.48×10^{-6}
	211	Oxygen Bottle	0.04×10^{-6}	
	212A	O_2 Regulator	32.28×10^{-6}	
	212B	O_2 Fill Port	0.68×10^{-6}	
	213	O_2 Shut Off Valve	2.48×10^{-6}	35.48×10^{-6}
IX.	220	Contaminant Control Subsystem		52.82×10^{-6}
	221	LiOH and Charcoal Canister	6.80×10^{-6}	
	222	Fan-Motor Assembly	45.54×10^{-6}	
	223	Vent System (Lower torso only)	0.48×10^{-6}	52.82×10^{-6}

SUMMARY OF FAILURE RATES FOR COMPONENTS (Continued)

				Failure Rate
X.	230	Thermal Control Subsystem		19.34×10^{-6}
	231	Sublimator	3.84×10^{-6}	
	232	Water Separator	1.04×10^{-6}	
	233	Pump Driver Assembly	12.46×10^{-6}	
	234	Water Connector	1.00×10^{-6}	
	235	Feedwater Reservoir Bladder	1.00×10^{-6}	19.34×10^{-6}
XI.	240	Controls and Displays		52.40×10^{-6}
	241A	Battery Switch	10.64×10^{-6}	
	241B	Fan Switch	10.64×10^{-6}	
	242	High Pressure O_2 Gage	8.00×10^{-6}	
	243	P. P. CO_2 Sensor	Eliminated	
	244	Suit Pressure Gage	9.32×10^{-6}	
	245	Diverter Valve	1.40×10^{-6}	
	246A	Water Shut-off Valve	1.76×10^{-6}	
	246B	Pressure Relief Valve		
	247	Pump Switch	10.64×10^{-6}	52.40×10^{-6}
XII.	250	Electrical Subsystem		5.88×10^{-6}
	251	Battery (includes relief valve)	3.76×10^{-6}	
	252	Battery Connector	0.80×10^{-6}	
	253	Wiring (Connectors between components)	0.88×10^{-6}	
	254	Terminal Board (includes all internal soldered conn.)	0.44×10^{-6}	5.88×10^{-6}
XIII.	260	Emergency Return Subsystem		33.83×10^{-6}
	261	Emergency O_2 Bottle	0.04×10^{-6}	
	262A	Emergency O_2 Regulator	32.28×10^{-6}	
	262B	Emergency O_2 Actuating Mech.	0.04×10^{-6}	
	263	Emergency Battery	0.20×10^{-6}	
	264	Emergency Battery Switch	0.67×10^{-6}	
	265	Emergency Battery Connector	0.40×10^{-6}	
	266	Emergency O_2 Connector	0.20×10^{-6}	33.83×10^{-6}

SUMMARY OF FAILURE RATES FOR COMPONENTS (Continued)

			Failure Rate
200	COMPLETE LIFE SUPPORT SYSTEM		199.75×10^{-6}
210	Primary O_2 Subsystem	35.48×10^{-6}	
220	Contaminant Control Subsystem	52.82×10^{-6}	
230	Thermal Control Subsystem	19.34×10^{-6}	
240	Controls and Displays	52.40×10^{-6}	
250	Electrical Subsystem	5.88×10^{-6}	
260	Emergency Return Subsystems	33.83×10^{-6}	199.75×10^{-6}

SUMMARY OF FAILURE RATES FOR SYSTEM

Combined Complete Space Suit and Integral Life Support System

(100 + 200 + 300) –		529.85×10^{-6}
100 + 300 Complete Space Suit	330.20×10^{-6}	
200 Complete Life Support System	199.75×10^{-6}	529.85×10^{-6}

(NOTE: All failure rates are in terms of λ, the number of failures per million hours of use, but for simplicity the symbol λ has not been used after each failure rate.)

CALCULATION OF RELIABILITY NUMBER FOR SYSTEM

As previously stated, under the heading Method of Calculating Reliability Numbers, forumlae 2) $R = 1 - \lambda t$ will be used to calculate the Reliability Number for the components, divisions of the Space Suit, subsystems of the Life Support System and the whole overall assembly.

The last column of the large summary sheets attached gives the reliability number for all the components calculated using the above method and therefore the Space Suit divisions, Life Support System subassemblies, and overall assembly are given below:

CALCULATION OF RELIABILITY NUMBER FOR SYSTEM (Continued)

A. SPACE SUIT DIVISIONS

100 HARD SUIT PART $(1-85.56 \times 10^{-6}) = 0.99992344$

110 Helmet $(1-1.12 \times 10^{-6}) = 0.99999888$
120 Upper Torso $(1-19.28 \times 10^{-6}) = 0.99998072$
130 Lower Torso $(1-65.16 \times 10^{-6}) = 0.99993484$

300 SOFT SUIT PART $(1-243.64 \times 10^{-6}) = 0.99975636$

310 Thermal Meteroid Garment $(1-110.00 \times 10^{-6}) = 0.99989000$
320 Liquid Cooling Subsystem $(1-10.60 \times 10^{-6}) = 0.99998940$
330 Arms $(1-77.16 \times 10^{-6}) = 0.99992284$
340 Parts $(1-45.88 \times 10^{-6}) = 0.99995412$

100 + 300 Complete Space Suit $(1-330.20 \times 10^{-6}) = 0.99966980$

B. LIFE SUPPORT SYSTEM AND SUBSYSTEMS

200 LIFE SUPPORT SYSTEM $(1-199.75 \times 10^{-6}) = 0.99980025$

210 Primary O_2 Subsystem $(1-35.48 \times 10^{-6}) = 0.99996452$
220 Contaminant Control Subsystem $(1-52.82 \times 10^{-6}) = 0.99994718$
230 Thermal Control Subsystem $(1-19.34 \times 10^{-6}) = 0.99998066$
240 Controls and Displays $(1-52.40 \times 10^{-6}) = 0.99994760$
250 Electrical Subsystem $(1-5.88 \times 10^{-6}) = 0.99999412$
260 Emergency Return Subsystem $(1-33.83 \times 10^{-6}) = 0.99996617$

C. COMBINED COMPLETE SPACE SUIT AND LIFE SUPPORT SYSTEM ASSEMBLY

100 + 300 Complete Space Suit $(1-330.20 \times 10^{-6}) = 0.99966980$
200 Complete Life Support System $(1-199.75 \times 10^{-6}) = 0.99980025$
100 + 200 + 300 Overall Assembly $(1.529.85 \times 10^{-6}) =$

0.99947015
or 0.99947

This exceeds the target of 0.999.

