Prepared Under Contract
No. NAS2-7008

ACUREX Corporation
Mountain View, California

for

Ames Research Center
National Aeronautics
And Space Administration

AEROTHERM
ACUREX Corporation

TABLE OF CONTENTS

LIST OF FIGURES

SECTION 1
INTRODUCTION

The High Pressure Space Suit Glove Program was a seven month effort which yielded one prototype glove assembly with an operating pressure of 8.0 psi.

The goal of the program was to produce one glove which would have an operating pressure of 8 psig (changed from the initial 10 psig requirement to be compatible with future EVA suits operating pressures).

The Phase I effort has resulted in the following developments.

1) A new layup technique for the incorporation of the previously developed and highly successful mini-convolute systems.

2) Modification in the mini-convolute construction to assure cycle life at 8.0 psi in excess of 100,000 cycles (proven in cycle test).

3) The development of a unique non-orthogonal low torque wrist joint which will yield joint life in excess of 250,000 cycles.

4) The development of a low torque single axis joint for use in the thumb and finger first metacarpal joints. Prototype joints were developed and submitted independent of the Phase I program glove.

5) A number of approaches to 1st metacarpal joints were fabricated and tested to establish the joint techniques which would provide the mobility, tactility, ruggedness and reliability which must be inherent in an EVA glove designed for future space missions.

Section 2 of this report covers the development history of the program. Section 3 covers the Phase II recommendations. Section 4 is the Summary. Appendix A covers Test Reports.

SECTION 2
DEVELOPMENT

The development effort covered the following areas:

1) Materials and Fabrication

2) Joint Implementation
    a) Finger
    b) Finger First Metacarpal Joint
    c) Thumb First Metacarpal Joint

3) Wrist Joint
    a) Single Axis Implementation
    b) Dual Axis Implementation

4) Glove Restraint

2.1 MATERIALS AND FABRICATION

The 5.0 psig glove, developed under Contract NAS2-6154 utilized the mini-convolute and demonstrated the appropriateness of this technique for the implementation of finger mobility. However, that glove used flat pattern development and required several stitching and assembly steps, all of which could jeopardize the reliability of the glove.

It was decided that the 8.0 psig glove would employ a layup or dipping technique wherein the glove would be fabricated by subsequent layering of marquesette cloth reenforcement and elastomeric material. Both neoprene and polyurethane were investigated as candidate materials for the layup process. Since the mini-convolute would be inlaid into the dorsal aspect of the digits, and this layup would utilize a neoprene sandwich between nylon rip stop fabric, it was decided to use neoprene as the elastomer because of its compatibility with the mini-convolute layup.

A three-ply system of layup was decided upon, although this provided a tensile strength far in excess of what was required from a pure hoop or axial load consideration, the additional strength would minimize fabric growth with pressurization and would provide additional puncture protection.

Several practice layups were made to assure us of the validity of the process prior to the actual fabrication of the prototype glove. These layups also verified mandrel adequacy and, in fact, led to considerable changes in the final mandrel, (finger length and diameter as well as 1st metacarpal contour and dimensions were changed as the result of preliminary fabrication; see Figure 1 and 2).

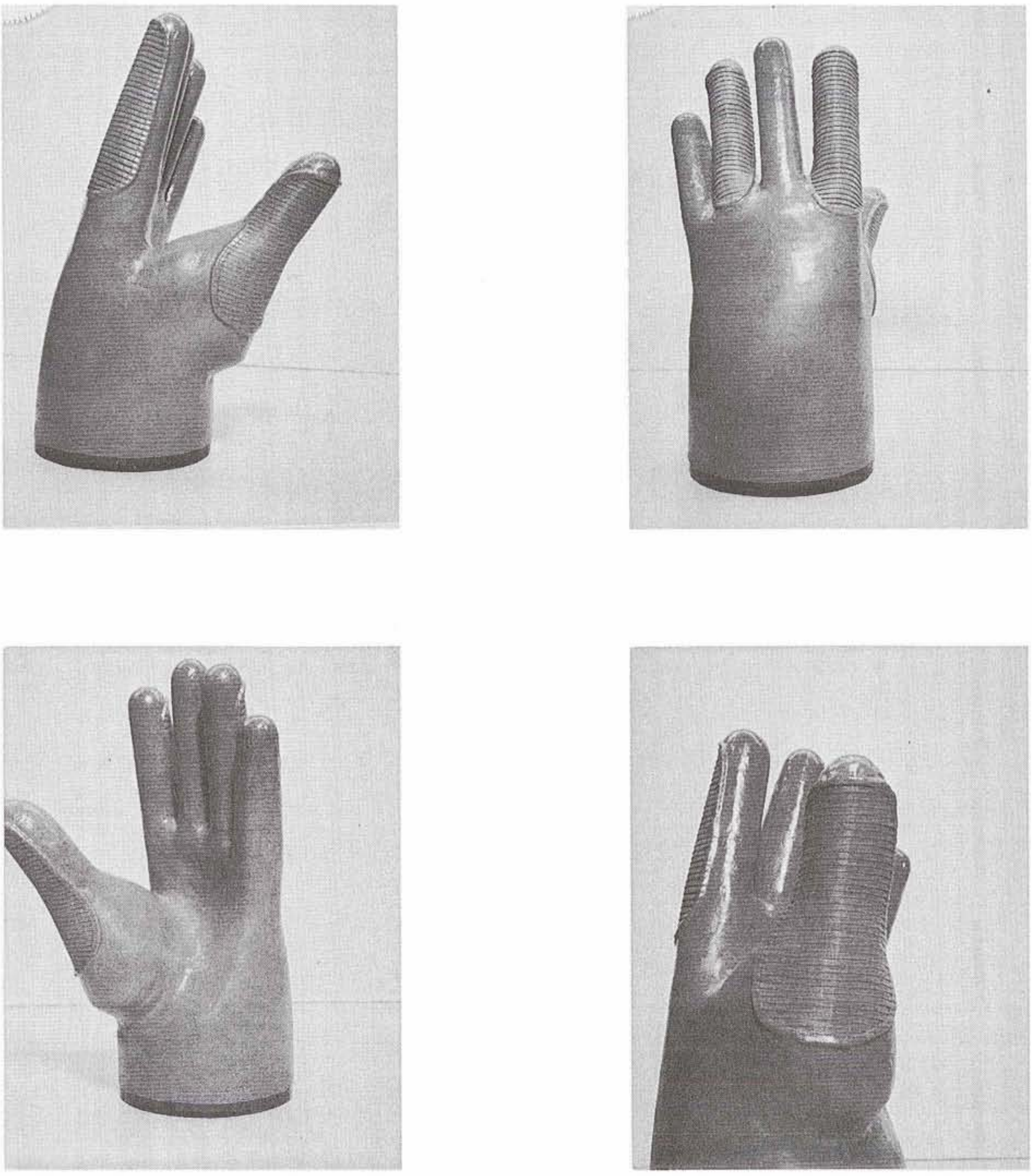


Figure 1
Mockup Glove

Figure 2. Glove Mandrel

The fabrication layup technique has the following advantages:

a) Minimizes hand assembly.

b) Provides a smoothly finished glove

c) Results in inherent leak-proof assembly.

Thickness of the prototype glove appeared excessive and subsequent layup techniques will reduce wall thickness from .030 inch to .017 inch.

The fabrication technique also eliminated the need for external and end restraint on each of the digits.

The mini-convolutes are inlaid only on the dorsal side of the fingers leaving a smooth frontal surface which presents a more tactile and less vulnerable surface to the critical working surface of the glove.

The palmar area was additionally reenforced with a 17 - 4 stainless steel palm restraint and nomex cloth.

Because of the recommended changes in mobility techniques, the stainless steel reenforcement will be replaced in the Phase II glove with a fiberglass/epoxy shell which will have integral pivot pin bushings of aluminum laid into the assembly.

