REPORT NO.
TOR-469(5527-39)-1

Pressure Suit and Extravehicular Performance Data for MOL

FEBRUARY 1965

Prepared by

SPECIAL STUDIES DIRECTORATE
Manned Orbiting Laboratory System
Manned Systems Division

Prepared for **COMMANDER SPACE SYSTEMS DIVISION**
AIR FORCE SYSTEMS COMMAND
LOS ANGELES AIR FORCE STATION
Los Angeles, California

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The information in a Technical Operation Report is developed for a particular program and is therefore not necessarily of broader technical applicability.

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PART I

PRESSURE SUIT DATA

1.0 INTRODUCTION

1.1 Purpose

The characteristics and performance information, derived from a number of pressure suit tests and specifications, are presented herein to assist in the design of extravehicular operations. Assembly, alignment, and servicing of large structures is a primary objective of the MOL program, and MOL suit development should support this objective to a maximum extent.

1.2 Scope

Since extended duration operations with minimum restraint during extravehicular assembly are desired, the requirements for the MOL extravehicular suit are similar in many respects to the requirements of the Apollo suit. Therefore, the Apollo suit technology (viz, that represented by the A-5H prototype garment) embodies many characteristics desirable in the MOL extravehicular suit. Water cooling may be required to reduce body water losses from perspiration during high metabolic energy expenditures. Performance data on the A-5H type suit was not available for inclusion in this document; thus, design and performance data from numerous pressure suit tests, including G-4C suit specification data, is presented. This data is intended for use as a guide and, in general, it can be expected that the MOL suit will provide improved mobility and dexterity.

The MOL mission profile imposes two extremes on suit design and development: (1) The first requirement is for a flight suit to be worn in the Gemini B capsule during launch and re-entry. This suit must be compatible with the flight operations and ejection seat, and with the MOL tunnels and hatches; the environment and lower torso mobility is less stringent than for the extravehicular mission. (2) The second requirement is for EVA, where environmental and task design constraints challenge the current suit state-of-the-art.

Two suits may be necessary to provide maximum crew performance for the flight (G-4C type) and extravehicular modes (A-5H type); however, every effort will be made to integrate both requirements into a one-suit concept without degradation of suited-operator performance.

I. 3 Criteria

The MOL space suit (or suits) will be designed to withstand launch, on-orbit, and re-entry environments as defined in the MOL General System Specification and associated Work Statement.

2.0 PERFORMANCE AND DESIGN DATA

2.1 Motion Limitations

2.1.1 Neutral Position

The suit neutral positions cannot be determined until the suit has been fabricated; however, the NASA G-2C suit neutral position may be used as an approximation. Details may be obtained from David Clark Company Drawing No. S-964.

2.1.2 Motion Limits

The gross motions necessary for transfer, locomotion, and soaring tasks require 30 to 60 percent more time for the suited condition than for the unsuited condition. Normally, however, most non-emergency extravehicular tasks will be performed slowly to reduce overcontrol, overheating, tumbling, and entanglement problems. Except for emergency retrieval functions, better indices of adequate performance will be force, contact, displacement, and kinetic criteria.

Suited motions can be performed by the in-orbit crewman that cannot be performed in the suited condition on earth (e.g., the crewman can transfer from the Gemini B to the laboratory vehicle with arm motions only).

2.1.3 Mobility

Figure I-1 depicts body contacts for the egress motion; typically, upper torso contacts are more frequent and positive, and lower contacts are generally the result of aimless, flailing limbs.

Previous evaluations of the X-20, AP-22s-2, Gemini, and Apollo suits have included single measures of arm reach, arm grasp, manipulation times, and finger dexterity tests of the seated operator. A series of time, kinetic, and kinematic tests to systematically assess the operator's total motion capability will be conducted on the MOL suit when available.

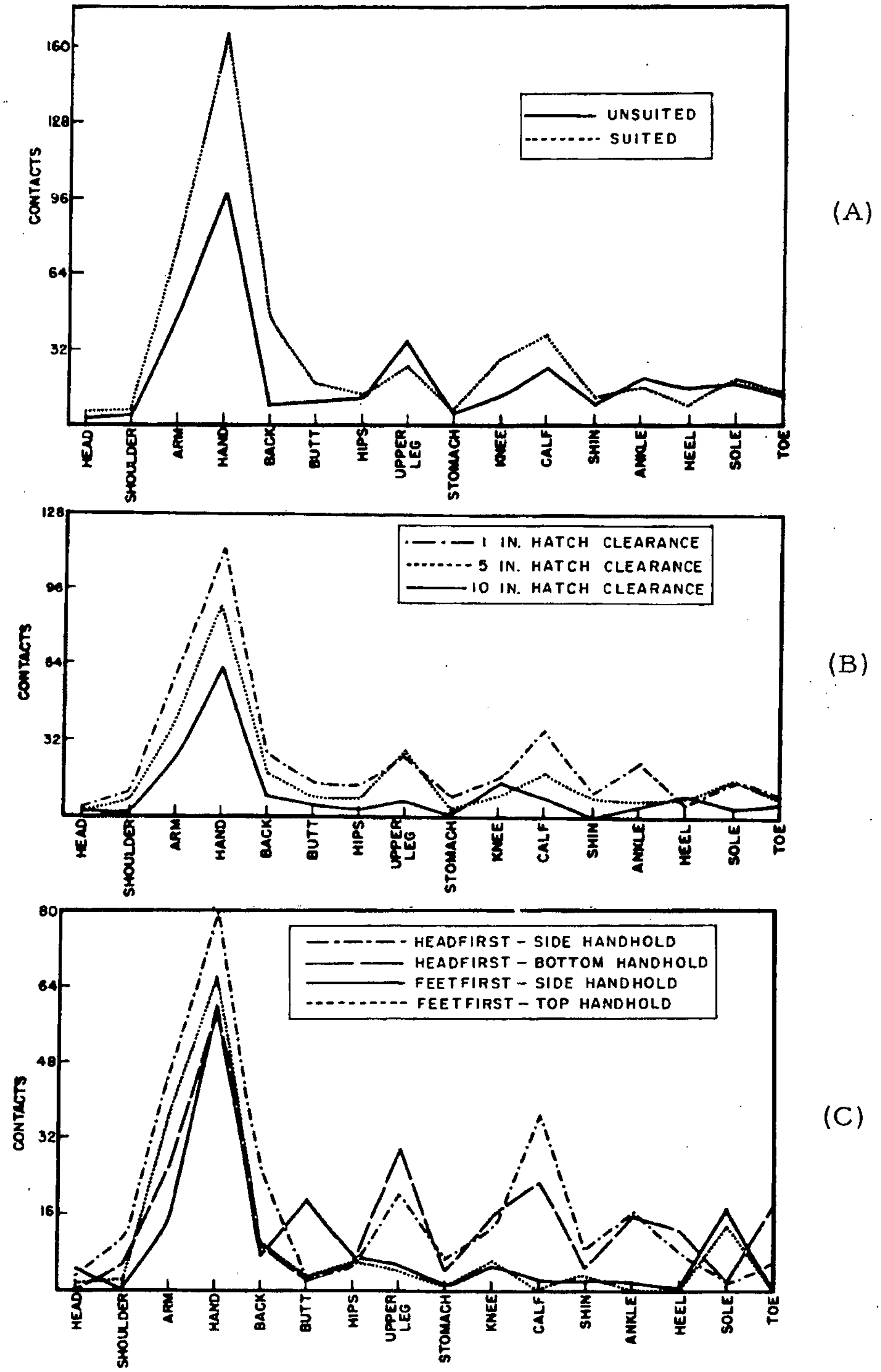

Figure I-1. Total Number of Contacts for Each Body Segment for Suit: (A) Body Clearance; (B) Egress Configuration; and (C) Conditions

2.1.4 Arm Mobility

Figures I-2 and I-3 relate the effect of control location on response time of the left hand for the unsuited subject. Such baseline data is available for comparative studies of suited subjects. The 6570th AMRL has conducted such analyses of the Gemini and Apollo suits and presented the data as suited decrements by zone area. For example, the 5 percent line in Figure I-3 indicates the locations in space wherein the unsuited subject suffers a 5 percent reduction decrement in performance (reaction + reach + manipulation time) with the left hand pushing push-buttons.

Figure I-4 illustrates that reach tests have yielded total decrements of up to 62.6 percent for the X-20 suit (1st figure) and 6 percent between inflation levels of the AP-22s-2 suit (2nd figure); however, such measurements must be carefully related to the test situation.

A crewman's reach capability while wearing the Gemini 3C suit is shown in Table I-1. The X-20 suit functional arm-reach test results are shown in Table I-2.

Table I-1. Reach Capability Wearing G-3C Full Pressure Suit
(One Subject)

Volumes of Reach Envelope	
Shirtsleeve	23.4 cu ft (approximately 15th percentile)
Gemini suit - vented	18.0 cu ft (reduction of 23 percent)
Gemini suit - pressurized (3.5 psi)	7.2 cu ft (reduction of 69 percent)
Subject's Stature	5th percentile
Subject's Weight	50th percentile