SECTION V

SYSTEM LOGISTICS

Logistics are normally thought of as the amount and mode of resupply required to maintain system operation. Since resupply has been predicated as a major operational mode for this system, and as such, has been fully discussed elsewhere, this section will deal with a somewhat expanded definition of logistics as applied to the IEVA space suit system. Four areas of interest will be discussed. These are as follows:

- Controls and Displays
- Checkout, Startup and Shutdown
- Recharge Procedures
- Stowage and Retrieval

CONTROLS AND DISPLAYS

All controls and displays must be placed so that the crewman can make positive identification of the item being considered and its value or setting. This is necessary to preclude (1) inadvertant actuation of the wrong control, (2) setting the right control to the wrong setting, and (3) either committing or not committing some act due to misinterpretation of a display readout. The simplest means of positive identification is visual. The top plate of the lower torso covering the expendables package is accessible manually and visually. Therefore, all controls and displays will be flush-mounted or recessed into this structure. The controls will consist of the following:

- Main Power Supply Switch
- Emergency Power Supply Switch
- Fan Switch
- Pump Switch
- Feed and Drain Water Shutoff Valve Control Handle
- Diverter Valve Control Handle
- Primary Oxygen Actuator
- Emergency Oxygen Actuator

The system displays are:

- Primary oxygen supply pressure
- Emergency oxygen supply pressure
- Suit pressure
- Battery voltage

There are many other displays that could be integrated into the system. These are listed below but are not included as a part of the system.

- CO_2 partial pressure

(Continued)

- Sublimator liquid loop ΔT
- Suit inlet oxygen temperature
- LiOH canister outlet temperature
- Battery current
- Feedwater quantity
- Oxygen loop flowrate

OPERATIONAL PROCEDURES

The following procedures are to be used during checkout, startup, and shutdown of the Integrated IEVA Space Suit system. These procedures are only tentative at this time since the detail design phase has not been concluded.

CHECKOUT

- Retrieve suit system from stowage area
- Visually examine all sections for defects
- Attach soft pants section to lower torso
- Open expendables compartment and check to determine the following are properly installed:

  1) Primary O_2 Bottle
  2) Primary Battery
  3) Emergency O_2 Bottle
  4) Emergency Battery

- Attach soft arms to upper torso
- Don LCG
- Don lower torso and soft pants
- Connect Liquid Cooling Garment
- Don upper torso and lock entry connector
- Verify primary and emergency O_2 bottle pressures at $527,000 \pm 7.040$ gm/cm^2
- Verify main and emergency battery voltages of 16.5 ± 0.8 vdc by actuating battery switches.

STARTUP

The startup procedure should be preceded by the checkout outlined above. Therefore, the system startup will assume the system to be in the configuration of last step of checkout above.

- Switch main battery on
- Switch fan on and verify flow at neck vent tube
- Switch pump on

(Continued)

- Don gloves and helmet
- Open primary O_2 shut off valve and verify suit pressure at 352 ± gm/cm^2
- Perform leakage check
- Reduce cabin pressure to 0 psia while continuously verifying that suit pressure remains at 352 ± 14 gm/cm^2
- Set diverter valve to minimum cool position
- Open water shutoff valve

If all is in order, the system is ready for egress.

SHUTDOWN (IN A PRESSURIZED CABIN)

- Connect with umbilical from vehilce suit loop
- Close water shutoff valve prior to vehicle ingress
- Turn off pump
- Close primary oxygen valve
- Turn off fan
- Open purge port and equalize suit and cabin pressures
- Remove helmet and gloves
- Turn off main power supply
- Doff upper torso
- Disconnect LCG and doff lower torso and soft pants
- Replace expendables and recharge feedwater reservoir
- Disconnect soft pants and arms
- Doff LCG
- Stow in assigned area

E.V. RECHARGE PROCEDURES

It is a system requirement that the LSS must be capable of recharge during EVA. This will require the use of umbilicals to supply pressure, makeup oxygen, and water during the recharging procedure.

- Attach O_2 and umbilical
- Close O_2 shutoff valve
- Turn off main power supply
- Close water shutoff valve
- Attach water supply umbilical
- Detach depleted mission expendables package
- Attach new expendables package
- Verify 527,000 ± 7,040 gm/cm^2
- Verify battery voltage
- Detach water supply umbilical
- Open water shutoff valve

(Continued)

- Turn on main power supply
- Open O_2 shutoff valve
- Detach O_2 and power umbilicals

During recharge, the pump, fan, and feedwater are shut off. There is about 0.6 lb H_2O downstream of the feedwater shutoff valve which may be partially sublimed and, if no heat load is put into the sublimator, frozen. Also, the transport water within the sublimator may be frozen. Tests indicate (43.8 Kcal) must be rejected before the transport water freezes while the total theoretical heat rejection capacity of the sublimator in this configuration is (0.6) (272) or 163 Kcal. Therefore, it would seem that 163-44 or 119 Kcal must be added to prevent freezing. However, this is true only if the time to recharge is greater than the time require to reject 43.8 Kcal. Again, tests were run on a sublimator simulating shutdown conditions. Complete freezing was found to occur after 10 minutes. If recharge can be accomplished within that 10 minute period, additional heat to prevent freezing will be unnecessary.