The wrist joint employed aluminum clamps, and interfacing rings as well as 300 series stainless steel compression and tension rings.

The wrist joint was preformed on an aluminum mandrel (see Figure 3) of a nomex HT-5 and nylon ripstop/neoprene sandwich.

The unique convolute development is a modification of the joint technique used in the AES suit developed for NASA-MSC. However, convolute contour was modified for the higher operational pressure of the glove. This convolute system has been previously life tested to 250,000 cycles (at 5.0 psig).

2.2 JOINT IMPLEMENTATION

2.2.1 Fingers -

The fingers of the 5.0 psig glove predecessor to this program utilized mini-convolutes on the posterior portion of the fingers. The joint was pressure balanced by providing channels along the sides of each finger which contained restraint cords which could traverse in the plane of flexion/extension. This provided excellent joint stabilization but represented a reliability/wear problem and required a great deal of hand work in assembly.

It was decided to investigate the feasibility of balancing the convolutes by establishing a ratio of convoluted circumference to smooth circumference. This was accomplished empirically by fabricating a series of test

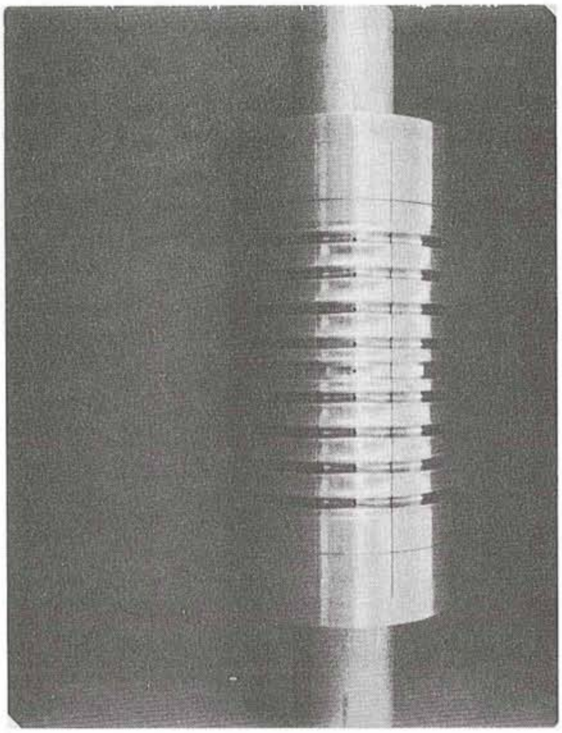


Figure 3
Wrist Joint Mandril

sections and operating them at glove pressure (8.0 psig). The ratio was then applied to each finger diameter.

The prototype finger assembly underwent two sets of life tests. The first test met the ground rule requirements established in the contract in that failure occurred at 10,750 cycles (5,000 cycle life required), but was not acceptable to our established goal of 100,000 cycle life. The fiber orientation of the convolute was changed to 45° to the axis of flexure and a second finger was tested through 100,000 cycles (see Figure 4).

The prototype glove does have some variation in stiffness from finger to finger, but finger torques are acceptably low for all digits. Further effort will be devoted to more specifically establishing this ratio in the Phase II glove.

2.2.2 Palm First Metacarpal Joint -

Effort was made in Phase I to establish the minimum of "hard elements" required to establish a functional glove. As a result, the first metacarpal joint implementation does not represent the final technique developed and recommended for the Phase II glove. It does utilize a rolling convolute restrained by teflon covered restraint cords at the crotch between each finger.

It is functional, but torques are considered to be unacceptably high. The prototype system, separately submitted, using a chevron shaped rolling convolute and rigid shoulder pin bearings has only a .15 ft/lb. torque at 8.0 psig. (See Figure 5.)

2.2.3 Thumb First Metacarpal Joint -

A major effort of Phase I was made to implement a two axis thumb first metacarpal joint. In retrospect this effort which investigated a variety of techniques, was extended beyond the time we should have allowed if proper implementation was to be made in the prototype glove.

The two axis implementation was abandoned and an internally fabric hinged thumb first metacarpal joint was used in the prototype glove. Torques were excessive and it must be considered as an unacceptable technique.

An independent chevron shaped rolling convolute single axis first metacarpal joint was submitted with the glove to demonstrate the technique which will be used in the Phase II glove (see Figure 6). Its torque at 8 psig is only .15 in/lb. In fact torques do not vary from .5 psig through 8 psig.