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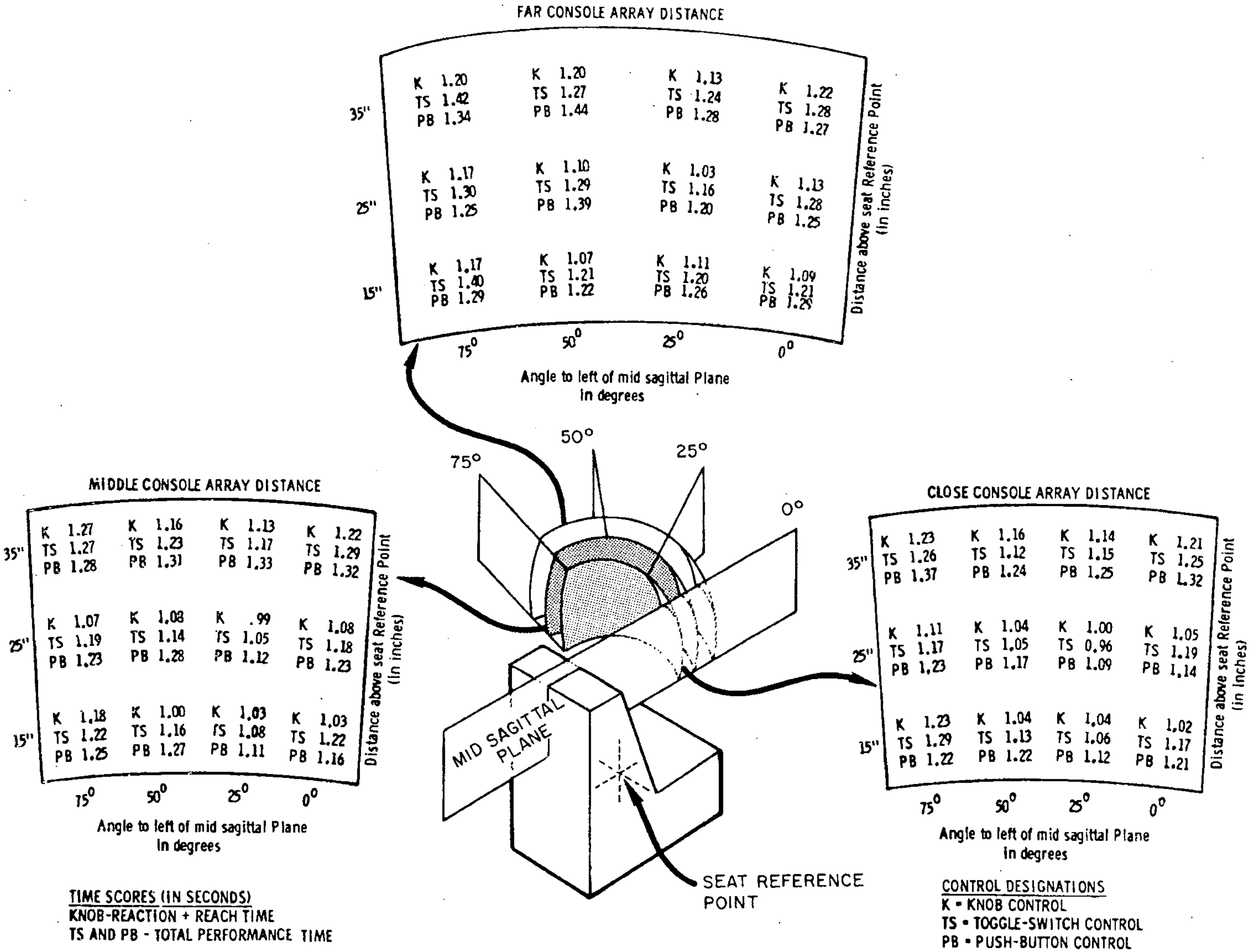


FAR CONSOLE ARRAY DISTANCE

Distance above seat Reference Point (in inches)	75°	50°	25°	0°
35"	K 1.20 TS 1.42 PB 1.34	K 1.20 TS 1.27 PB 1.44	K 1.13 TS 1.24 PB 1.28	K 1.22 TS 1.28 PB 1.27
25"	K 1.17 TS 1.30 PB 1.25	K 1.10 TS 1.29 PB 1.39	K 1.03 TS 1.16 PB 1.20	K 1.13 TS 1.28 PB 1.25
15"	K 1.17 TS 1.40 PB 1.29	K 1.07 TS 1.21 PB 1.22	K 1.11 TS 1.20 PB 1.26	K 1.09 TS 1.21 PB 1.25

Angle to left of mid sagittal Plane in degrees

MIDDLE CONSOLE ARRAY DISTANCE

Distance above seat Reference Point (in inches)	75°	50°	25°	0°
35"	K 1.27 TS 1.27 PB 1.28	K 1.16 TS 1.23 PB 1.31	K 1.13 TS 1.17 PB 1.33	K 1.22 TS 1.29 PB 1.32
25"	K 1.07 TS 1.19 PB 1.23	K 1.08 TS 1.14 PB 1.28	K .99 TS 1.05 PB 1.12	K 1.08 TS 1.18 PB 1.23
15"	K 1.18 TS 1.22 PB 1.25	K 1.00 TS 1.16 PB 1.27	K 1.03 TS 1.08 PB 1.11	K 1.03 TS 1.22 PB 1.16

Angle to left of mid sagittal Plane in degrees

CLOSE CONSOLE ARRAY DISTANCE

Distance above seat Reference Point (in inches)	75°	50°	25°	0°
35"	K 1.23 TS 1.26 PB 1.37	K 1.16 TS 1.12 PB 1.24	K 1.14 TS 1.15 PB 1.25	K 1.21 TS 1.25 PB 1.32
25"	K 1.11 TS 1.17 PB 1.23	K 1.04 TS 1.05 PB 1.17	K 1.00 TS 0.96 PB 1.09	K 1.05 TS 1.19 PB 1.14
15"	K 1.23 TS 1.29 PB 1.22	K 1.04 TS 1.13 PB 1.22	K 1.04 TS 1.06 PB 1.12	K 1.02 TS 1.17 PB 1.21

Angle to left of mid sagittal Plane in degrees

TIME SCORES (IN SECONDS)
KNOB-REACTION + REACH TIME
TS AND PB - TOTAL PERFORMANCE TIME

CONTROL DESIGNATIONS
K • KNOB CONTROL
TS • TOGGLE-SWITCH CONTROL
PB • PUSH-BUTTON CONTROL

Figure I-2. Spatial Configuration of Console Array Distances with Average Performance Scores for Each Location

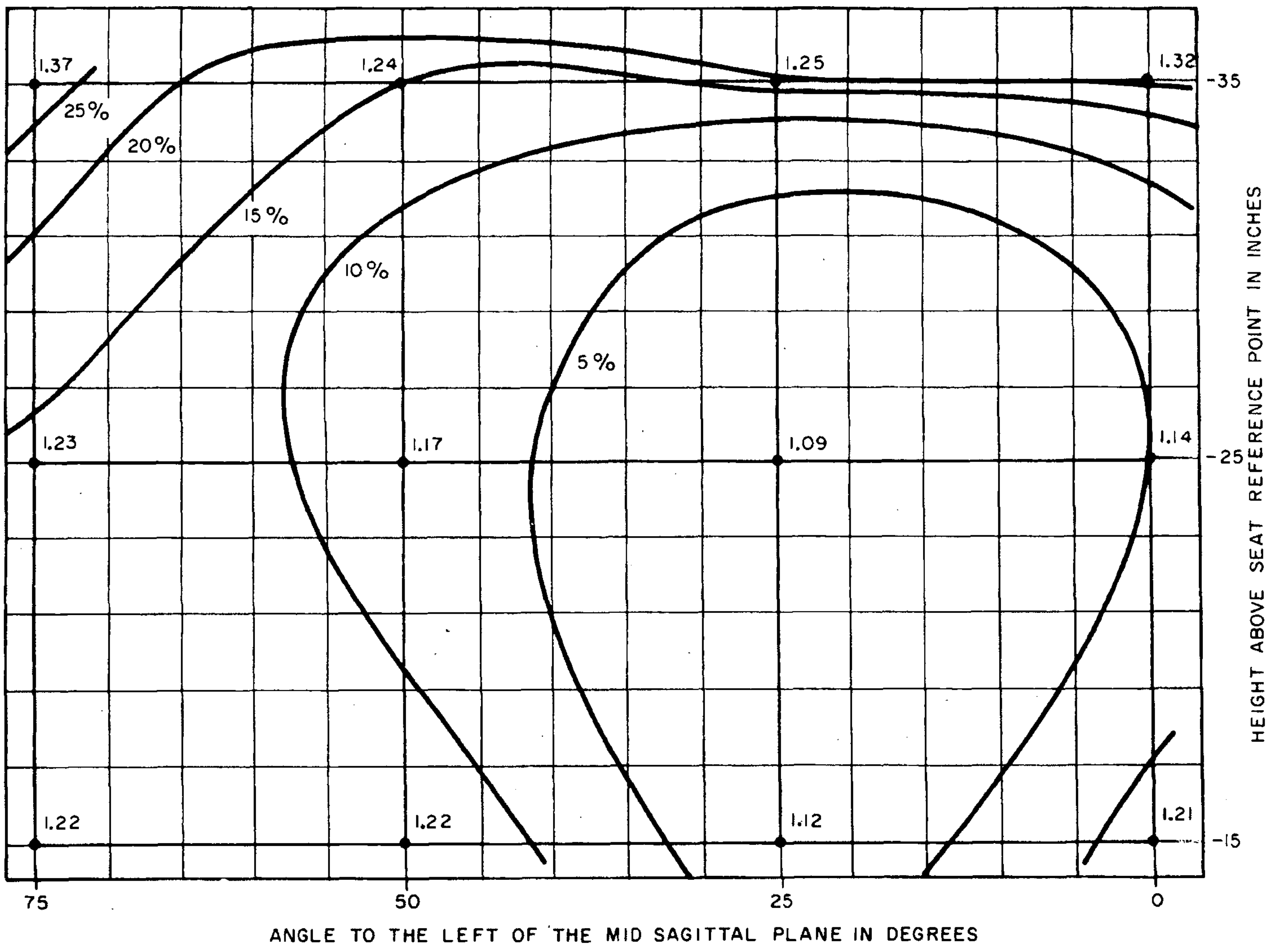
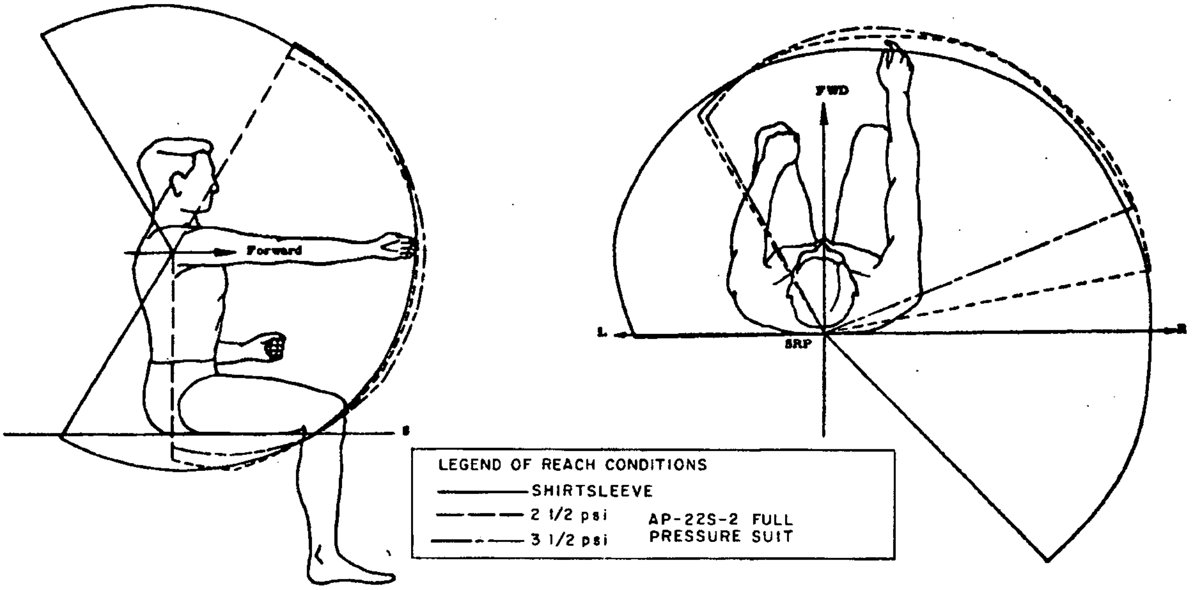