SECTION VI
ASSEMBLY
LOWER TORSO ASSEMBLY SEQUENCE, REF. SVSK 69544-2

1.0 Reservoir Assembly SVSK 69544-5

1.1 Remove enclosure, (item 57 on SVSK 69544-5), from reservoir (SVSK 69544-5)

1.2 Bladder (SVSK 69544-31) to reservoir (SVSK 69544-5)

1.3 Door (SVSK 69544-19) to reservoir

2.0 Rear section of Lower Torso Assembly

2.1 Temp. Control Valve (SVSK 69544-16) and packing, preformed (69490L12) to reservoir

2.2 Tube (SVSK 69544-13) and tube (SVSK 69544-15) to reservoir

2.2.1 Hoses (SV 713863-1) to temp. control valve and tube to reservoir

2.3 Water Separator (SVSK 69544-4) and packing preformed (69483D070D5062) to reservoir

2.3.1 Hose (SV 713864-2) to tube on reservoir

2.4 Sublimator (SVSK 69544-8) to reservoir with only 1 screw on right side

2.4.1 Hoses (SV 713864-2) from sublimator to reservoir sublimator to water separator

2.5 Tube (SVSK 69544-14) and hose (SV 701751-2) to reservoir and sublimator

2.6 Pump Motor Assembly (SVSK 69544-3) to bracket on reservoir

2.6.1 Hose (SVSK 69544-116-00-1) from pump to sublimator

2.6.2 Clamp (SVSK 69544-115) and left side sublimator mounting screw

2.6.3 Hose (SV 713863-1) between pump and tube (SVSK 69544-15)

2.6.4 Hose (SVSK 69544-15) and tube (SVSK 69544-9) between pump and temp control valve

LOWER TORSO ASSEMBLY SEQUENCE, REF. SVSK 69544-2

2.7 Fan Motor Assembly (SVSK 69544-7) and packing, preformed (69490L23) to reservoir

2.7.1 Hose (SV 713864-2) from fan to reservoir

2.7.2 Hose (SV 713863-1) from fan to tube (SVSK 69544-13)

2.8 Tube (SVSK 69544-12) and hoses (SV 713863-1) between fan and sublimator

2.9 Water Shut-Off Valve (SVSK 69544-6) to reservoir

2.9.1 Hoses (SV 701751-2) to tube (SVSK 69544-14) and Water Separator

2.10 Tube (SVSK 69544-64) to reservoir

2.10.1 Hose (SV 701751-2) between tube (SVSK 69544-64) and water shut-off valve and tube (SVSK 69544-15)

2.11 Electric wire harness from fan (SVSK 69544-7) and pump (SVSK 69544-3) to terminal board (SVSK 69544-43)

2.12 Enclosure, Back (on SVSK 69544-5) to reservoir

3.0 Front section of Reservoir Assembly

3.1 Hose (SV 701751-2) and clamp (SV 038-1) to tube (SVSK 69544-64)

3.2 Recharge Conn, O_2 (SVSK 69544-40-1) with packing, preformed (69490B26)

3.2.1 To reservoir (2 places)

3.3 O_2 Conn, LiOH (SVSK 69544-32) and packing, preformed (69490B27) to reservoir

3.4 Tube (SVSK 69544-57) to reservoir

3.5 Tube (SVSK 69544-63) to reservoir

3.5.1 Hose (SV 701751-2) and clamp (SV 038-1) to tube (SVSK 69544-57)

LOWER TORSO ASSEMBLY SEQUENCE, REF. SVSK 69544-2

3.6 Emergency Battery (SVSK 69544-77) to reservoir and to terminal board (SVSK 69544-41)

3.7 Bracket (SVSK 69544-75) and bracket (69544-61)

3.8 O_2 Emergency Bottle (SVSK 69544-114) to brackets (SVSK 69544-75) and (SVSK 69544-61) with screw (SVSK 69544-75)

3.9 Tube (SVSK 69544-57), backing, preformed (69490-F-9), backing, preformed (69490-F-5), ring (SVSK 69544-127-2) and ring-back up (SVSK 69544-127-1) to emergency O_2 bottle (SVSK 69544-114)

3.10 Cover, Emergency Package (SVSK 69544-78) to reservoir.

3.11 Shims (SVSK 69544-128-1) and (SVSK 69544-128-2) on Cover, Emergency Package (SVSK 69544-78)

3.12 Shim (SVSK 69544-128-3) on Cover, Emergency Package (SVSK 69544-78)

3.12.1 Emergency O_2 Regulator (SVSK 69544-38) to reservoir

3.13 Tube (SVSK 69544-57), packing, preformed (69490-F-9), packing, preformed (69490-F-5), ring (SVSK 69544-127-2) and ring-back up (SVSK 69544-127-1) to Emergency O_2 Regulator (SVSK 544-38)

3.14 Subassemble the following: (SVSK 69544-80), (SVSK 69544-93), (SVSK 69544-85), (SVSK 69544-81), (SVSK 69544-71-1), (SVSK 69544-83), (69725-T4-10), (SVSK 69544-71-2), (SVSK 69544-90), (69725-T4-16), (NAS 620 C8), (69725-T4-18), (AN 380C2-1), mount above to the reservoir

3.15 Cup, terminal box (SVSK 69544-42) to reservoir

3.16 Switches (SV 712949), Voltmeter, Battery (SVSK 69544-34), Current Limiter (SV 710978-20), Current Limiter (SV 730307) and Cable, Primary Battery (SVSK 69544-36) to terminal board (SVSK 69544-41)

3.17 Terminal Board (SVSK 69544-41), Gasket, Terminal Box (SVSK 69544-44), Ferrule Assembly, Terminal Box (SVSK 69544-43), to reservoir

3.18 Gage, Suit Pressure (SVSK 69544-33) and hose (SV 701751-2) to reservoir

LOWER TORSO ASSEMBLY SEQUENCE, REF. SVSK 69544-2

3.19 Cover, Control Panel (SVSK 69544-94) to reservoir

3.20 Cap, Humidity (SVSK 69544-105) and Humidity Receptacle (SVSK 69544-37) to cover, control panel (SVSK 69544-94)

3.21 Connector, Water Fill (SV 706140-2) and packing, preformed (69494P110) to Cover, Control Panel (SVSK 69544-94)

3.22 Connector, Water Drain (SV 706141-2) and packing, preformed (69494P11) to Cover, Control Panel (SVSK 69544-94)

3.23 Actuator, Shut-Off (SVSK 69544-37) to Cover, Control Panel (SVSK 69544-94) and Water Shut-Off Valve (SVSK 69544-6)

3.24 Actuator, Temperature Control Valve (SVSK 69544-61) to Cover, Control Panel (SVSK 69544-94) and Valve, Temperature Control (SVSK 69544-16) and Rack (SVSK 69544-16-10)

4.0 Top section of Reservoir Assembly

4.1 Connector, Water (SV 706141-2) and hose (SVSK 69544-116-00-2) to reservoir

4.2 Shoulder Harness (SVSK 69544-102) to reservoir

SECTION VII
PARTS LIST
SPACE SUIT ASSEMBLY
(SVSK 69544-2)