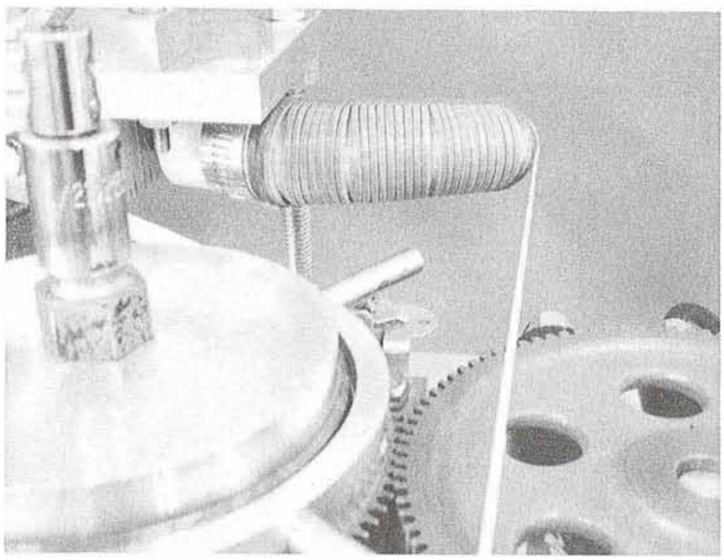


Figure 4. Glove Finger in Life Test

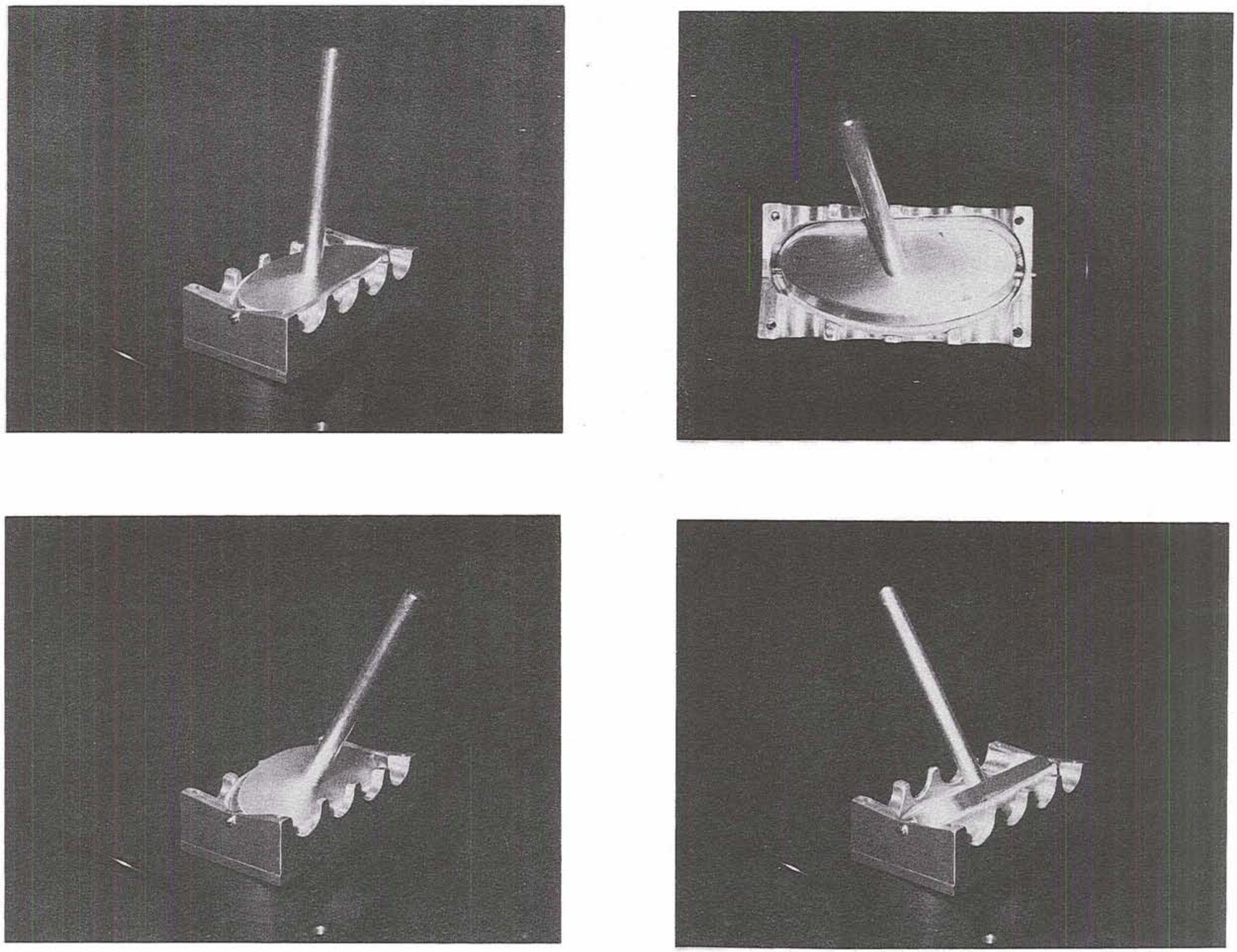


Figure 5. Palm First Metacarpal Joint

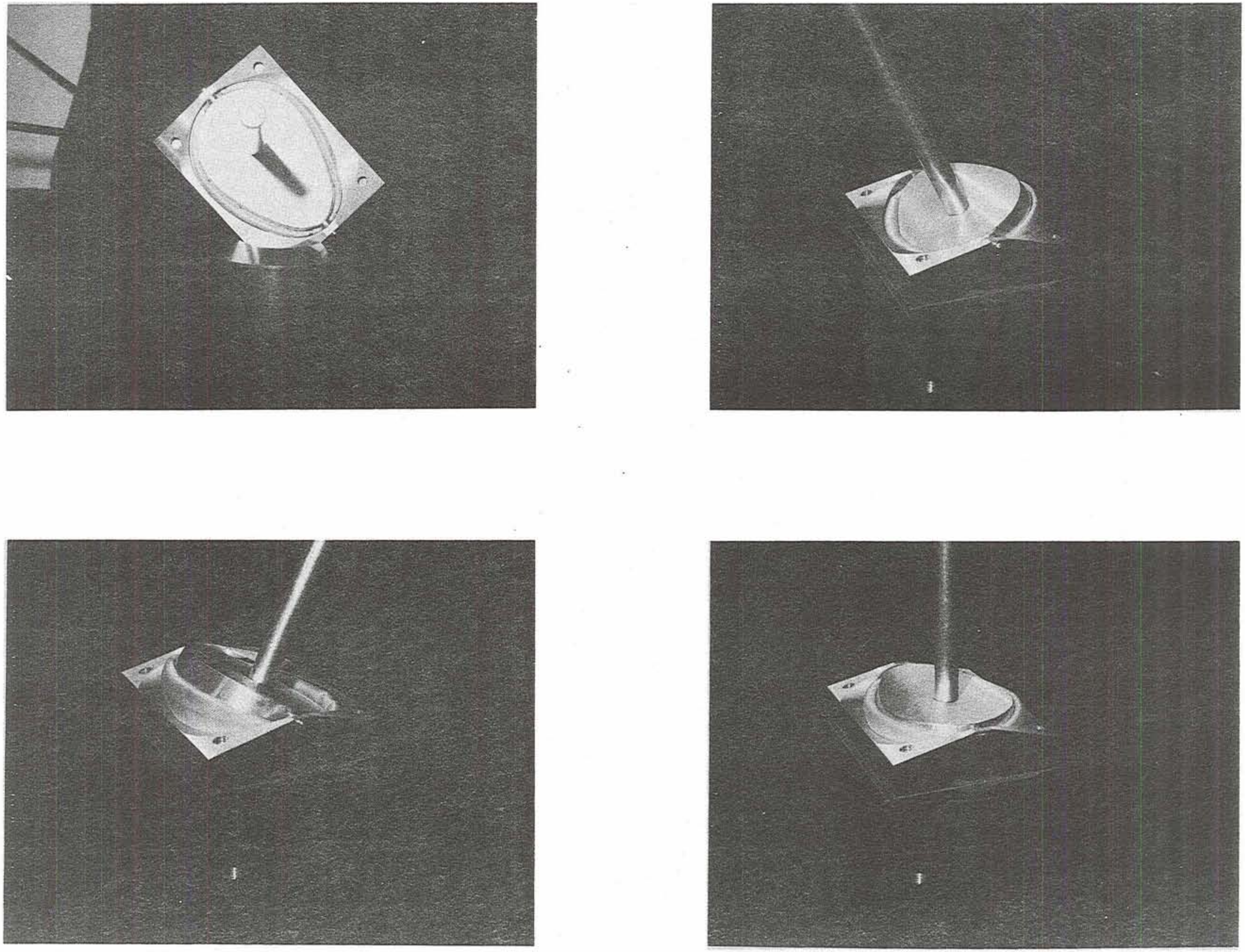


Figure 5. Thumb First Metacarpal Joint

2.2.4 Wrist Joint -

In keeping with the attempt to minimize the hard elements of the glove, a single wall laminate "gathered" convolute joint was investigated (see Figure 7).

The 8.0 psig pressure required the introduction of compression rings to aid in controlling the joint and the prospect of establishing a high reliability joint using this technique seemed low.

The gathered technique was abandoned in favor of a less difficult and highly successful "torroidal" joint technique and no problem whatever occurred in its implementation. Contour of the convolute was modified to compensate for the higher operational pressures. The joint is stable throughout its range and this type of joint has exhibited extreme durability in the past.

Two axis mobility is established by mounting two single axis joints in series. Each single axis element has a range of ± 40° and these restraint cables are offset from the wrist lateral plane by 25° (the included angle between subsequent restraint cables is 50°).

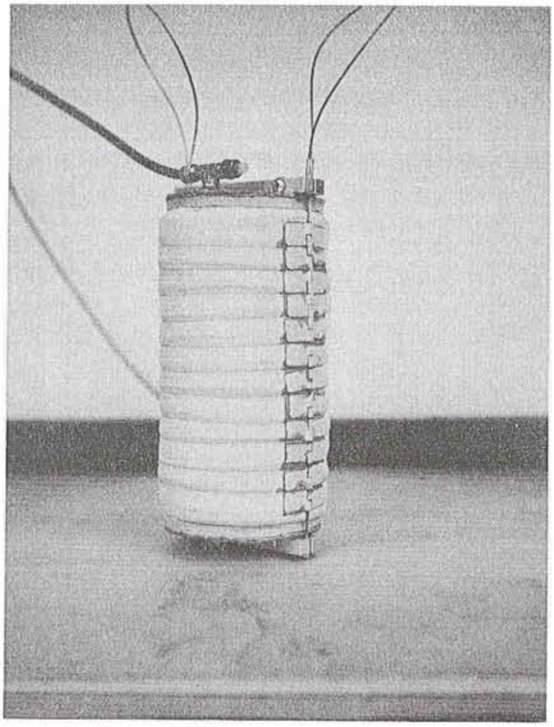
This arrangement provides ± 77° in flexion/extension and ± 32° in adduction/abduction. It should be noted that the total range of the two single axis joints if they were aligned is only ± 80°. This non-orthogonal alignment technique therefore yields two axis mobility with practically no increase in joint length except for the height of the intervening cable support ring.