Figure I-3. Total Performance Time for the Push Button
(% Decrement in Performance vs Control Location)



VERTICAL SAGITTAL PLANE THROUGH THE ARM REACH ENVELOPES AT A POINT CORRESPONDING TO THE RIGHT SHOULDER

HORIZONTAL PLANE THROUGH THE ARM REACH ENVELOPES AT 35 INCHES ABOVE THE SEAT REFERENCE POINT

Figure I-4. AP-22s-2 Arm Reach Envelope

Table I-2. Functional Arm-Reach Test - X-20 Full Pressure Suit (Three Subjects)

	Shirtsleeves	Suited - Unpressurized	Suited - Pressurized (5 psi)
Volume			
Grasping Reach Envelope	31.94 cu ft	23.59 cu ft	11.95 cu ft
Percent Decrement from Shirtsleeves	---	26.2 percent	62.6 percent
Radius of Sphere of Equal Volume	23.61 in.	21.32 in.	17.05 in.
Percent Decrement from Shirtsleeves	---	9.7 percent	27.8 percent

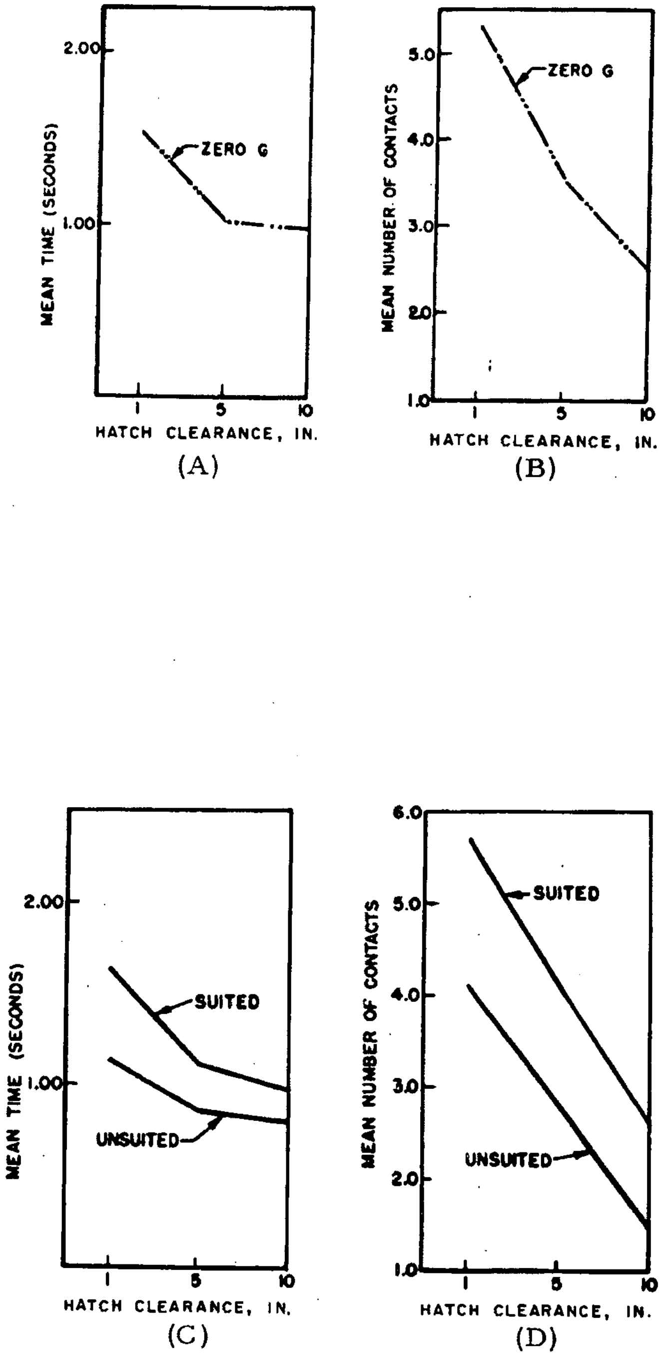
2.1.5 Egress Motion

During zero-gravity, egress time is inversely related to hatch size. One inch of shoulder clearance requires 55 percent more time for egress than 10 inches of shoulder clearance; five inches of clearance requires 11 percent more time than 10 inches. The curve appears to approach an asymptote between five and 10 inches of clearance. The only aborted trials (subject stuck in the hatch) occurred with a one-inch shoulder clearance.

The USAF AP-22s-2 high pressure suit inflated to 2.5 psi was used for the series of tests described in Figure I-5.

Figures I-5(A) and (C) indicate that the largest time improvement appears to be within the one- to five-inch clearance range, whereas contacts [Figures I-5(B) and (D)] appear to decrease linearly within the one- to 10-inch clearance range.

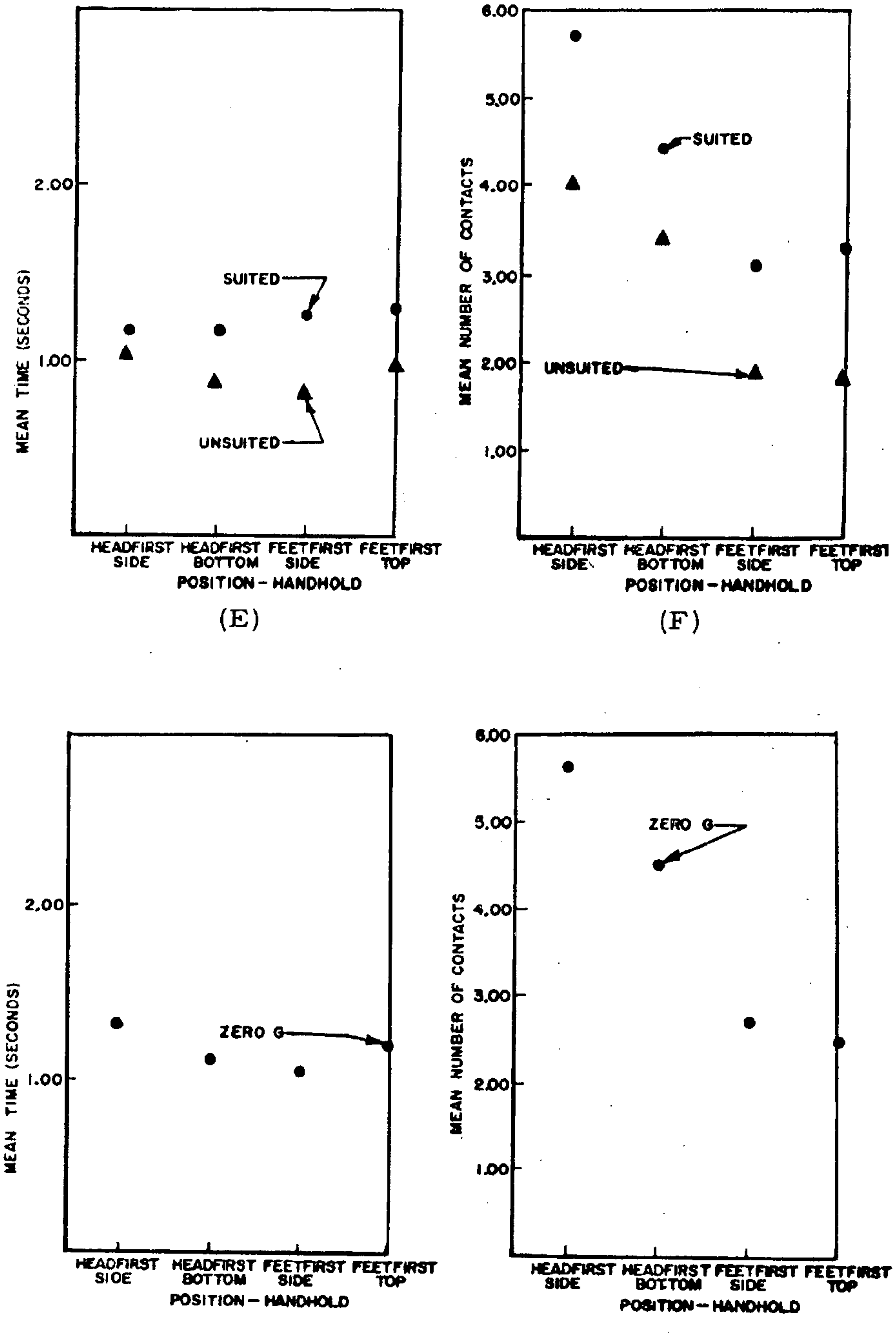
Figures I-5(F) and (H) indicate that the feetfirst techniques yield the smoothest egress, probably due to the suited subject's ability to see his legs in



(A) (B)

(C) (D)

Figure I-5. Egress Motion



(E) (F)

(G) (H)

Figure I-5. Egress Motion (continued)

relationship to the hatch, and thus better position his lower torso. Suited subjects often reported that they "did not know where their legs were", apparently due to poor kinesthetic feedback because of the lack of forces on the pressure receptors while suited under pressure and sailing over, rather than walking on, the floor. Accuracy of motion, rather than time of motion, appears to be a more sensitive measure of operator performance for the egress motion.