Part Number	No. Required	Part Name
SV 731680	3	Clamp, Loop
AN960PD10L	10	Washer, Flat
NAS 1101 C3-5	5	Screw, Fillister Head
NAS 1101 C3-8	1	Screw, Fillister Head
69510-80	3	Nut, Self Locking
SVSK 69544-12	1	Tube, Fan to Sublimator
AN960PD8L	16	Washer, Flat
SVSK 69544-21-2	2	Insert, Special, IEVA
NAS 1101 C08-5	5	Screw, Fillister Head
69490L12	1	Packing, preformed
SVSK 69544-5	1	H_2O Reservoir
SV 713863-1	4	Hose, Flexible
SV 701751-2	16	Clamp, Ratchet
MS 20995C20	As Required	Wire, Lock
SVSK 69544-16	1	Valve, Temperature Control
SVSK 69544-21-1	5	Insert, Special, IEVA
AN960PD6L	10	Washer, Flat
NAS 1101 C06-5	13	Screw, Fillister Head
SV 701818 A1HR	2	Clamp, Cushioned, Center
SVSK 69544-9	1	Tube, Diverter to Pump, IEVA
SVSK 69544-3	1	Pump, Motor Assembly
SVSK 69544-8	1	Sublimator, IEVA
SVSK 69544-13	1	Tube, Fan to Diverter
SVSK 69544-15	1	Tube, Pump to Shut-Off and Res.
NAS 1101 C08-8	4	Screw, Fillister Head
69758SS2-6	1	Clamp, Loop
69372S4T	5	Clamp, Loop, Cushioned
SV 701751-7	16	Clamp, Ratchet
SV 713864-2	4	Hose, Flexible
NAS 1101 C08-6	5	Screw, Fillister Head
SVSK 69544-4	1	H_2O Separator
NAS 1121 C-4	1	Screw Fillister Head
NAS 1291 C-06	1	Nut, Self Locking
SVSK 69544-117	1	Clamp, Tube
SV 713863-2	7	Hose, Flexible
SV 701751-1	14	Clamp, Ratchet
SVSK 69544-6	1	H_2O Shut-Off Valve
SVSK 69544-7	1	Fan Motor Assembly

SPACE SUIT ASSEMBLY
(SVSK 69544-2)

Part Number	No. Required	Part Name
SVSK 69544-14	1	Tube, Shut-Off to Res.
NAS 1101 C3-20	1	Screw, Fillister Head
SVSK 69544-21-3	1	Insert, Special, IEVA
SVSK 69544-115	1	Clamp, Tube
SVSK 69544-116-00-1	1	Hose, Flexible
SVSK 69544-1	1	Upper Torso, Assembly
697458SS-2-4-HR	1	Clamp, Cushioned
NAS 1101 C06-6	2	Screw, Flat
SVSK 69544-105	1	Cap, Humidity, Primary Battery
SVSK 69544-36	1	Cable, Primary Battery
SVSK 69544-37	1	Humidity, Receptacle, Battery Cable
SVSK 69544-68	1	Actuator, Shut-Off
NAS 1102 C06-5	10	Screw, Flat Head
NAS 1102 C06-7	6	Screw, Flat Head
SVSK 69544-40	1	Vehicle, Recharge Conn., O_2
SVSK 69544-32	1	O_2 Connector, LiOH
NAS 1102 C08-5	14	Screw, Flat Head
SVSK 69544-78	1	Cover, Emergency Package
SVSK 69544-75	1	Bracket, Emergency
SVSK 69544-52	4	Screw, Ball End
NAS 1101 C08-7	26	Screw, Fillister Head
SVSK 69544-50	1	O_2 Bottle, Emergency
SVSK 69544-114	1	Waist Ring and Pants Assembly
SVSK 69544-122	2	Shoulder Ring and Arm Assembly
SVSK 69544-33	1	Gage, Suit Pressure
SVSK 69544-34	1	Volt Meter, Battery
SVSK 69544-38	6	O_2 Regulator, Emergency
SVSK 69544-102	2	Shoulder Harness, IEVA
SVSK 69544-116-00-2	2	Hose, Flexible
SV 706141-2	3	Connector, Water Drain
NAS 1102 C06-4	8	Screw, Flat Head
SV 712949	5	Switch, Pump
SVSK 69544-94	1	Cover, Control Panel
SVSK 69544-16-10	1	Rack, T.C.V.
NAS 1101 C06-4	4	Screw, Fillister Head
SVSK 69544-19	1	Door, Bladder
SV 038-1	4	Clamp, Nylon Electrical
SVSK 69544-77	1	Battery, Emergency
SVSK 69544-63	1	Tube, Bladder Door to Fill Fitting
NAS 1122 C-54	2	Bolt, Fillister Head

SPACE SUIT ASSEMBLY
(SVSK 69544-2)

Part Number	No. Required	Part Name
NAS 1291 C08	2	Nut, Self Locking
SV 594674-3	1	Clamp, Loop, Cushion
SVSK 69544-61	1	Actuator, T.C.V.
SVSK 69544-76	1	Bracket and Pin, Emergency Bottle
69490B-27	2	Packing, preformed
SVSK 69544-80	1	Lever, Lock Release
SVSK 69544-93	1	Rod, Indicator
SVSK 69544-85	1	Housing, Lock Mechanism
SVSK 69544-81	1	Lever, Safety
SVSK 69544-71-1	1	Spring, Lock
69725-T4-10	2	Pin, Straight, Headed
SVSK 69544-83	1	Lock, Plunger
SVSK 69544-71-2	1	Spring, Locking
SVSK 69544-90	1	Latch, Canister Lock
69725-T4-16	1	Pin, Straight, Headed
NAS 620 C8	4	Washer, Flat
69725-T4-18	1	Pin, Straight, Headed
AN 380C2-1	4	Pin, Cotter
NAS 620 C5L	4	Washer, Flat
SVSK 69544-71-4	1	Spring, Flat
SVSK 69544-82	1	Bushing
69490B26	2	Packing, preformed
SVSK 69544-40-1	2	Vehicle, Recharge, Conn, O_2
SVSK 69544-51	2	Bracket, Primary Bottle
SVSK 69544-49	1	O_2 Bottle, Primary
NAS 620 C8L	20	Washer, Flat
SVSK 69544-21-2	25	Insert, Special
NAS 1101 C08-10	3	Screw, Fillister Head
SVSK 69544-55	1	Tube, Primary O_2 to Regulator
SVSK 69544-35	1	O_2 Regulator, Primary
STSV 046-15	As Required	Shim, Laminated
SVSK 69544-48	1	Battery, Primary
SVSK 69544-73	1	LiOH Canister
SVSK 69544-21-3	3	Insert, Special
NAS 1101 C3-10	3	Screw, Fillister
69490L23	1	Packing, preformed
69758SS2-4HR	1	Clamp, Cushioned
NAS 1101 C08-4	1	Screw, Fillister Head
SVSK 69544-127-1	4	Ring, Backup
SVSK 69544-127-2	4	Ring, Backup