There is, as can be seen by Figure 8, an off-axis "S" effect as the joint is flexed. But, in mobility model tests utilizing orthogonal as well as non-orthogonal configuration, this interfered less with mobility than did the additional (30%) length of the joint required for orthogonal orientation (see Figure 9). The current range of the joint can be compromised to gain reduced length of the glove and reduced "S" effect and is recommended for the Phase II program (see Section 3).

2.2.5 Glove Restraint -

The palmar area of the prototype glove uses a palm restraint constructed of steel wire and sheet which is located through a reenforcing nomex cloth/neoprene laminate which reenforces the entire hand (exclusive of the digits).

An aluminum formed sheet aids in first metacarpal restraint. The incorporation of shoulder pin bearings in the Phase II glove for both first metacarpal joints has led to the recommendation of a fiberglass shell structure which will incorporate bearing bushings in its assembly.



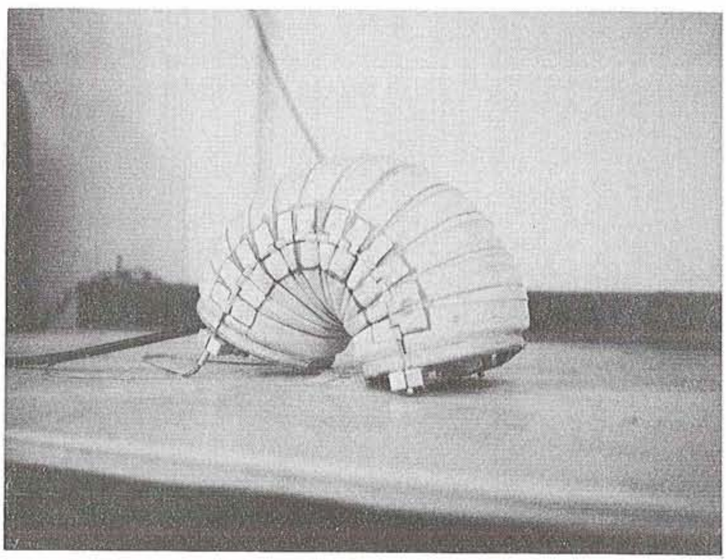
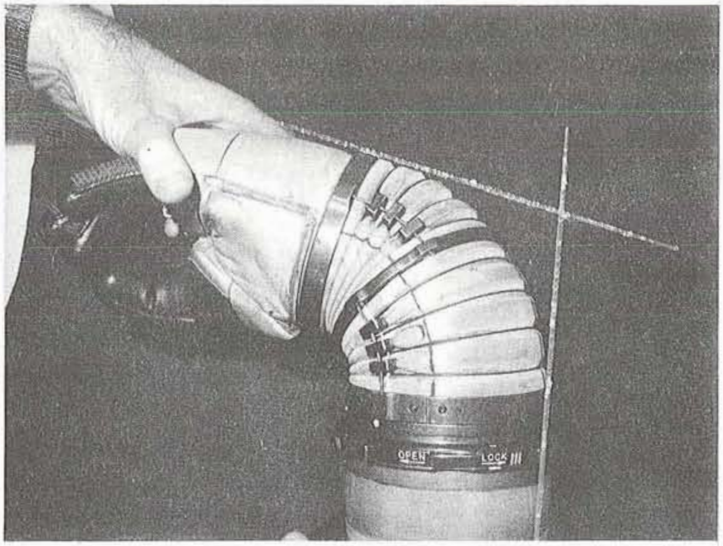
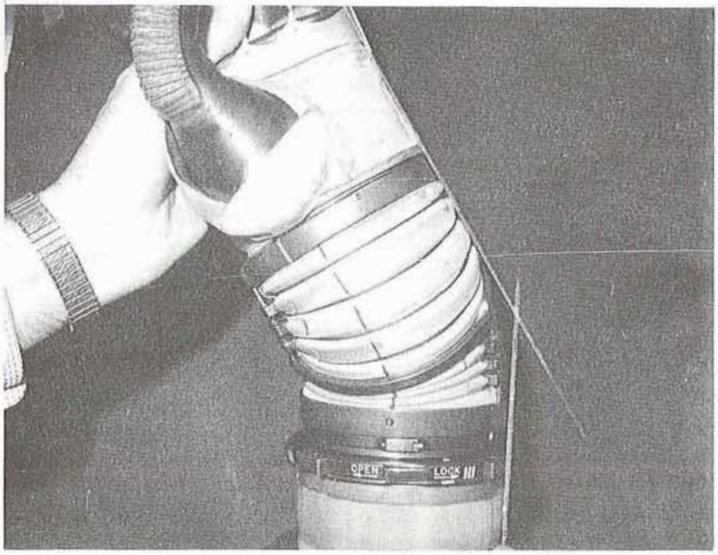


Figure 7. Single Axis Joint



Flexion ± 77°



Adduction Abduction ± 32°

Figure 8. Wrist Joint Range

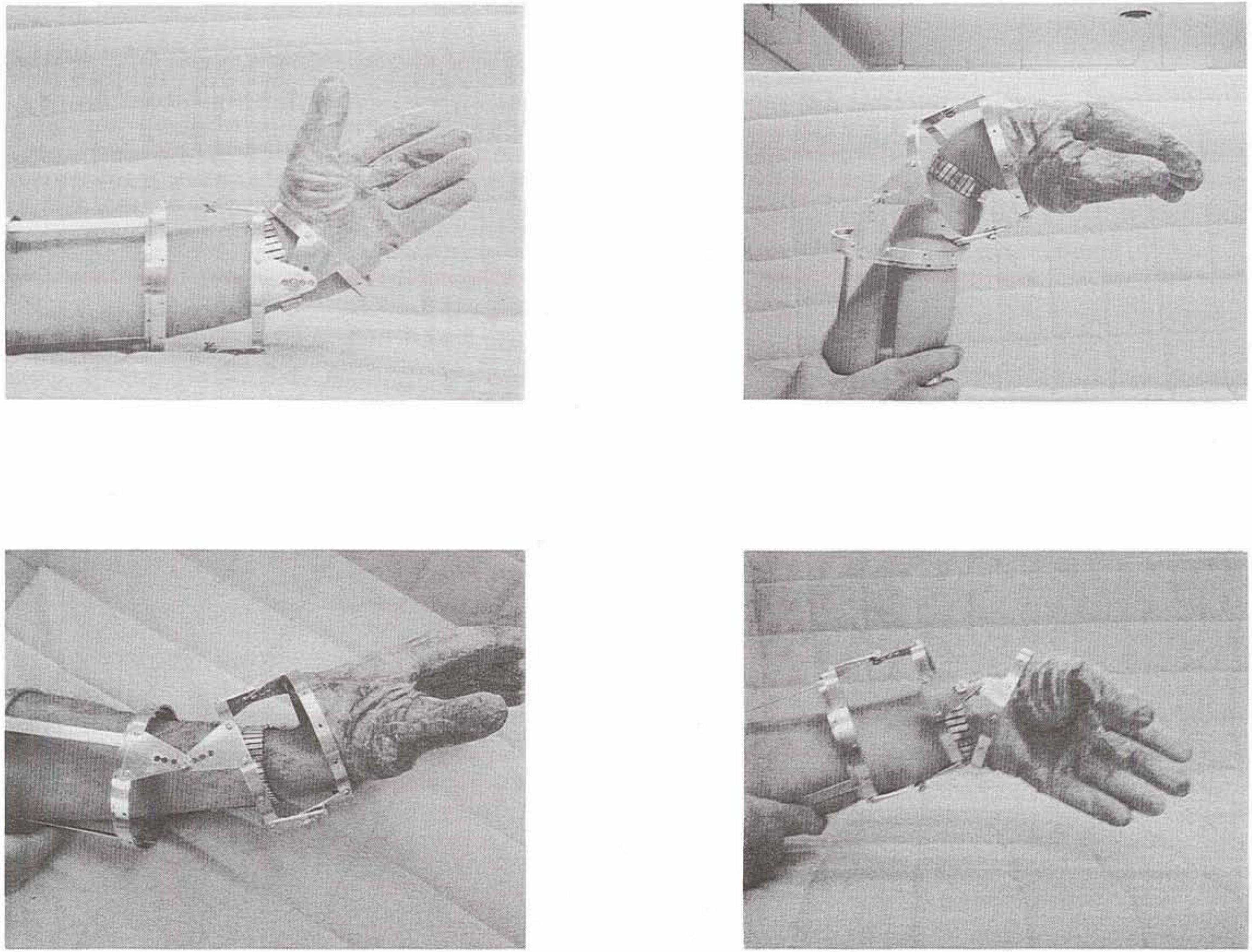


Figure 9
Orthogonal Wrist Joint

SECTION 3
RECOMMENDATIONS

The prototype glove has demonstrated valid techniques for the development of a highly mobile and durable 8.0 psi EVA glove.

