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Contract NAS8-24840

# Restraint System Development

## VOLUME I FINAL REPORT

JULY 1970





vol. 1 of 2

MARTIN MARIETTA CORPORATION

MCR-70-222

# RESTRAINT SYSTEM DEVELOPMENT

FINAL REPORT

JULY 1970

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Prepared Under Contract No. NAS8-24840

for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
George C. Marshall Space Flight Center
Huntsville, Alabama

Approved

Joseph C. Spencer
Program Manager

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Denver Division
Denver, Colorado 80201

## FOREWORD

This report describes the work performed under National Aeronautics and Space Administration Contract NAS8-24840; Design, Development, Fabrication, Testing, and Delivery of a Restraint System (Positioning Tool for Maintenance and Repairs in Space). The work was performed by the Martin Marietta Corporation, Denver Division, P. O. Box 179, Denver, Colorado for the NASA Marshall Space Flight Center, Huntsville, Alabama. Mr. E. L. Brown of the Manufacturing Engineering Laboratory was the Contracting Officer's Representative. Mr. J. C. Spencer was Martin Marietta's Program Manager.

This report is presented in two volumes. Volume I is the narrative description of the contract effort with results, conclusions and recommendations. Volume II contains the design drawings for the Restraint System.

## SUMMARY

A full-scale prototype of a Restraint System was developed and delivered to NASA-MSFC under this contract, NAS8-24840. The Restraint System is a device which provides the restraining forces necessary to allow the performance of maintenance and repair tasks by a man in a zero-gravity environment. The System is designed to be worn by the man, provide attachment of the man to structure at a work site, allow mobility once attached, and provide rigid restraint at any position within the mobility envelope when desired.

The contract was to be performed in four phases; design and development, fabrication of test hardware, testing, and fabrication of one set of deliverable hardware. The third and fourth phases were modified to extend the period of performance from 27 June 1969 to 30 July 1970 and to provide for additional design and refurbishment of the test hardware in lieu of the structural testing and new hardware fabrication. The modification was the result of zero-gravity simulation tests which were performed at the completion of Phases One and Two. The tests provided valuable data which were then incorporated into the Restraint System design. The hardware was modified to reflect the design changes.

The Restraint System (Fig. 1) is composed of a Belt Assembly, two Telescoping Boom Assemblies, and two Grip Assemblies. Each Boom is attached to the Belt and to a Grip with quick-disconnect couplings. The total Restraint System weighs less than 35.6 newtons (8 pounds) and provides a minimum of 40.65 meter-newtons (30 ft-lbs) torque restraint and will support a 1070 newtons (241 lbs) axial load.

The zero-gravity simulations (including air bearing, neutral buoyancy, and KC-135 tests) have shown the Restraint to be an easy device to use which provides the required mobility and rigidity.

The following hardware was delivered under this contract

| | |
|---|---|
| Belt Assembly (1) | SRD 484010000 |
| Boom Assembly (2) | SRD 484013000 |
| Grip Assembly (2) | SRD 484012000 |
| Grip Assembly (1) | SRD 484014000 |
| Grip Assembly (1) | SRD 484015000 |
| Boom Assembly (1) | SRD 484011000 |

It is appropriate to acknowledge the technical direction, support and cooperation of the NASA-MSFC personnel; particularly Mssrs. E. Brown, W. Wilson, V. Yost, and H. Blaise.