2.1.6 Hand Dexterity

The Purdue Pegboard Dexterity Test has been used to estimate the effects of vented and pressurized gloves on finger dexterity; the results in performance decrements are shown in Tables I-3 and I-4.

Table I-3. Dexterity Test Summary and Percentage (n = 17) - AP-22s-2 Suit

Conditions	Right Hand	Left Hand	Both Hands	Assembly
Barehanded	100%	100%	100%	100%
Gloved, no pressure	65%	63%	52%	43%
Gloved, 2.5 psi	35%	35%	21%	20%

Table I-4. Hand Dexterity - X20A Suit - Mean Percentile Totals

Condition	Right Hand	Left Hand	Both Hands	Assembly
Barehanded	100%	100%	100%	100%
Gloved, vent	68%	67%	61%	57%
Gloved, 2.5 psi	49%	40%	36%	38%

2.1.7 Ballooning Measurements

Selected anthropometrics have been made with the Gemini 2C suit inflated while in both a standing and a sitting position. The resulting measurements are shown in Tables I-5 and I-6.

Table I-5. Gemini Full Pressure Suit Pressure Growth Increments - Standing

Dimensions*	Uninflated	Vent 13 in. Hg	0.5 psi	1.5 psi	2.5 psi	3.5 psi	Total Inflation Growth
Axillary Chest Circumference	39.0	42.8	43.2	44.5	44.8	45.5	+6.5
Measured Waist Circumference	35.9	40.1	40.5	41.5	41.9	42.4	+6.5
Axillary Arm Circumference	12.7	12.8	13.0	14.4	14.8	14.7	+2.0
Measured Forearm Circumference	12.2	12.6	12.7	12.8	13.1	13.5	+1.3
Measured Thigh Circumference	16.8	16.7	17.0	18.3	18.3	18.9	+2.1
Measured Calf Circumference	14.8	16.0	16.3	18.3	18.6	18.5	+3.7
Measured Shoulder Breadth	19.4	20.4	21.3	21.8	22.1	22.3	+2.9
Elbow-to-Elbow (Pressed)	18.5	19.85	20.4	21.55	22.45	22.45	+3.95
Hip Circumference	38.9	40.9	41.4	42.1	42.7	42.8	+3.9

Table I-6. Gemini Full Pressure Suit Pressure Growth Increments - Seated

Dimensions*	Uninflated	Vent 13 in. Hg	0.5 psi	1.5 psi	2.5 psi	3.5 psi	Total Inflation Growth
Axillary Chest Circumference	38.40	43.20	44.00	44.50	45.00	45.20	+6.80
Measured Waist Circumference	37.30	41.50	42.20	42.70	43.30	43.30	+6.00
Axillary Arm Circumference	12.60	13.50	13.70	14.60	14.70	14.50	+1.90
Measured Forearm Circumference	12.20	12.50	13.00	13.30	13.30	13.50	+1.30
Measured Thigh Circumference	17.50	18.00	17.90	18.40	18.40	18.50	+1.00
Measured Calf Circumference	16.00	17.15	17.80	18.20	18.20	18.20	+2.20
Measured Shoulder Breadth	19.70	21.2	21.20	22.00	22.10	22.25	+2.55
Elbow-to-Elbow (Pressed)	18.60	19.3	19.70	21.30	21.45	23.15	+4.55
Measured Hip Breadth	15.15	13.25	14.30	14.50	14.65	14.85	+1.70
Posterior Plane of Back-to-Anterior Knee Area	24.85	25.95	27.85	28.65	29.30	29.75	+4.90
Thigh Clearance from Floor	23.50	23.55	23.75	24.55	24.70	25.00	+1.50
Sitting Height	36.00	36.00	36.40	36.95	37.05	37.00	+1.00
Arm Reach from Wall	33.85	33.55	34.65	33.25	32.05	31.15	-2.70
Hand Length	8.40	8.40	8.40	8.50	8.55	8.75	+0.35
Finger Tip to Glove Tip	0.00	0.00	0.50	0.55	0.70	0.70	+0.70

*All measurements in inches.

2.2 Visor Data

The effect of rapid alterations of high and low illumination levels and the effects of viewing a direct working area within a bright surrounding will have a critical influence on extravehicular performance. AMRL is currently investigating this problem; the results of the investigation will be included in this section at a later date.

2.2.1 Clear Visor Properties

Normally, the refractive power of the visor in any meridian should not exceed by more than ±0.06 diopters the power inherent in a spherical lens with concentric surfaces having the proper radii of curvature and thickness. The inherent power of the visor is calculated by use of the following formulae:

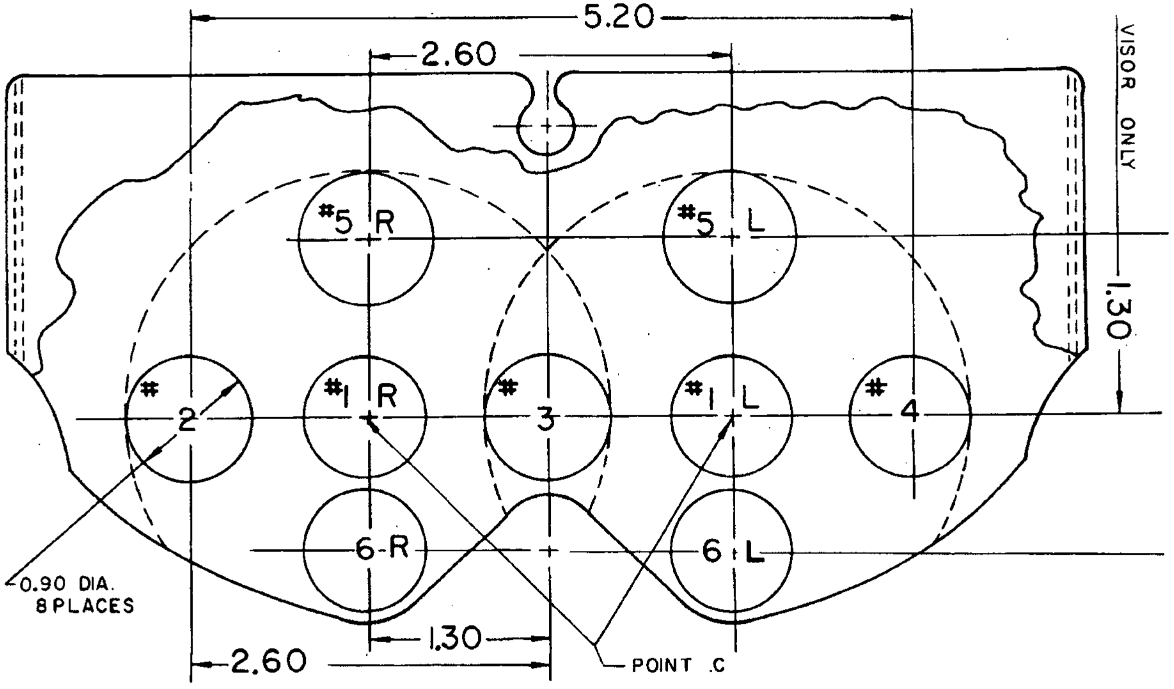
$$F = F_1 + F_2 - \frac{t}{n} \quad , \quad F_1 F_2 \quad ; \quad F_1 = \frac{n' - n}{r_1} \quad ; \quad F_2 = \frac{n - n'}{r_2}$$

where

F = Power of the lens in diopters
F_1 = Power of the convex surface in diopters
F_2 = Power of the concave surface in diopters
n = Index of refraction of air
n' = Index of refraction of the material
r_1 = Radius of first or convex surface
r_2 = Radius of second or concave surface
t = Thickness in meters.

Figure I-6 illustrates probable optical properties for the visor.

The vertical prismatic deviation between point "C" for the right eye and point "C" for the left eye should not be more than 0.18 diopters nor shall the vertical prism at any point in the critical area of vision exceed 0.18 diopters. The algebraic sum of the horizontal prismatic deviation at point "C" for the



Critical areas are located within the dotted circles. Noncritical areas are located outside dotted circles. Numbered circles within the critical areas are designated as points of choice for prismatic and distortion tests. Points bearing the same number, for example, 5R and 5L, shall be compared with each other, except that point No. 2 shall be compared with point No. 3 and point No. 3 shall be compared with point No. 4 when measuring refractive power or prismatic deviations. This figure is intended to serve only as a guide since visor configurations differ.

Figure I-6. Visor Critical and Non-Critical Optical Areas right eye shall not exceed 0.75 diopters. The algebraic differences between the horizontal deviation at point "C" for the left eye and at point "C" for the right eye shall not exceed 0.18 diopters. The luminous transmittance should not be less than 90 percent throughout the critical area. The non-critical area should not vary in transmittance by more than ±2 percent of the critical area transmittance. No visible distortion or optical defects detectable by the "unaided eye" (20/20) at the typical "as worn" position shall be visible. The haze value of the visor should not exceed 5 percent.

The spectral transmittance may vary with wavelengths between 380 and 770 μ; the average percentage deviation within nine spectral bands should be less than 12 (see Table I-7). The spectral distribution curve should show a reasonably even distribution throughout the visible spectrum to insure that color distortion will not be excessive.

The transmission of ultraviolet radiation in the range of 220 to 320 μ should be such that the total energy incident on the cornea and facial skin shall not exceed 1.0×10^5 ergs cm^{-2} in any 24-hour period. In computing the total energy transmission:

(a) The maximum expected flux in the earth orbital environment, including reflected ultraviolet, should be determined for each of 10 spectral bands, each band being 10 μ wide, between 220 and 320 μ.

(b) The percentage transmittance of ultraviolet light in each of the 10 spectral bands (10 μ width) between 220 and 320 μ shall be determined for Visor 1 by spectophotometry.