It does not represent, in itself, an end point in that development for there are definite improvements which must be made before the glove can be considered representative of an operational EVA glove.

The Phase II glove will be nearly 1 1/2 inches shorter in overall length; will incorporate improved mobility in the fingers; will incorporate highly mobile first metacarpal joints (demonstrated as separate elements at the end of Phase I (see Figures 5, 6, 10, 11 and 12).

The Phase II glove will maintain the smooth palmar side to fingers to enhance tactile qualities and will maintain three ply fabric layup as a safety factor.

The 100,000 cycle life, proven for the digits will be extended to the first metacarpal joints. Minimum bulk between fingers will allow implementation of a thermal overglove with minimum degradation of glove performance.

Because of the constant volume techniques employed, the glove does not require a very tight fit to the hand to effect minimum torques, therefore the design lends itself to modular sizing for production and results in increased comfort for the wearer.

Flow of circulating air around the digits will also increase subject comfort, without compromising glove mobility.

The specific recommended changes, by element, are defined below:

1) Fingers -

The fingers will be fabricated of thinner wall section layup. (The Phase I wall thickness is .030 inch while the Phase II glove wall will be .017 inch thick. Sample layups have been made to verify feasibility of the thinner wall.)

The mini-convoluted area will be reduced by approximately 30% and each finger will be "trimmable" to a minimum torque condition after assembly.

The fingers will be custom fabricated to fit a subject specified by NASA.