SPACE SUIT ASSEMBLY
(SVSK 69544-2)

Part Number	No. Required	Part Name
69490-F-9	4	Packing, preformed
69490-F-5	4	Packing, preformed
STSV 055-4C-11	3	Pin, Straight, Headless
69494 P11	3	Packing, preformed
69483D070D5062	1	Packing, preformed
SVSK 69544-64	1	Tube, Bladder Door to S. O. V.
NAS 1102 C04-14	1	Screw, Fillister Head
NAS 1102 C04-5	20	Screw, Flat Head
SVSK 69544-123	1	Cover, Expendables Package
SVSK 69544-42	1	Cup, Terminal Box
SVSK 69544-44	1	EMI Gasket, Terminal Box
SVSK 69544-43	1	Ferrule Assembly, Terminal Box
SV 710978-20	1	Current Limiter, 2 Amp.
SV 730307	1	Current Limiter, 4 Amp.
69494P110	1	Packing, preformed
SV 706140-2	1	Connector, Water Fill
SVSK 69544-31	1	Bladder, Reservoir
NAS 1101 C3-7	1	Screw, Fillister
NAS 620 C10	1	Washer
SVSK 69544-57	1	Tube, Emergency O_2 to Regulator
SVSK 69544-41	1	Terminal Board, IEVA
SVSK 69544-128-1	2	Shim, Cover Assembly
SVSK 69544-128-2	2	Shim, Cover Assembly
SVSK 69544-128-3	2	Shim, Cover Assembly

COVER, CONTROL PANEL
(SVSK 69544-94)

Part Number	No. Required	Part Name
SVSK 69544-94-1	1	Cover
SVSK 69544-86	1	Cover, Switch
SVSK 69544-87	1	Pin, Hinge
SVSK 69544-89	1	Hinge, Switch Cover
	1	1/32" Cotter Pin
	4	1/16 " Rivet, Alum
SVSK 69544-88	1	Backplate, Hinge
SV 715421-3	10	Bushing
NAS 686 - #8-32	5	Floating Nut
MS 20426 AD3-4	10	Rivet
STSV 071N1-0750	As Needed	Velcro Pile
SVSK 69544-100	1	Nameplate, Batt. Stow.
SVSK 69544-96	1	Nameplate, Switch, Pin. Batt.
SVSK 69544-95	1	Nameplate, Switch Ident.
SVSK 69544-99	1	Nameplate, Water, Fill and Drain
SV 715421-2	8	Bushing

COVER, EMERGENCY PACKAGE
(SVSK 69544-78)

Part Number	No. Required	Part Name
SVSK 69544-78-0	1	Cover
SVSK 69544-92-1	1	Track
SVSK 69544-92-2	1	Track
SVSK 69544-73-8	1	Stop, Canister
NAS 1068 C08M	8	Miniature Anchor Nut
NAS 1032 C08K	2	Miniature Anchor Nut
MS 204 26 AD3-4	20	Rivet
NAS 1102 C08-8	10	Screw

CANISTER, LiOH
(SVSK 69544-73)

Part Number	No. Required	Part Name
SVSK 69544-73-12	1	Housing
SVSK 69544-73-13	1	Cover, Rear
SVSK 69544-73-9	1	Cover, Canister
SVSK 69544-21-2	8	Insert
NAS 1622-C2	8	Screw
SVSK 69544-73-11	2	Fitting, Canister
SVSK 69544-73-14	2	Shim
SVSK 69544-73-15	2	Boss
SVSK 69544-73-7	1	Lock, Canister
SVSK 69544-73-1	1	Housing, Lock, Upper
SVSK 69544-73-3	1	Spring, Locking
SVSK 69544-73-6	1	Rod, Locking
SVSK 69544-73-3	1	Bushing, Locking Rod
SVSK 69544-73-2	1	Bearing, Canister
SVSK 69544-73-5	1	Housing, Locking
SVSK 69544-73-4	1	Pawl, Locking
SVSK 69544-73-16	1	Filler
SVSK 69544-73-17	2	Filler
SVSK 69544-73-19	1	Filler
SVSK 69544-73-10	1	Tube, Canister
SVSK 69544-73-20		Lithium Hydroxide
SVSK 69544-73-21		Activated Charcoal
SVSK 69544-73-22	1	Liner, Top
SVSK 69544-73-23	1	Liner, Bottom
SVSK 69544-73-24	1	Plate, Rear
SVSK 69544-73-25	1	Screen, Rear
SVSK 69544-73-26	1	Liner, Rear
SVSK 69544-73-27	1	Liner, Front
SVSK 69544-73-28	1	Screen, Front
SVSK 69544-73-29	1	Plate, Front
SVSK 69544-73-18	4	Pads
69522-8F16	1	Pin
69522-8F26	1	Pin
69490-B44	1	Seal

CAP, HUMIDITY, PRIMARY BATTERY
(SVSK 69544-105)

Part Number	No. Required	Part Name
SVSK 69544-105-2	1	Connector Cap
SVSK 69544-105-1	1	Knob

HARNESS, SHOULDER
(SVSK 69544-102)

Part Number	No. Required	Part Number
SVSK 69544-101	1	Web, Shoulder, Harness
SV 714147	1	Buckle Adjustment
SV 714143	1	Ring, Harness
SV 714144	1	Hook and Spring, Harness
Make from SV 593192-13	1	Strap, Harness
Make from SV 593192-11	1	Strap, Harness

SHOULDER RING AND ARM ASSEMBLY

(SVSK 69544-122-1)