(c) The following weighting factors are normally used for each 10 μ band:

220 - 230 μ	0.10
230 - 240 μ	0.15
240 - 250 μ	0.20
250 - 260 μ	0.25
260 - 270 μ	0.30

Table I-7. Example for Calculation of Spectral Transmittance Deviations

Wave-length (μ)	T	Band n	Wave-length Range	Average Trans-mittance Tn	Percent Deviation 100(1-Tn/Tc)	Weight	Product
430	0.114						
440	0.118						
450	0.127						
460	0.137	1	430-490	0.133	14	5	70
470	0.142						
480	0.144						
490	0.145	2	460-520	0.145	7	10	70
500	0.147						
510	0.149						
520	0.151	3	490-550	0.151	3	10	30
530	0.153						
540	0.154						
550	0.155	4	520-580	0.155	0	10	0
560	0.157						
570	0.158						
580	0.159	5	550-610	0.159	2	10	20
590	0.160						
600	0.160						
610	0.160	6	580-640	0.160	2	10	30
620	0.161						
630	0.161						
640	0.160	7	610-670	0.160	3	10	30
650	0.159						
660	0.159						
670	0.158	8	640-700	0.158	2	5	10
680	0.157						
690	0.156						
700	0.153	9	670-730	0.153	1	1	1
710	0.151						
720	0.149				Totals	71	261
730	0.148						

NOTES:

a. Spectral transmittance, Tc = 0.155.

b. T = Transmittance at 10 μ intervals.

c. Tn = Average transmittance of 60 μ band.

d. The average transmittance, Tn, for a given band is the average of the seven tabulated values within that band, except that the first and last values are divided by 2, and the average computed by dividing the sum of the values by 6.

e. Average percentage deviation of spectral transmittance within nine spectral bands = 261/71 = 3/7 percent.

f. This table is based on illuminant "C".

270 - 280 μ	0.35
280 - 290 μ	0.90
290 - 300 μ	0.50
300 - 310 μ	0.15
310 - 320 μ	0.10

These factors represent differential sensitivity of the cornea within the ultraviolet range.

(d) The flux is multiplied by the transmittance and by the weighting factor for each 10 μ band. The resulting corrected transmitted fluxes for each 10 μ band shall be summed, and the sum multiplied by the maximum time of exposure. The resulting energy absorption shall not exceed 1.0×10^5 ergs cm^{-2}, in any one 24-hour period.

The transmittance of infrared radiation between 770 and 2500 μ can be as low as possible and not exceed a total value of 30 ±5 percent. The transmittance of infrared radiation between 2.5 and 100 μ should not exceed 10 ±5 percent.

2.2.2 Antiglare Visor

SAM(USAF) plans to study the NASA/Gemini double-filter concept which uses an additional gray and opaque visor, as well as other USAF in-house filters before recommending a final filter system. The essential problem seems to be the effects of simultaneous and successive contrast on adaptation as the worker or vehicle moves between unidirectionally illuminated areas to dark areas. The SAM plan will include visor testing and crew training with full-scale mockups illuminated in darkened chambers.

2.2.3 Visor Quality Assurance

After the visors have been subjected to flight qualification testing, neither the spectral (380 - 770 μ) nor the ultraviolet transmittance should change by more than 20 percent. The flight qualification testing program may include exposure of the visors to a spectrum simulating as closely as possible that of the combination of the solar flux in the free space environment plus the reflected flux from the earth's atmosphere. Any metallic film should not be dislodged or affected in any way when subjected to the adhesion of metallic film test. No major damage should be visible in any portion of the rubbed area of a coated surface which has been subjected to the abrasion resistance test. The critical and non-critical areas of the visors should be free of visible striae, waviness, cloudiness, and imperfections such as pits, bubbles, scratches, and foreign particles. The visors should have smooth, rounded edges and be free from cracks, check marks, or any defects which might affect appearance or functionability. The visors will be sampled for:

(a) Erythemal ultraviolet transmittance (220 - 320 μ)
(b) Spectral transmittance
(c) Transmittance (380 - 770 μ) after accelerated weathering.
  (1) All transmittance tests before flight qualification testing.
  (2) All transmittance tests after flight qualification testing.

2.2.4 Helmet Angular Visibility

Visual angles have been measured with the eyes and head fixed; eyes moving, head fixed; eyes and head moving; and show the decrements presented in Table I-8:

Table I-8. X-20 Full Pressure Suit Field of Vision Test

Motion	Fields	Eyes, Head Fixed R-Eye	Eyes, Head Fixed L-Eye	Eyes Moving Head Fixed	Eyes, Head Moving
Horizontal	Right	85	55	93	102
Horizontal	Left	52	77	80	100
Vertical	Up	45	47	50	50
Vertical	Down	50	50	--	70

Due to the similarity between the X-20 Dyna-Soar helmet and the MOL helmet, the data in Table I-8 may be used as a guide to total visual degradation until actual data is available.

2.3 Suit Dimensions

Dimensions of the inflated suit will be determined after delivery of the first prototype MOL suit. Until this data is available, Drawing No. S-964 of the G-2C suit, prepared by the David Clark Co., and obtainable through the AFSPO, may be used as a guide.

2.4 Environmental Data

The environmental data shown in tabular form in this section represents information abstracted from the NASA G-4C Work Statement, Revision 1, dated 12 June 1964. Data contained herein will be modified as changes are implemented or as test results become available. The suit assembly will be designed to perform in the applicable conditions specified in Table I-9.

Pressure	
Proof	8.0 psig (15 min duration)
Operating	3.7 ±0.2 psia for max duration of 5 hr
Relief Valves (2)	4.6 ±0.3 psig (with combined minimum total flow of 150 standard LPM)
Suit Pressure Indicator	Absolute type with scale range from 2 to 10 psia
Leakage (maximum allowable leak rate, standard temperature and pressure)	
Complete Suit Assembly	A. 200 cc/min, with

Combination		Max Time	
Internal Pressure	External Pressure	Hr	Min
3.7 psia	1.1×10^{-7} TORR	2	15
5.6 ± 0.4 psia	5.5 ± 0.4 psia	360	--

B. 200 cc/min for spacecraft preinstallation and ground tests. Pressurized to 3.7 psia and 0.15 psig.

Components (at 3.7 psia or 0.2 psig)		
	Gloves (each):	20 cc/min
	Helmet:	30 cc/min
	Torso:	130 cc/min

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RELEASE 1 JULY 2015

Table I-9. MOL Extravehicular Space Suit Environmental Design Requirements

Environment	Prelaunch	Launch	Orbit	Re-Entry	Postlanding	Ejection	Extravehicular
Ambient Pressure	14.7 to 15.5 psia	14.7 to 10^{-7} psia	5.1 to 10^{-7} psia	5.1 to 10^{-7} to 15.5 psia	15.5 psia	14.7 psia to 12.9 mm Hg	1.1 x 10^{-7} psia
Ambient Temperature	-15°F to $+110^\circ$F	$0^\circ$to 160°F	0° to 160°F	Curve I	-15° to $+160^\circ$ F	-69° to $+250^\circ$F Curve II	(N/A)
Suit Inlet Temperature	40° to 80° F	50° to 80° F	50° to 80° F	50° to 90° F	65° to 105° F	To be determined	40° F
Suit Inlet Flow	0 to 12 SCFM	7.25 SCFM	11.5 CFM @ 5 psia, 88°F	To be determined	7.25 SCFM	0.036 lb/min	5.0 CFM @ 3.5 psia
Suit Pressure	0-3.7 $\pm$0.2 psia	0.2 psig or 3.7 psia	0.2 psig or 3.7 psia	0.2 psig or 3.7 psia	0.2 psig	0.2 psig or 3.7 psia	3.7 psia
Spacecraft External Surface Temp.	(N/A)	(N/A)	-135° to $+250^\circ$ F	(N/A)	(N/A)	(N/A)	-135° to $+250^\circ$ F
Vibration	Protected (Shipping)	MAC Report 8610	(N/A)	MAC Report 8610	(N/A)	(N/A)	(N/A)
Shock	Protected (Shipping)	MAC Report 8610	(N/A)	MAC Report 8610	(N/A)	(N/A)	(N/A)
O_2 Exposure	0-100%	0-100%	0-100%	0-100%	(N/A)	0-100%	0-100%
Relative Humidity	0-100%	0-100%	0-100%	0-100%	15-100%	0-100%	0-100%
Acoustic Noise	Protected (Shipping)	MAC Report 8610	(N/A)	MAC Report 8610	(N/A)	(N/A)	To be determined
Acceleration	1g	MAC Report 8610	0	MAC Report 8610	1g	40g for 1 sec all axes	0
Dynamic Loading	(N/A)	(N/A)	(N/A)	(N/A)	(N/A)	820 lb/ft^2	(N/A)
Time Suit Pressurized to 3.7 $\pm$0.2 psia	5 hrs	8 min	4 hr @ $60-90^\circ$F 90 min @ 160°F	Curve I	(N/A)	15 min Curve II	2 hours 15 min
Time Suit Pressurized to 0.2 psig	100 hrs	10 min	360 hours	20 min	10 min @ $+160^\circ$F 36 hr @ -15°F to $+110^\circ$F	5 min @ $+250^\circ$F, 14.7 psia 10 min @ -69°F, 33.6 mm Hg Curve II	(N/A)
Total Time	4 Months	10 min	360 hours	20 min	36 hours	20 min	2 hours 15 min

Ventilation Distribution System		
Pressure Drop		
Suitably sized subject restrained in position in orbit	Pressure drop not to exceed 4.75 in. H_2O for the following conditions:	
	Inlet vent flow rate	11.5 ACFM
	Inlet vent gas	100% O_2
	Inlet temperature	55° F
	Inlet relative humidity	65 to 100%
	Ambient pressure	5.5 ±0.4 psia
	Suit outlet to ambient	0 to 1 in. H_2O
Through components	Evaporator (conditional)(Hex)	0.78 in. H_2O drop
	Ejector	13.55 in. H_2O rise
	Suit	9.86 in. H_2O drop
	Ducts, hoses, misc.	2.91 in. H_2O drop
Specified for	Weight flow (O_2) at suit inlet	23.8 lb/hr
	Spacecraft flow requirement	9.5 lb/hr
	Overboard dump	
	- O_2	9.3 lb/hr
	- CO_2	0.3 lb/hr
Helmet CO_2 Removal	Helmet vent system to provide adequate CO_2 removal for all mission conditions.	
	Normal	3.8 mm Hg
	Maximum	7.6 mm Hg
	Emergency	15 mm Hg
Mobility	Suit pressurized or unpressurized: Adequate mobility to perform required mission tasks, both normal and emergency.	
	Suit pressurized at 3.7 psi: Crewman will be capable of unassisted egress through spacecraft hatch opening at zero-g.	
Comfort	Comfortable (easily tolerated) for periods up to and including:	
	Unpressurized	14 days
	Pressurized	5 hr at 3.7 psia

Donning	From partial don condition Donning time (gloves and helmet) 3 min, total
Suit Assembly Life	
Assembly	Capable of being donned and doffed for 50 consecutive cycles without major overhaul or unsatisfactory performance.
Helmet Visor	Capable of 5000 cycles of operation without failure.
Helmet and Glove	Capable of being connected and disconnected for 500 cycles.
Ventilation Inlet-Outlet and Blood Pressure Fittings	Capable of being connected and disconnected for 500 cycles without failure.
Inflight Drinking Port	Capable of 500 probe insertions at 3.5 psig suit pressure without failure.
Entrance Pressure Sealing Closure	Capable of 500 openings and closures without failure.