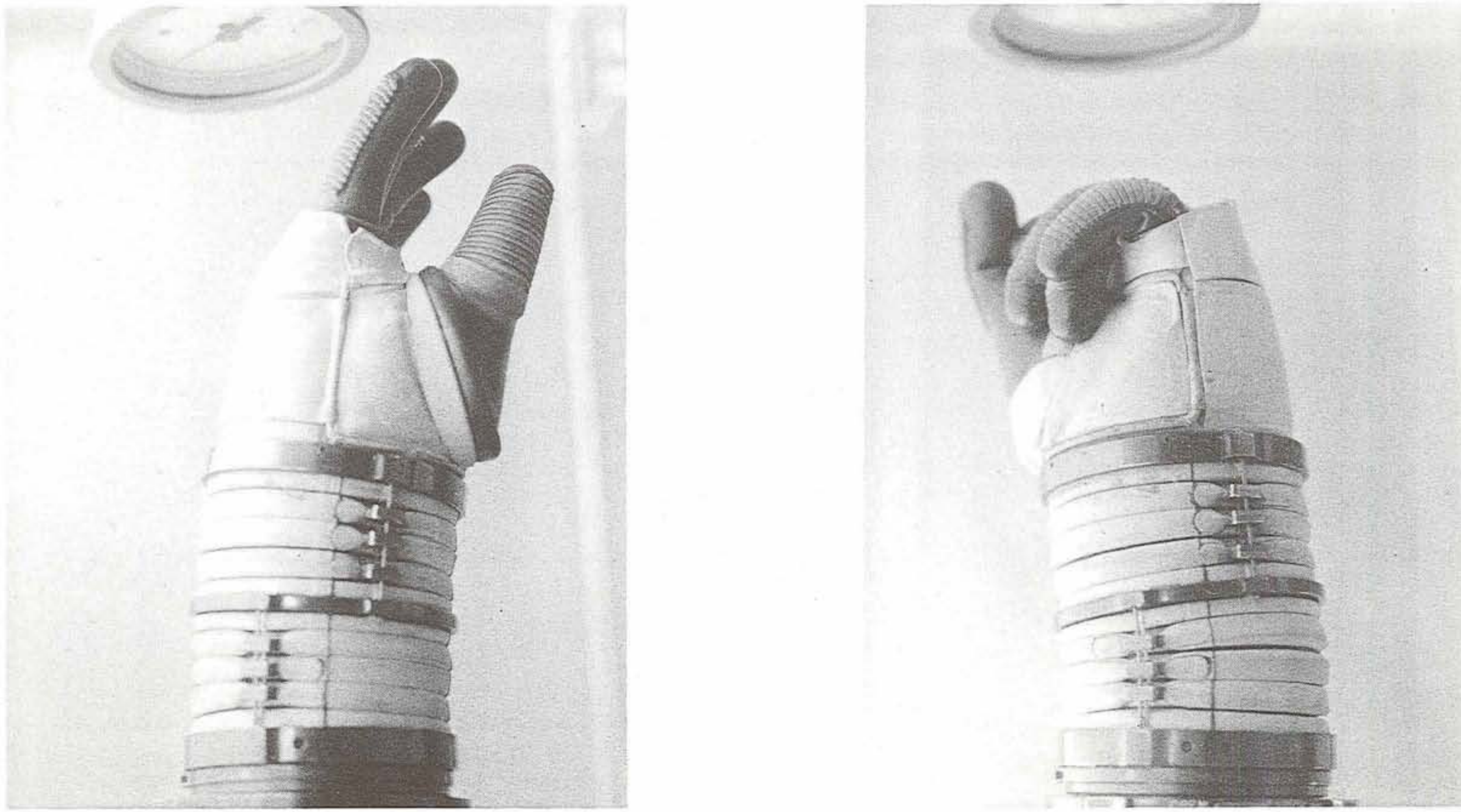


Figure 10. 8.0 psi - Phase I Glove

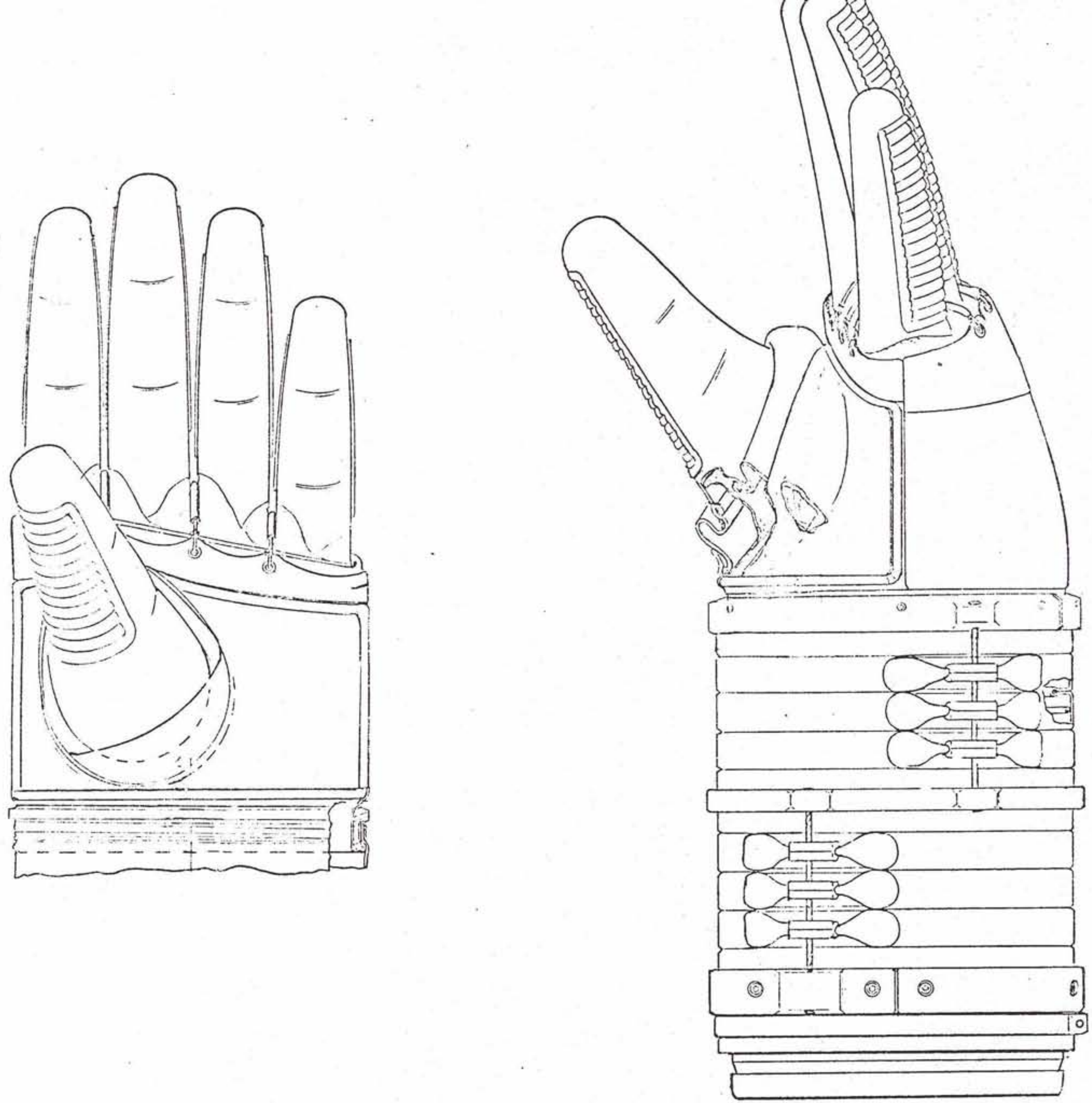


Figure 11. Phase I Glove

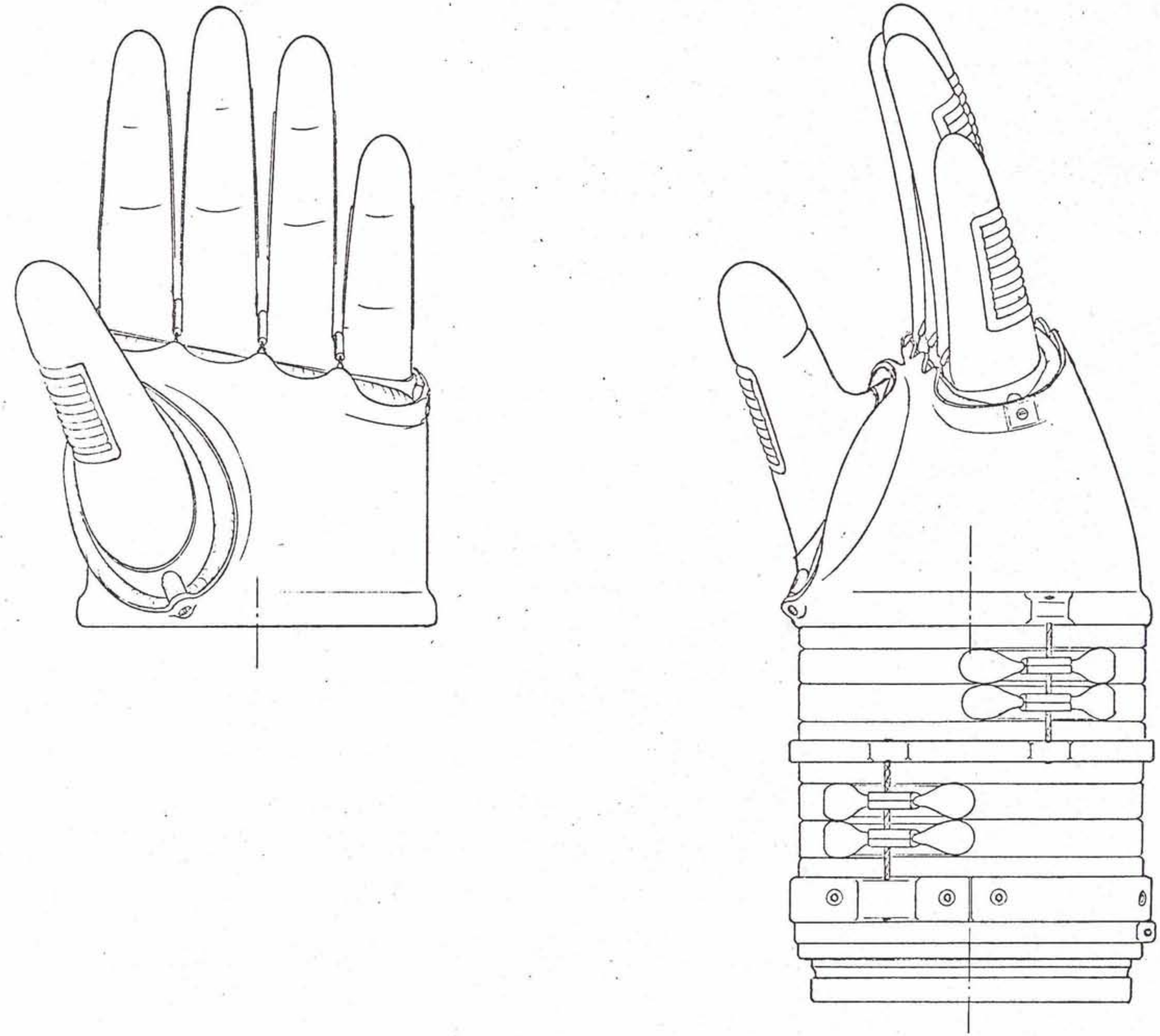


Figure 12. Proposed Phase II Glove

The tactile areas of the glove will be coated with polyurethane to increase abrasion resistance.

2) First Metacarpal Joints -

The first metacarpal joints, demonstrated as separate models at the end of Phase I program, will be incorporated into the Phase II glove.

The joints have demonstrated feasibility of implementing low torque joints for both the base of the thumb and the base of the fingers.

The thumb first metacarpal joint will be rotated away from the palmar area by approximately 20° to 30°. This will increase the palm area available for gripping and will provide clearance for the fingers to act in opposition to the palmar surface.

The first metacarpal joints will employ rigid pivots and chevron shaped rolling convolute joints. Range will be 46° for the thumb and 52° for the palm first metacarpal. The fingers will be set at approximately 30° to the neutral axis of the palm first metacarpal joint which itself is set at approximately 30° to the plane of the palm therefore the minimum finger to palm include angle will be 82°. This combined with the excellent finger flexibility whould allow the firm gripping of rod diameters well below 3/8 inch.

Similar pivot arrangements were used in the RX series hard suit single axis linkages and they exhibited life well in excess of 100,000 cycles with much greater load applications.

3) Palm Restraint -

The palm restraint will integrate pivot bushings and first metacarpal restraint as well as the palm area concave contour into a single fiberglass shell element. The cable support shoulders for the wrist joint will also integrate into this shell eliminating .5 inch in glove length.

The palm restraint shell will surround the hand and will receive the various elements (i.e., wrist joint, thumb assembly, finger assembly) which will be bonded to its inner surfaces. Fabric to shell bond areas will be prevented from experiencing peel loads by overlapping the bonded areas with .030 aluminum strips. This arrangement will lend itself to a modular sizing system wherein different palm restraint sized elements can be assembled to a matrix of thumb and finger assemblies.