Part Number	No. Required	Part Name
SV 721625-1	1	Arm, Left
SVSK 69544-120	1	Ring, Shoulder
SVSK 69544-119	1	Ring, Retaining
SV 721645-213	1	Venting System, Arms
NAS 1102-06-6	24	Screw
STSV 071N1-0750	As Required	Velcro Pile

SHOULDER RING AND ARM ASSEMBLY, R.H.
(SVSK 69544-122-2)

Part Number	No. Required	Part Name
SV 721625-2	1	Arm, Right
SVSK 69544-120	1	Ring, Shoulder
SVSK 69544-119	1	Ring, Retaining, Arm
SV 721645-213	1	Venting System, Arms
NAS 1102-06-6	24	Screw
STSV 071N1-0750	As Required	Velcro Pile

RESERVOIR,WATER

Part Number	No. Required	Part Name
SVSK 69544-5	1	Reservoir - Water, IEVA
SVSK 69544-5-9	1	Tube, LCG, Outlet, IEVA
SVSK 69544-5-9-0-1	1	Tube
SVSK 69544-5-10	1	Flange Insert, IEVA
SVSK 69544-5-11	1	Fitting, IEVA
SVSK 69544-1-6-2	1	IEVA Space Suit Ring Assembly
SV 721646-1-1	1	Guard, Spring
SV 721643-1-1	1	Spacer, Spring
SV 721642-1-1	1	Spring, Actuator
SV 721648-1-1	1	Spring Locking
SV 721626-1-1	1	HSG, Plunger
SV 730075-1-1	1	Support Latch
SV 721631-1-1	1	Plunger and Catch, Helmet
SVSK 69544-1-3	1	Ring and Insert Reservoir (Upper)
SVSK 69544-17	1	Mount Plate, IEVA
69522 C6-6	2	Power Pin
SVSK 69544-1-4	1	Ring, Latching, IEVA
SV 721627-1-1	1	Pin, Shoulder
SV 721633-1-1	3	Pin, Straight Headless
SVSK 69544-1-5	1	Seal, Static
AN 960 C4L	2	Washer Flat
STSV 062-04-2	2	Bolt
MS 24585-C241	1	Spring, Compression
AN 505C6-6	2	Screw, Mach
SVSK 69544-5-0-1	1	Reservoir Inner Wall
SVSK 69544-5-0-2	1	Reservoir Outer Wall
SVSK 69544-5-13	1	Tube, LCG, Inlet, IEVA
SVSK 69544-5-0-3	3	Rib
SVSK 69544-5-0-4	1	Base Housing
SVSK 69544-5-0-5	2	Cover Pin
SVSK 69544-5-0-6	2	Boss
SVSK 69544-5-0-7	2	Rib
SVSK 69544-5-0-8	4	Bracket
SVSK 69544-5-0-9	1	Rib
SVSK 69544-5-0-10	1	Boss
SVSK 69544-5-0-11	1	Rib
SVSK 69544-4-6	1	Mounting Boss, Water Separator, IEVA
SVSK 69544-5-0-12	1	Rib
SVSK 69544-5-0-13	1	Rib
SVSK 69544-5-0-14	1	Rib

RESERVOIR, WATER

Part Number	No. Required	Part Name
SVSK 69544-5-0-15	1	Boss
SVSK 69544-5-0-16	1	Rib
SVSK 69544-5-0-17	1	Rib
SVSK 69544-10	1	Tube, Fan to Reservoir, IEVA
SVSK 69544-5-0-18	1	Rib
SVSK 69544-5-0-19	1	Rib
SVSK 69544-5-0-20	1	Rib
SVSK 69544-5-0-21	1	Rib
SVSK 69544-5-0-22	1	Rib
SVSK 69544-5-0-23	3	Boss
SVSK 69544-5-0-24	1	Rib
SVSK 69544-5-0-25	1	Rib
SVSK 69544-5-0-26	1	Rib
SVSK 69544-5-0-27	1	Rib
SVSK 69544-5-0-28	1	Rib
SVSK 69544-5-0-29	3	Cover Bracket
SVSK 69544-5-8	1	Bracket - Pump, IEVA
SVSK 69544-11	1	Fitting, Sublimator to Reservoir, IEVA
SVSK 69544-1-6-1	1	IEVA Space Suit Ring Assembly
SV 721646-1-1	1	Guard, Spring
SV 721643-1-1	1	Spacer, Spring
SV 721642-1-1	1	Spring, Actuator
SV 721648-1-1	1	Spring Locking
SV 721626-1-1	1	HSG, Plunger
SV 730075-1-1	1	Support Latch
SV 721631-1-1	1	Plunger and Catch Helmet
SVSK 69544-1-4	1	Ring, Latching, IEVA
SV 721627-1-1	1	Pin, Shoulder
SVSK 68544-1-5	1	Seal, Static
AN 960 C4L	2	Washer, Flat
STSV 062-04-2	2	Bolt
MS 24585-C241	1	Spring, Compression
AN 505 C6-6	2	Screw, Mach.
SVSK 69544-5-0-30	1	Rib
SVSK 69544-5-0-31	2	Boss
SVSK 69544-5-0-32	1	Rib
SVSK 69544-5-0-33	1	Boss
SVSK 69544-5-0-34	1	Rib
SVSK 69544-5-3	1	Duct, Fan Inlet, IEVA
SVSK 69544-5-1	1	Tube Assembly
SVSK 69544-5-0-50	1	Boss

RESERVOIR, WATER

Part Number	No. Required	Part Name
SVSK 69544-5-0-51	1	Boss
SVSK 69544-22	1	Washer, C'Sunk
SVSK 69544-5-0-52	1	Boss
SVSK 69544-5-0-53	2	Grill
SVSK 69544-5-0-54	3	Rib
SVSK 69544-5-0-55	1	Rib
SVSK 69544-5-0-56	1	Pad
SVSK 69544-5-0-57	1	Pad
SVSK 69544-5-0-58	1	Pad
SVSK 69544-5-0-59	1	Rib
SVSK 69544-5-0-60	1	Rib
SVSK 69544-5-0-61	1	Ring
SVSK 69544-5-0-62	1	Bracket
SVSK 69544-5-0-63	1	Bracket
SVSK 69544-5-0-64	2	Tube
SVSK 69544-5-14	1	Manifold, LiOH Canister Inlet, IEVA
SVSK 69544-5-15	1	Manifold, LiOH Canister Outlet, IEVA
SVSK 69544-5-0-68	1	Tube, Reservoir to Drain Fitting
SVSK 69544-5-0-65	1	Insert
SVSK 69544-5-0-66	1	Spacer
SVSK 69544-5-0-67	1	Boss
SV 715421-2	4	Bushing, Tapered
SVSK 69544-91	1	Tube, Emergency O_2 Regulator to Manifold