2.5 Life Support Provisions

Information contained herein was derived, in part, from NASA, MSC document "Exhibit 'A' Project Gemini Extravehicular Life Support System (ELSS) Statement of Work", dated 4 August 1964, and in part from a Gemini pressure suit briefing presented by NASA, MSC on 12 August 1964. A portable life support system acceptable for the MOL mission has not been developed. The following information defines the suit, chest pack, and umbilical interface problem, and should be used only as a guide.

Chest Pack	This item, described by NASA as "Extravehicular Life Support System" (ELSS), is shown schematically in Figure I-7. The system is basically a semi-open pneumatic loop, utilizing spacecraft O_2 supplied via an umbilical. O_2 is provided for metabolic needs and ventilation for thermal and CO_2 control.
Normal Mode	During normal operation, the umbilical will supply either 5.1 lb/hr or 9.5 lb/hr of oxygen. A high-low selector valve will enable the crewman to select either flow rate.

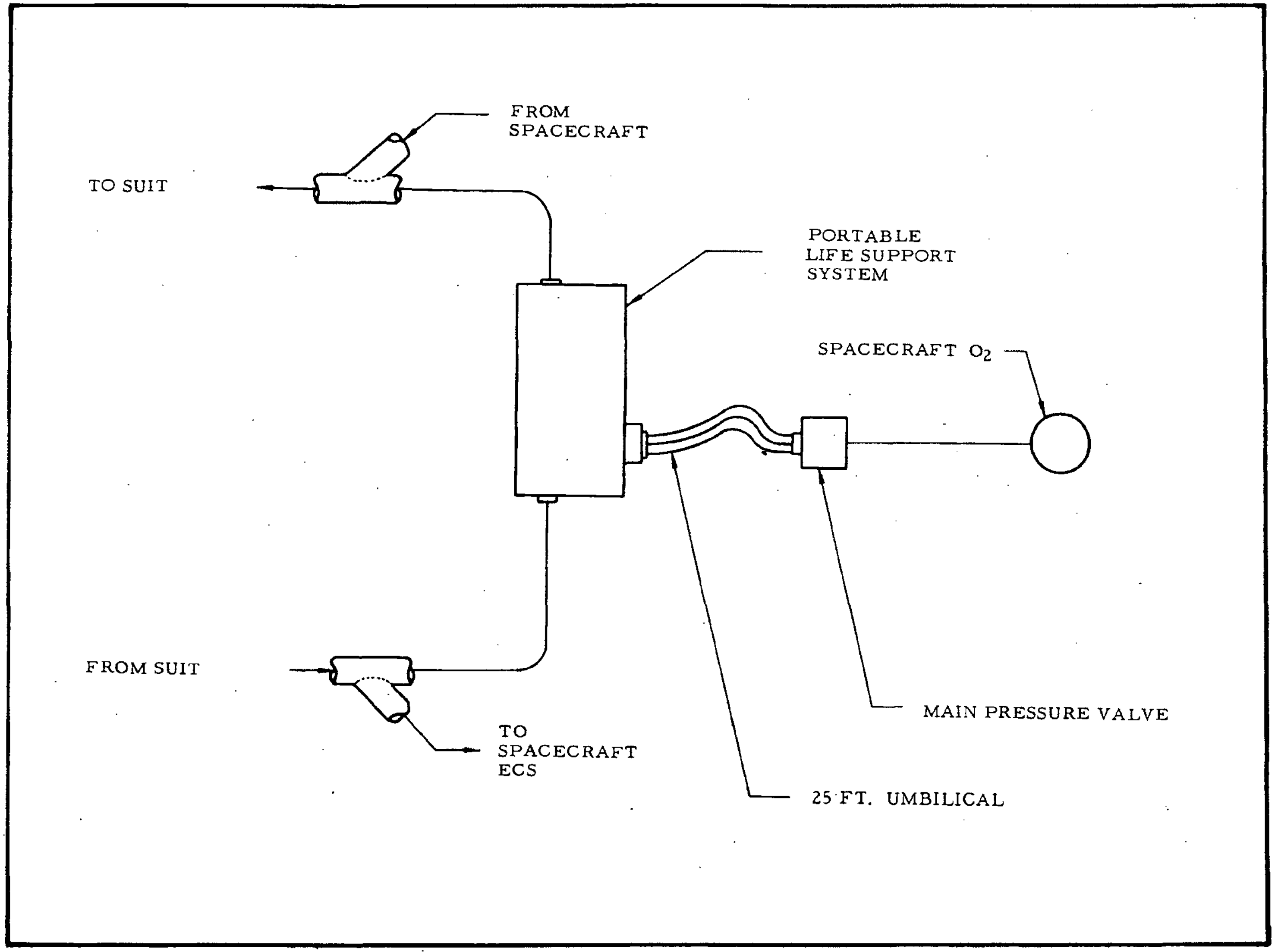

Figure I-7. Portable Life Support System Schematic

Emergency Mode	ELSS emergency O_2 system automatically supplies O_2 to the suit if umbilical supply line pressure drops below 90 psig. Emergency O_2 supplied by the ELSS is adequate for either 5.1 lb/hr or 9.1 lb/hr for 11 minutes. Activation of the chest pack will be signalled by an audible alarm and by a warning light on the panel of the chest pack; the extravehicular mission will be aborted if the emergency O_2 flow is activated. Suit pressure loss (nominal 3.5 psig) will also activate the audible alarm and will signal the crewman to abort the extravehicular mission.
Umbilical	(See Figure I-7.) The umbilical will be approximately 25 ft long, and will supply O_2 to the crewman via connection to the chest pack. A tetherline and an electrical cable for transmission of biomedical and suit condition data will also be incorporated into the umbilical. The umbilical has two interfaces: umbilical-to-spacecraft, and umbilical-to-chest pack.
System Weight	Weight of the complete ELSS (including chest pack, umbilical, and connectors) shall not exceed 52 lb.

2.6 Instrumentation Provisions

The bioinstrumentation package will be supplied as an integral part of the suit by the suit contractor. Physiological and ECS parameters which may be monitored (based on those for which provisions are being made in the NASA G-4C pressure suit and associated life support systems) are as shown below:

Impedance Pneumograph	Located on chest. Biomed recorder and telemetry (T/M).
Electrocardiogram	Axillary, sternal biomed recorder, and T/M.
Temperature	Skin, oral; T/M.
Blood Pressure	Left arm; T/M.
Suit Pressure	T/M (EVA) in CP wrist gauge (2 - 10 psia).
Temperature	Suit ventilation inlet (EV) biomed recorder; T/M.

2.7 Damage Resistance

The suit is a multi-layered garment with a highly tear-resistant outer material (NOMEX fabric, HT-90-40). Tests conducted during July, 1964, established the criteria for both NOMEX and dacron. Dacron is used for the construction of the secondary thermal layer.

Gloves are presently designed for intravehicular operation. A new glove, or glove covering, is under development for extravehicular activity.

The helmet visor is the most susceptible to damage. Current studies indicate that a helmet visor constructed of CR-39 is shatterproof when subjected to tests by the NASA hypervelocity gun duplicating micro-meteoroid bombardment of a particle 1/64 inch in diameter traveling at approximately 27,000 ft/sec. This material is being studied for possible use on the MOL suit helmet.

2.8 Waste Disposal Provision

The G-4C has no internal provision for body waste storage or disposal. The suit is equipped with double pressure-sealing zippers extending from the abdomen through the crotch.

2.9 Food Handling Provisions

A drinking or liquid squeeze-tube feeding port is located on the front lower edge of the helmet (see Figure I-8).

2.10 Interface Provisions

Suit fittings are of a type compatible with those utilized in the Gemini vehicle ECS. Therefore, fittings on the umbilical for extravehicular operations and all fittings from all ECS systems will be of a type compatible with those existing in the Gemini vehicle-suit-ECS loop. Fittings for extravehicular ECS support systems in the Gemini Program will be defined by January, 1965.