4) Wrist Joint -

The wrist joint assembly will be reduced in length and the cable offset angle will be increased from 50° in the prototype glove to 60° in the Phase II end item glove.

The range of the glove will be reduced from the current ± 77° in flexion/extension and ± 32° adduction/abduction to ± 53° flexion/extension and ± 30° adduction/abduction. Overall length of the glove will be reduced by 1.5 inch and will be therefore compatible with current Apollo glove lengths. The reduced range will also reduce the apparent "S" displacement of the hand as the non-orthogonal joint is flexed (see Figure 13a and 13b).

Effective angle curves for the current glove and Phase II glove wrist joints are shown in Figure 14.

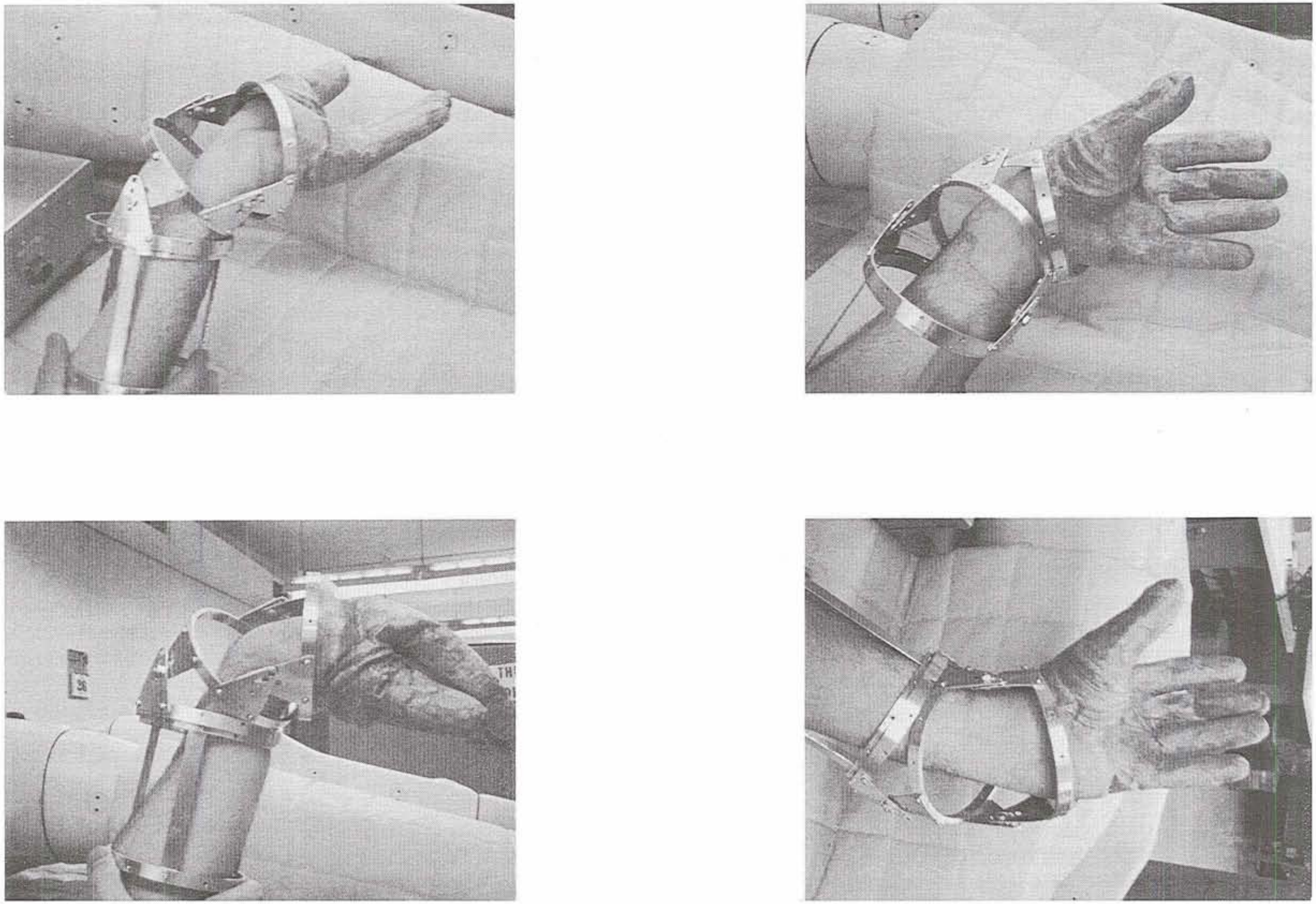


Figure 13A

Phase I
Non-Orthogonal Wrist Joint

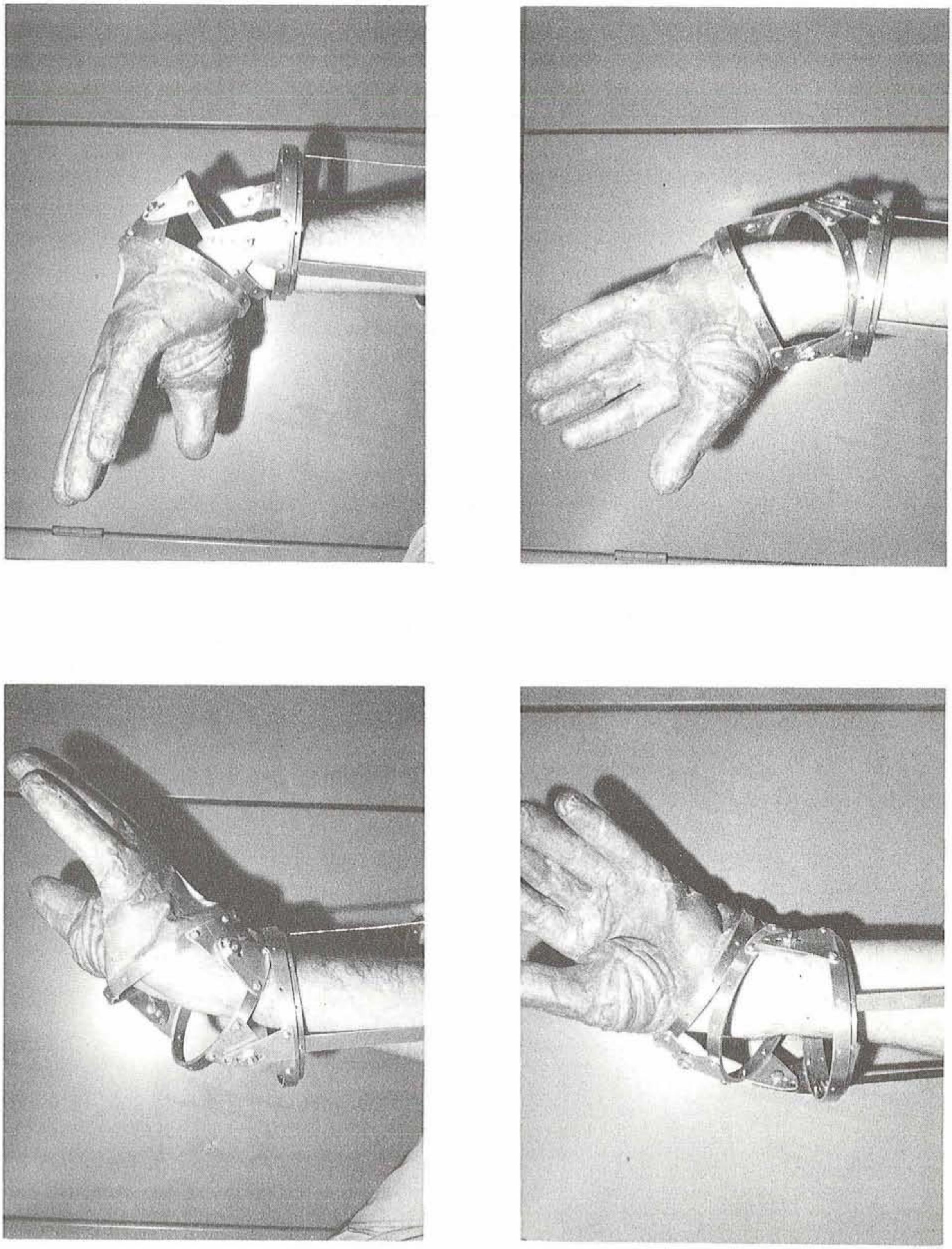


Figure 13B; Phase II Proposed Wrist Joint Size and Range

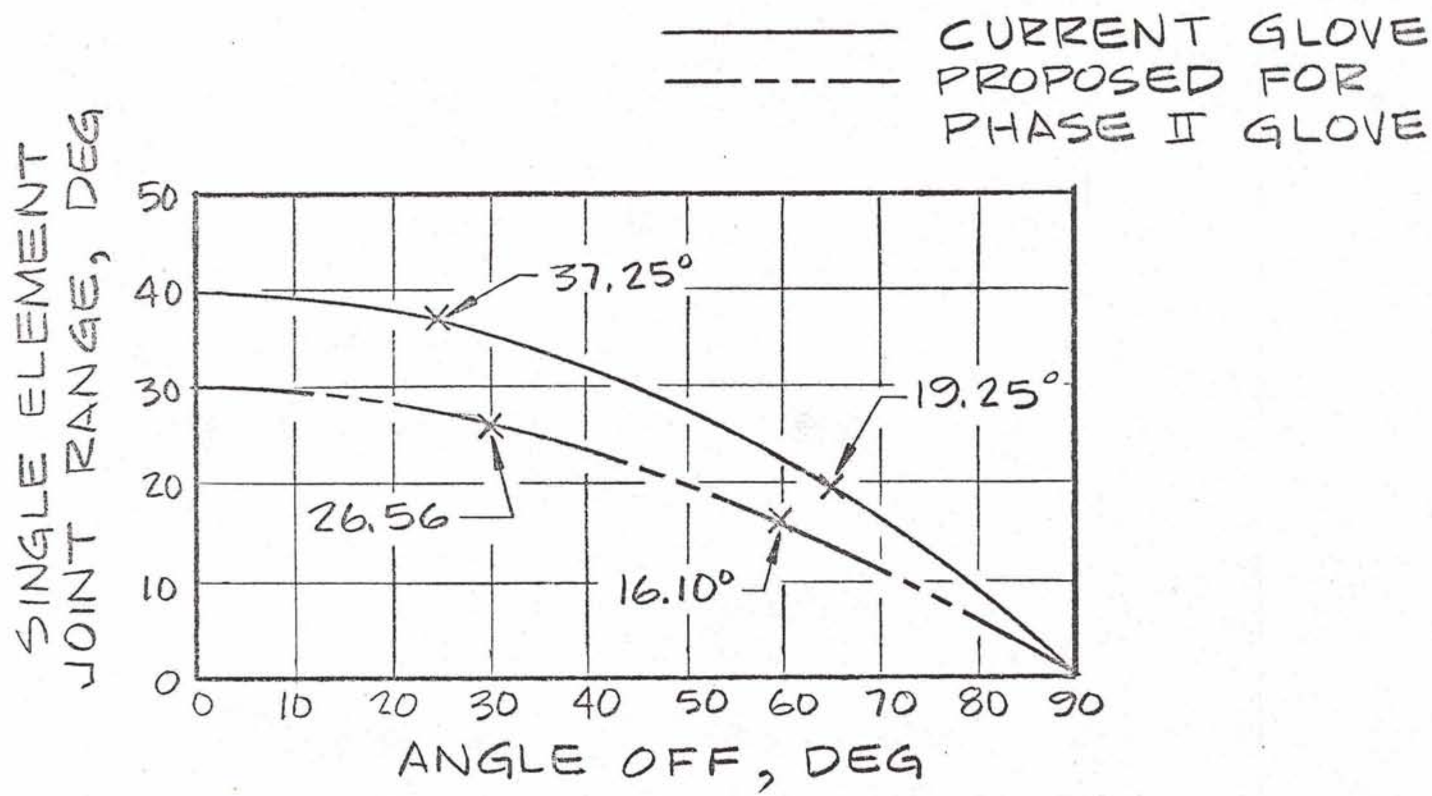


FIGURE 14 EFFECTIVE ANGLE CURVES (FOR TOTAL RANGE MULTIPLY CORRESPONDING POINT ON CURVE BY 2)

SECTION 4

SUMMARY

The Phase I effort has proven feasibility of providing a highly mobile 8.0 psig glove. It also exposed the problem areas which could only be ascertained through fabrication of the testing of the Phase I glove.

Solutions to these problem areas have been tested and the Phase II effort will implement the desired changes.

The end product of the Phase II effort will be one pair of rugged, highly mobile and highly durable 8.0 psig space suit gloves.

APPENDIX A

TEST REPORTS

TEST PLAN-PROCEDURE

PROGRAM 10 PSI GLOVE   No. 7056-12   DATE 9-28-72

TEST NO. I

PURPOSE Proof Test (15 psi) & Life Cycle Test

STEP	SET-UP	PROCEDURE	DATA	VERIFY