TUBE, EMERGENCY O_2 TO REGULATOR

Part Number	No. Required	Part Name
SVSK 69544-57	1	Tube, emergency O_2 to regulator, IEVA
SVSK 69544-57-1	1	Tube
SVSK 69544-46	2	Nut, high pressure
SVSK 69544-47	2	Fitting, high pressure

FERRULE ASSEMBLY, TERMINAL BOX

Part Number	No. Required	Part Name
SVSK 69544-43	1	Ferrule Assembly, Terminal Box, IEVA
SVSK 69544-43-00-1	12	Ferrule
SVSK 69544-43-00-2	1	Housing

TERMINAL BOARD

Part Number	No. Required	Part Name
SVSK 69544-41	1	Terminal Board, IEVA
SVSK 69544-41-00-1	2	Buss Bar
SVSK 69544-39-3	5	Terminal Pin
SVSK 69544-39-2	2	Terminal Pin
SVSK 69544-39-1	4	Terminal Pin

TEMPERATURE CONTROL VALVE

Part Number	No. Required	Part Name
SVSK 69544-16	1	Temperature Control Valve, IEVA
MS 21295-20	3	Screw
69546C10	3	Washer
SVSK 69544-16-3	1	Housing, TCV, IEVA
SVSK 69544-16-4	1	Washer, TCV, IEVA
SVSK 69544-16-2	1	Spool Assembly, TCV, IEVA
SVSK 69544-16-1		End Cap, TCV, IEVA
69494H12	1	Packing, preformed
69494H17	1	Packing, preformed
69494N22	1	Packing, preformed
SVSK 69544-16-5	1	Spool, TCV, IEVA
SVSK 69544-16-6	1	Bushing, Spool, TCV, IEVA
SVSK 69544-16-8	1	Tube, Coolant, TCV, IEVA
SVSK 69544-16-7	1	Tube, By Pass, TCV, IEVA
SVSK 69544-16-9	2	Pin, TCV, IEVA
69522-3H11	2	Pin, straight

H_2O SEPARATOR

Part Number	No. Required	Part Name
SVSK 69544-4	1	H_2O Separator, IEVA
SVSK 69544-4-3	1	Adaptor, H_2O Separator, IEVA
SV 700800	1	Glass Bead Assembly
69490L14	1	Packing, preformed
69490L15	1	Packing, preformed
69456A9	2	Washer
NAS 1101 C06-4	2	Screw
SVSK 69544-4-4	1	Wick, H_2O Separator, IEVA
SVSK 69544-4-5-2	2	Wick, H_2O Separator, IEVA
SVSK 69544-4-2-2	1	Spring, H_2O Separator, IEVA
SVSK 69544-4-2-1	1	Spring, H_2O Separator, IEVA
SVSK 69544-4-1	1	H_2O Separator HSG, IEVA
SVSK 69544-4-5-1	1	Wick, H_2O Separator, IEVA
SVSK 69544-4-5-8	1	Wick, H_2O Separator, IEVA

ACTUATOR, SHUT-OFF

Part Number	No. Required	Part Name
SVSK 69544-68	1	Actuator, Shut-Off, IEVA
SVSK 69544-67	1	Flex Cable, Shut-Off, IEVA
----	1	Hose Clamp, 0.230 diameter
AN960DD8L	1	Washer, Flat
NAS 1101 C8-4	1	Screw
69522C12-11	1	Pin, Headless
SVSK 69544-65	1	Housing, Shut-Off Actuator, IEVA
SVSK 69544-62	1	Screw, Actuator, IEVA
SV 585395-3	1	Plunger, Ball
SVSK 69544-66	1	Handle, Shut-Off Actuator, IEVA

ACTUATOR, TCV

Part Number	No. Required	Part Name
SVSK 69544-61	1	Actuator, TCV, IEVA
69522C12-11	1	Pin, headless
SVSK 69544-59	1	Housing, TCV Actuator, IEVA
SVSK 69544-58	1	Flex Cable, TCV, IEVA
----	1	Hose Clamp, 0.250 diameter
AN 960PD8L	1	Washer, flat
NAS 1101 C8-4	1	Screw
SVSK 69544-62	1	Screw, Actuator, IEVA
SV 585395-3	1	Plunger, Ball
SVSK 69544-60	1	Handle, TCV Actuator, IEVA

WAIST RING AND PANTS ASSEMBLY
(SVSK 69544-114)

Part Number	No. Required	Part Name
SVSK 69544-109	1	Ring, Waist
SVSK 69544-113	1	Ring, Retaining
SVSK 69544-110	1	Manifold, Ventilating System
SVSK 69544-108	6	Rod End, Restraining Cord
SVSK 69544-107	6	Swivel, Rod End
SVSK 69544-106	6	Bracket, Restraint Cord
MS20613-5C9	6	Rivet
SVSK 69544-112	12	Spacer, Rod End
SVSK 69544-111	1	Seal, Ventilating System
	1	Transition, Pants
Make from SV 721600	1	Legs
Make from SV 721645	2	Venting System, Legs
NAS 1102C06-6	48	Screw
NAS 1102C06-4	12	Screw

RESERVOIR WATER

Part Number	No. Required	Part Name
SVSK 69544-5-0-35	2	Boss
SVSK 69544-5-0-36	1	Rib
SVSK 69544-5-0-37	2	Rib
SVSK 69544-5-0-38	1	Boss
SVSK 69544-5-0-39	1	Rib
SVSK 69544-5-0-40	1	Boss
SVSK 69544-5-0-41	1	Rib
SVSK 69544-5-0-42	1	Rib
SVSK 69544-5-0-43	1	Wall, Reservoir Bottom
SVSK 69544-5-0-44	1	Reservoir Outer Wall (Lower)
SVSK 69544-5-0-45	2	Strip
SVSK 69544-5-0-46	1	Block, Fitting
SVSK 69544-18	24	Screw, Enclosure, IEVA
SVSK 69544-20	1	Back Enclosure
NAS 1622C-1	2	Screw
M13700-82	24	Miniature Anchor Nut - Two LUG.
MS 20426-B3-4	48	Rivet
SVSK 69544-21-2	2	Insert, Special IEVA
SVSK 69544-5-0-47	2	Boss
SVSK 69544-5-0-48	1	Boss
SVSK 69544-5-0-49	1	Housing
SVSK 69544-5-0-50	1	Plate
SVSK 69544-5-0-51	1	Washer
SVSK 69544-5-6	1	Bearing Assembly, IEVA
SVSK 69544-5-6-1	1	Housing
SVSK 69544-5-6-2	1	Bearing