A parachute harness is integrated into the parachute/restraint harness assembly. An interface exists between the suit and seat of the Gemini vehicle (e.g., the neck ring of the suit imposes position interference in the area of head rest; mobility in the pressurized state is reduced to such a degree in the

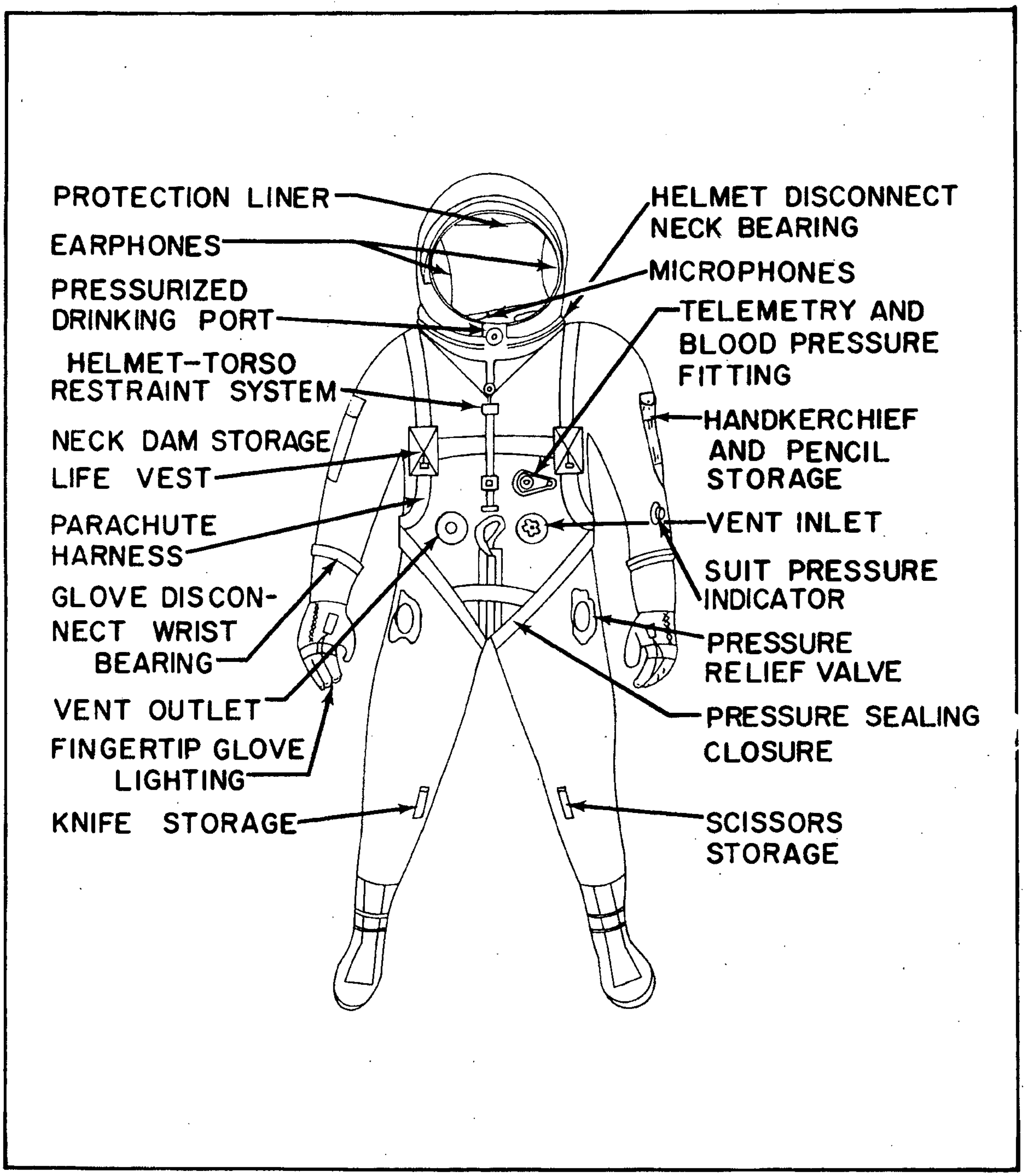

Figure I-8. MOL Type Extravehicular Space Suit

(e. g., the neck ring of the suit imposes position interference in the area of head rest; mobility in the pressurized state is reduced to such a degree in the hip/torso area as to make successful reinsertion into the seat followed by hatch closure a complex and difficult maneuver).

Tethering systems utilizing hook and strap devices integrated into pressure suits have been designed, built, and successfully tested. Such a system may be provided as an integral part of the suit.

Fittings requiring actuation by the crewman will present a major vehicle interface because of lack of dexterity and reduced mobility in the pressurized suit and gloves.

Subsystems Interface	Suit-to-seat interface vented and pressurized.
	Electrical-bioinstrumentation; common. Quick-disconnect type.
	Pneumatic-ventilation, blood pressure measurement. Vent is locking type. BPMS* is insert-bayonet type.
	Harness and restraint-parachute harness acts as restraint; lap belt.
	Vehicle attachment points for tethering.
Types of Fittings Requiring Actuation by Crewman	
Suit-to-ECS or Suit-to-Chest Pack	Pneumatic, manual-locking, double sealing.
Suit-to-Spacecraft or Suit-to-Chest Pack	Electrical manual, quick-disconnect.
Suit-to-BPMS	Insert tube; oiling seal; squeeze bulb.
Lap Restraint	Buckle (MA-6 type) Koch fitting.
Parachute Harness	Koch fitting.
Umbilical-to-Chest Pack	Snap-tite, quick-disconnect.
Tether to Spacecraft	Snap fitting.

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* BPMS = Blood Pressure Measuring System

2.11 Bioinstrumentation and Communication

Electrical leads through the umbilical will be required for the following:

Parameter	No. of Wires
Power	3
Electrocardiogram	2 (shielded)
Impedance Pneumograph	2 (shielded)
Microphones	2 (shielded)
Earphones	2 (shielded)
Inlet Temperature	2
Total Suit Pressure	2
	15

PART II

PART II

EXTRAVEHICULAR ACTIVITY PERFORMANCE

1.0 INTRODUCTION

Planning data to be used in the parametric study of extravehicular operations supporting the assembly of large space structures for MOL experiments is provided herein. Specifically, it includes time allowances and factors for determining weight penalties for the following modes of possible extravehicular capability:

(a) Umbilical Life Support

Extravehicular suit (recirculating gas wet or dry suit) with backpack water boiler and CO_2 removal capability. An umbilical will provide metabolic and leakage oxygen.

(b) Self-Contained Life Support

Above capability with self-contained oxygen.

(c) Astronaut Stabilization and Maneuvering Unit

Reaction-jet (liquid monopropellant) backpack with rate gyro stabilization, providing the following command capabilities: up/down, right/left, and fore/aft translation accelerations; and pitch, roll, and yaw attitude rates. In absence of rate commands, zero rates will be held automatically. Automatic attitude hold can be turned off by the crewman. The unit will be stored in the airlock.

(d) Unmanned (remote controlled) Maneuvering Unit

Stabilized propulsion unit similar to the above, command-controlled from within the MOL; will provide a TV sensor with a video data link to the MOL. Stored externally; boom-launched and retrieved by remote control; refueled and refurbished by remote control. Can be considered for use in positioning structural elements, transporting tools or expendables, or remote visual monitoring.

(e) *Tether/Handhold Locomotion

Self-powered maneuvering along structural surfaces using appropriate handholds or tetherlines. In considering this mode, the user should carefully identify all structural penalties and special assembly procedures which may be required to make it feasible.

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*An alternate maneuvering mode; however, pertinent weight factors are not included herein.

The time data presented in Section 2.0 is intended for use in evaluating the comparative degree of manned participation in various space assembly schemes; it comprises elapsed-time factors for individual excursions and for overall station duty times allowable for extravehicular operations. The latter will permit evaluation of time-on-orbit consumed in implementing various degrees of extravehicular activity (EVA).

The weight factors given will permit assessment of the weight penalties of various operational modes once the user has identified his requirements in terms of extravehicular modes, maneuver profiles, and activity (metabolic profiles).

Requirements for work-station attachment devices, tools, and special equipment are not reflected herein. The user must establish these requirements for the specific task under consideration.

2.0 ELAPSED TIME

In determining the elapsed time associated with extravehicular operations, allowance must be made for "pre-EVA" and "post-EVA" time increments. These should include:

(a) For the manned AMU:

40 min:	Don and check suit, life support, and/or maneuvering unit; depressurize; refuel maneuvering unit; egress.
20 min:	Ingress; pressurize; doff and stow suit.
3 hr:	Post-EVA battery recharge (if life support only has been used). If next excursion must be conducted sooner, duplicate battery sets (silver-cadmium) must be provided (8 lb).
7 hr:	Post-EVA battery recharge (if maneuvering unit and life support have both been used). If next EVA must be conducted sooner, duplicate battery sets (silver-cadmium) must be provided (19 lb).

(b) For the Unmanned Maneuvering Unit:

20 min:	Refuel maneuvering unit and launch.
10 min:	Dock and retrieve maneuvering unit.
4 hr:	Post-EVA battery recharge. If next EVA must be conducted sooner, duplicate battery sets (silver-cadmium) must be provided (11 lb). Access to unit for replacement of batteries will require manned extravehicular operation. Unit could carry two battery complements, if necessary.

3.0 ALLOWABLE DUTY TIME

During manned extravehicular operation (from airlock depressurization through repressurization), safety dictates that a second crewman devote his principal attention (50 percent of his time) to monitoring. This is necessary for both umbilical and self-contained life support. Sleep constraints (non-simultaneous) and other crew duty requirements establish an upper limit of four man-hours available per 24 hours for sustained manned extravehicular operations (an 8-hour excursion may be possible on a non-recurring basis). Figure II-1 illustrates possible duty cycles for a 2-man station, consisting of:

(a) One 4-hour excursion, or two 2-hour excursions occurring during eight consecutive hours, or

(b) Two 2-hour excursions separated by a crew sleep period.

For a four-man operation (separately launched elements), crew sleep can be scheduled to provide 24 hours daily of two- or three-man availability. A maximum of 20 extravehicular man-hours can be made available per 24 hours, consisting of (see Figure II-2):

(a) A one-man, 4-hour excursion during the first 8-hour period, and

(b) A two-man 4-hour excursion during each of the second and third 8-hour periods.

(The 2-hour possibilities indicated previously are also applicable.)