1	Finger Pressure Test	15 psi for 15 min.	Start 11:07, Stop 11:22. No damage to finger.	WE
2	Cycle Test Finger	Pressure decay 8 psi to 4.8 psi Before test.	26 min.	WE
		Cycle Test	5,000 Cycles	WE
		Pressure decay 8 psi to 4.8 psi Before test	No Change	WE
3	Finger Pressure Test	15 psi for 15 min.	15 min. test. No damage to Finger.	WE
4	Cycle Test to Destruction	8 psi	10,750 cycles. Base of Convolute was worn out and started to leak.	WE

Figure A-1. Life Test No. 1

TEST PLAN-PROCEDURE

PROGRAM 10 PSI GLOVE　　No. ______　　DATE 10-19-72

TEST NO. II

PURPOSE Proof Pressure & Life Cycle Finger

STEP	SET-UP	PROCEDURE	DATA	VERIFY
1	Leak Test	Pressure Drop	8 psi - 7 psi - 10 Min.	WE
2	Burst Test	15 psi Proof Pressure	15 psi for 15 min.	WE
3	Cycle Test	Cycle for 5,000 Cycles at 8 psi	No Change in Finger	WE
4	Leak Test	Pressure Drop	8 psi - 7 psi - 10 Min.	WE
5	Cycle to Destruction	Cycle at 8 psi		
6	Leak Test	15,000 Cycles	8 psi - 7 psi - 10 Min.	
7	Leak Test	29,000 Cycles	8 psi - 7 psi - 10 Min.	
8	Leak Test	38,000 Cycles	8 psi - 7 psi - 10 Min.	
9	Leak Test	51,000 Cycles	8 psi - 7 psi - 10 Min.	
10	Leak Test	76,250 Cycles	8 psi - 7 psi - 10 Min.	
11	Leak Test	100,000 Cycles	8 psi - 7 psi - 10 Min.	WE

Figure A-2. Life Test No. 2

TEST PLAN-PROCEDURE

PROGRAM 8 PSI GLOVE   No.________   DATE 12-1-72

TEST NO. I

PURPOSE Leak & Proof Pressure Test Glove

STEP	SET-UP	PROCEDURE	DATA	VERIFY
1	Leak Test	8 psi for 15 min.	Leak rate too low to Measure -	WE
2	Proof Pressure	15 psi for 15 min.	No damage to glove	WE
3	Leak Test	8 psi for 15 min.	Leak rate too low to Measure -	WE

Figure A-3. Leak & Proof Pressure Test Glove

485 CLYDE AVENUE, MOUNTAIN VIEW, CALIFORNIA 94040

TELEPHONE (415) 964-3200 TELEX: 34-8355