UPPER TORSO ASSEMBLY
(SVSK 69544-1)

Part Number	No. Required	Part Name
SVL-11323	1	Helmet Assembly
SVSK 69544-1-2	1	Ring Assembly, Neck, IEVA
SV 721646-1-1	1	Guard, Spring
SV 721643-1-1	1	Spacer, Spring
SV 721642-1-1	1	Spring, Act.
SV 721648-1-1	1	Spring, Locking
SV 721626-1-1	1	HSG, Plunger
SV 730075-1-1	1	Support, Latch
SV 721631-1-1	1	Plunger and Catch Helmet
SVSK 69544-1-1	1	Ring and Inserts, Neck, IEVA
SV 721563	1	Duct, Inlet
MS 20326-DD2-4	2	Rivet, CSK
SV 721622-1-1	1	Ring, Latching
SV 721627-1-1	1	Pin, Shoulder
SV 721633-1-1	3	Pin, straight headless
SV 721623-1-1	1	Seal, Static
AN 960 C4L	2	Washer Flat
STSV 062-04-2	2	Bolt
MS 24585-C241	1	Spring, Comp.
AN 505 C6-6	2	Screw, Mach
SVSK 69544-1-8	1	Ring, Upper Torso (Inner), IEVA
SVSK 69544-1-7	1	Upper Torso, IEVA
SVSK 69544-1-7-1	1	Upper Torso
SVSK 69544-1-7-2	2	Ring
SVSK 69544-1-7-3	4	Pin
SVSK 69544-1-7-4	4	Spring
SVSK 69544-1-7-5	4	Washer
SVSK 69544-1-7-6	4	Cloth
SVSK 69544-1-7-7	8	Pile
SVSK 69544-1-7-8	As Required	Thread
SVSK 69544-1-7-9	8	Hook
SVSK 69544-1-7-10	2	Seal, Lip
SVSK 69544-30	1	Duct
SVSK 69544-27	1	Fitting
SVSK 69544-25	1	Seal
SVSK 69544-28	1	Fitting
SVSK 69544-24	1	Seal
SVSK 69544-29	4	Tab.
SVSK 69544-26	1	Guide

TUBE, PRIMARY O_2 TO REGULATOR

Part Number	No. Required	Part Name
SVSK 69544-55	1	Tube, primary O_2 to regulator, IEVA
SVSK 69544-55-1	1	Tube
SVSK 69544-46	2	Nut, high pressure
SVSK 69544-47	2	Fitting, high pressure

O_2 CONN., LiOH CANISTER

Part Number	No. Required	Part Name
SVSK 69544-32	1	O_2 Conn., LiOH Canister, IEVA
NAS 1102 C6-6	4	Screw Flat HD
SVSK 69544-32-00-2	1	Seal, Lip
SVSK 69544-32-00-2	1	End Cap
69483DO7OD1364	1	Packing, preformed
SVSK 69544-32-00-1	1	Poppet
SVSK 69544-32-00-5	1	Spring
SVSK 69544-32-00-3	1	Housing

FAN MOTOR ASSEMBLY

Part Number	No. Required	Part Name
69522-4C8	2	Pin, straight
SV 707979	As Required	Shim
69490B152	2	Packing, preformed
SVSK 69544-7-1	1	Fan Volute, machined, IEVA
AN 960 PD10L	6	Washer
AN 501 D10-7	6	Screw
SVSK 69544-7-2	1	Fan and Motor, IEVA
SV 594857	1	Nut
SV 594353	1	Bushing
SV 594862	1	Rotor
SVSK 69544-7-3	1	IEVA Fan Motor

H_2O SHUT-OFF AND RELIEF VALVE

Part Number	No. Required	Part Name
SVSK 69544-6	1	H_2O Shut-Off and Relief Valve
NAS 1101 C06-6	3	Screw
NAS 620 C6L	3	Washer
MS 21043-06	1	Nut
SVSK 69544-6-8	1	Adaptor, Fitting
69494P7	2	Packing, preformed
SV 730308	1	Poppet
SV 585350V86	As Required	Shim
SVSK 69544-6-7	1	Spring, Shut-Off and Relief Valve
69494P11	1	Packing, preformed
69494R113	4	Packing, preformed
SVSK 69544-6-11	1	Washer, Non-Metallic
SV 713511	As Required	Shim
SVSK 69544-6-6	1	Handle
NAS 620 C10L	1	Washer
NAS 1101 C-3-5	1	Screw
SVSK 69544-6-2	1	Cover
SVSK 69544-6-3	1	Fitting
SVSK 69544-6-4	1	Nut
69494N15	1	Packing, preformed
SV 717460	1	Visco Jet
69494N17	1	Packing, preformed
SVSK 69544-6-5	1	Adaptor, Visco Jet
SVSK 69544-6-1	1	Housing and Shaft, set
SVSK 69544-6-9	1	Shaft
SVSK 69544-6-10	1	Housing

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13. ABSTRACT

Continued success in coping with the space environment has led to increased crewman confidence in his ability to perform useful work during extraterrestrial missions. Future missions will require advanced suit/life-support-system concepts. Such a concept might logically take the form of a space suit for extravehicular activity with an integrated environmental control system. A design sutdy of this concept has been performed and drawings prepared in sufficient detail to permit fabrication of a working model in a suitably equipped model shop. Integration of the environmental control system within the hard torso of the suit assembly resulted in a system having a packaging density approaching 80 percent and able to pass through a 27 inch diameter hatch. The system will support a crewman working at 375 Kcal/hour for an indefinite time to a recharge in space capability. Additionally, the technology utilized to produce this system was entirely within the state-of-the-art. The calculated system reliability is 0.99947.

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Pressure Suits						
Altitude Suits						
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Maneuvering System (Integrated)						