Operation of the Unmanned Maneuvering Unit requires one creman inside the MOL. If an extravehicular crewman and the Unmanned Maneuvering Unit are deployed in the same visual sector, the crewman inside the MOL could also act as safety observer for the external crewman; the observer crewman may jettison the unmanned unit, if necessary, in an emergency. A second crewman must be available and on duty inside the MOL during retrieval of the Unmanned

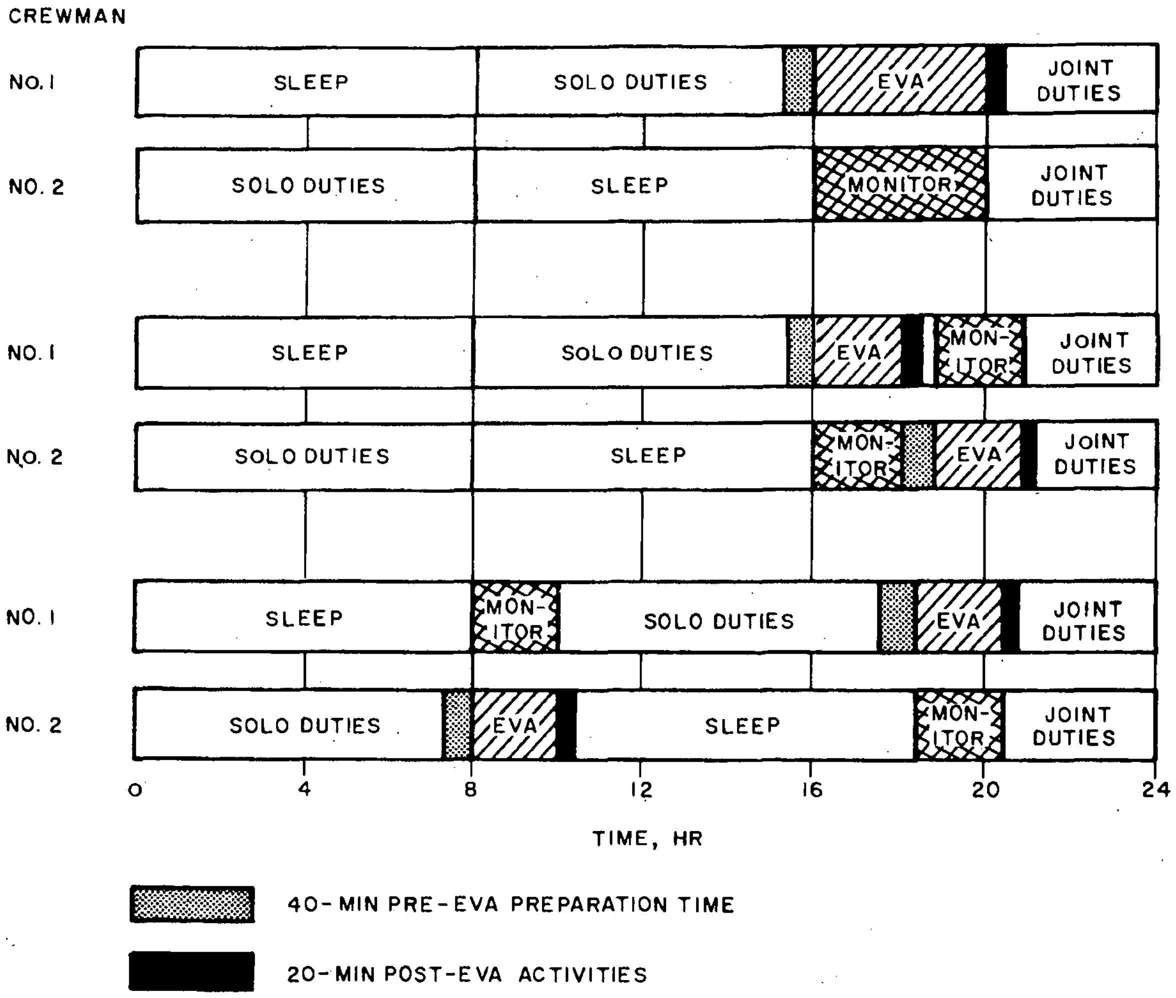

Figure II-1. Maximum Crew Duty Cycles, Two-Man Station (Three Cases)

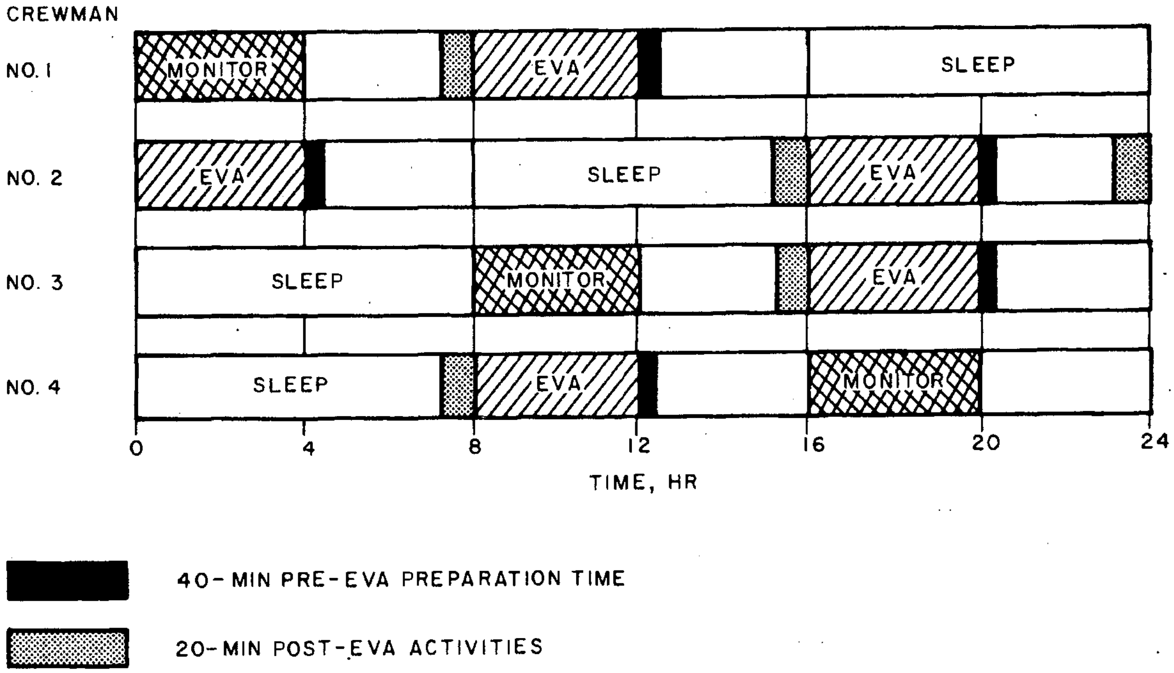

Figure II-2. Maximum Crew Duty Cycles,
Four Man Station (One Case)

Maneuvering Unit. It these requirements are met, the Unmanned Maneuvering Unit may be operated:

(a) Instead of any of the manned excursions previously identified,

(b) In conjunction with any of the manned excursions, or

(c) For up to four hours of any crew sleep period, ending with the second crewman awakened.

4.0 WEIGHT FACTORS

Weight factors for use in evaluating the umbilical and self-contained modes of extravehicular life support are presented in Table II-1. (All items are required for the umbilical mode; the umbilical is omitted for the self-contained mode. The weight of backpack oxygen tankage for the self-contained mode is negligible.) Metabolic oxygen is not allocated since it must be provided anyway; leakage is assumed negligible. Total weight will consist of fixed weight plus a variable weight increment calculated on the total number of excursions and total durations at different metabolic levels.

Table II-2 presents weight factors for calculating the additional increment required for crewman EVA maneuvering capability; total weight for maneuvering and life support requires use of both Tables II-1 and II-2. To calculate the required variable weight (mainly propellant), the user must determine an approximate maneuver profile for the assembly task. Propellant required for individual excursions is of interest as well as total propellants; at present, it is contemplated that the AMU will carry approximately 15 lb of propellant.

"Fine Station-Keeping" in Tables II-2 and II-3 refers to the precise (manual) control of relative position between the Unmanned Maneuvering Unit and a reference object, and the precise (manual plus automatic) control of relative attitude. It is representative of station-keeping at 1-2 ft range, or of the terminal phase of rendezvous or docking (such as would be involved in a transfer from MOL to an auxiliary object). It would also be typical of propellant required during traverse along a large assembly in close proximity (1-2 ft) thereto, or that required for untethered assembly operations at a work station.

"Coarse Attitude Maintenance" is the limit-cycle fuel expended by the automatic stabilization, plus the fuel required to manually (periodically) remove the attitude drifts inherent in the automatic system. Position is allowed to drift.

Table II-1. Weight Factors, Life Support

Fixed Weight	Weight (lb)
Extravehicular Suit	30
Umbilical	5
ECS Backpack	60
Communications	20
Battery Recharge	7
Tetherline and Reel	15
Mounting and Wiring	13
Contingency	14
Total	164
Variable Weight	
Airlock Repressurizing (per excursion)	15

	800 BTU/hr	1500 BTU/hr	2000 BTU/hr
Contaminant Removal	0.93 lb/hr	1.75 lb/hr	2.33 lb/hr
Battery Recharge	0.27 lb/hr	0.5 lb/hr	0.67 lb/hr
Water and Tankage	1.12 lb/hr	2.10 lb/hr	2.80 lb/hr

Table II-2. Weight Factors, AMU
(In Addition to Life Support Factors of Table II-1)

Fixed Weight	Weight (lb)
Maneuvering Unit (Dry, w/o ECS)	105
Battery Charger	2
Refueling System	18
Mounting and Wiring	26
Contingency	15
Total	165

Variable Weight	
Battery Charge	0.67 lb/EVA hr
Propellant	
Fine Station-Keeping (position and attitude)	2.3 lb/5 min
Coarse Attitude Maintenance	3 lb/hr
300-ft Translation and Single Rendezvous (5 min)	2.6 lb

Other translations should be calculated from mass and ΔV involved, using I_{sp} of 190 lbf-sec/lb

Table II-3. Weight Factors, Unmanned Maneuvering Unit
(Life Support Factors of Table II-1 Not Required)

Fixed Weight	Weight (lb)
Maneuvering Unit (Dry)	115
Battery Charger	5*
Receivers, Displays and Controls	75
Storage, Launch and Retrieval	70
Refueling System	15*
Remote Refueling Console	10
Mounting and Wiring	65
Contingency	35
Total	390

Variable Weight	
Battery Charge	0.67 lb/EVA hr
Propellant:	
Fine Station-Keeping (position and attitude)	0.67 lb/5 min
Coarse Attitude Maintenance	0.4 lb/hr
300-ft Translation and Single Rendezvous (5 min)	0.75 lb

Other translations should be calculated from the mass and ΔV involved, using I_{sp} of 190 lbf-sec/lb

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*Can be shared with AMU.

The propellant figure shown for "300-ft Translation and Rendezvous" is dominated by the rendezvous requirement, and hence is virtually independent of the translation velocity (and of the translation range) chosen. It is calculated for the mass of maneuvering unit, ECS, and man, without payload.

During tethered operation, the automatic stabilization system can be turned off to conserve fuel.

Table II-3 shows weight factors for the Unmanned Maneuvering Unit. Note that, in both Tables II-2 and II-3, there are no allowances for tools, fixtures, couplings, or payload carriers. These should be identified by the user as specialized requirements for the assembly tasks under study.

DISTRIBUTION LIST

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