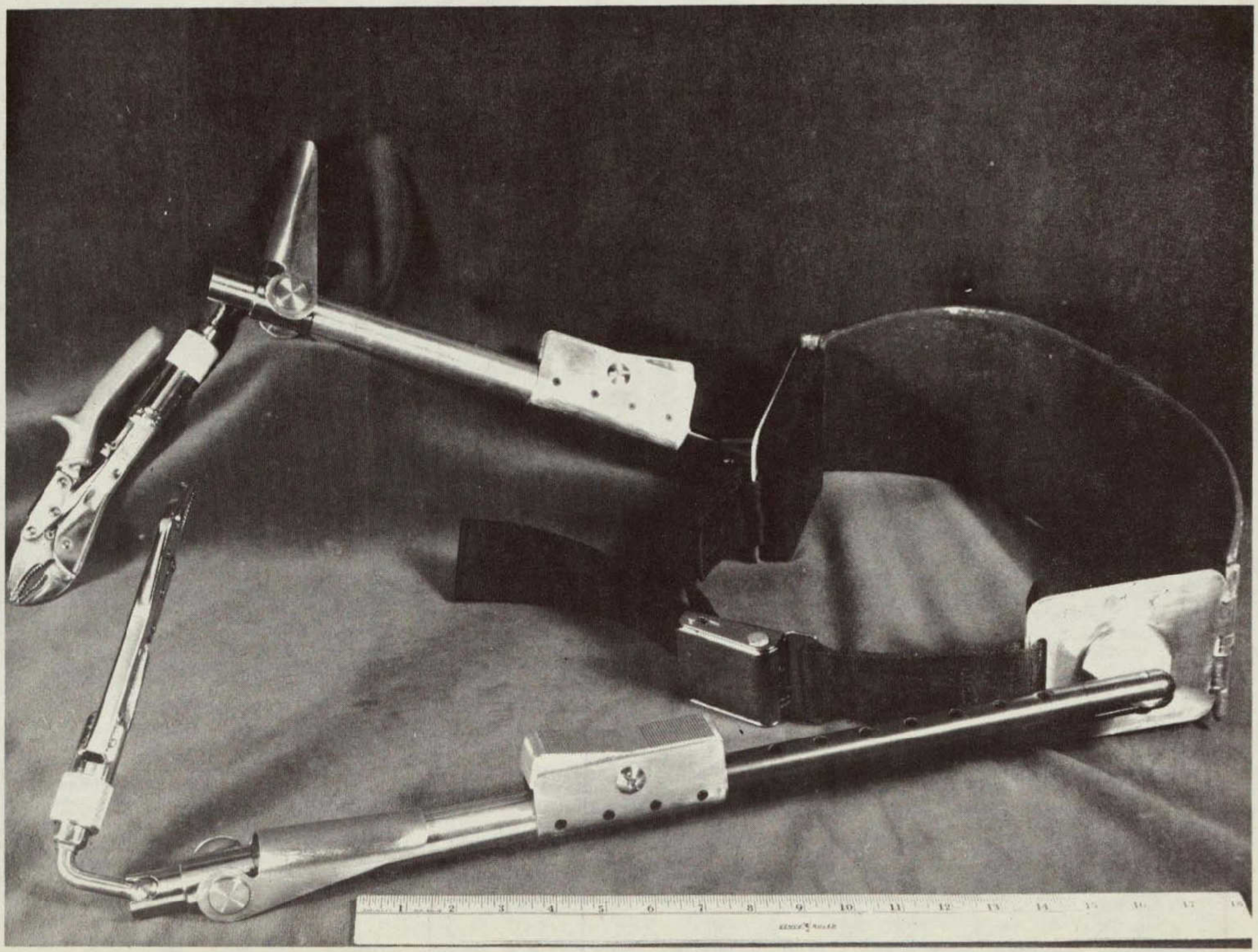

Fig. 1 Restraint System

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# I. INTRODUCTION

For man in a zero-gravity environment to perform maintenance and assembly tasks which require positioning and torque exertion, it is necessary for him to be restrained to the rigid body system upon which he is working. This report describes the development of a device designed to provide such restraint.

The contract was to be completed in four phases as follows. Phase I was to design and develop the Restraint System. Phase II was to fabricate the unit to the Phase I drawings and develop a test procedure for evaluation of the unit. Phase III was to include the evaluation testing with an updating of the design drawings to incorporate any changes resulting from the tests. Phase IV was then to be the fabrication of a deliverable unit to the updated drawings. A modification to the contract altered Phases III and IV. The modification substituted zero-gravity simulations for the detailed testing, added more design time to incorporate changes resulting from the simulations, and provided for refurbishment of the Phase II model rather than fabricate an entirely new unit.

This report is presented in two volumes. Volume I describes the Restraint System development by phases and presents the results and conclusions of the program. Volume II is the complete design drawing package. Volume II is presented in conventional units only.

## II. DEVELOPMENT PROGRAM

The description of the Development Program is presented as four phases; Design and Analysis, Fabrication, Test, and Redesign and Refurbishment.

### Phase I

The first phase of Contract NAS8-24840 for the development of a Restraint System began on 27 June 1969. This phase was to accomplish the design analysis and preliminary drawings.

An orientation meeting was held at MSFC to discuss the philosophy and general approach to the Restraint System. Prior to this contract, development work on a rigid boom concept had been accomplished by MSFC. This contract was to utilize the principles of that concept as the starting point. At the orientation meeting, however, it was decided to spend the first month on conceptual design of approaches other than the rigid boom concept. Also, during that period, the criteria for the system would be evaluated. The simplicity of operation and compactness of the system were to be of prime consideration. The requirements to be imposed on the system were reviewed and are summarized here.

1. The Restraint System would consist of three elements: Belt, Boom, and Grip Assemblies.

2. The Belt Assembly should be adjustable to accommodate both suited and unsuited modes. The assembly should not be deformed more than .0127 meters (1/2 inch) at the edges when a torque of 13.55 meter-newtons (10 ft-lbs) is applied to the boom. The assembly should incorporate quick release capability for ready removal of the Boom Assemblies and for Belt separation.
3. The Boom assemblies should not fail as a column in buckling or lateral bending when the boom is fully extended and an axial compressive force of 889.6 newtons (200 pounds) is applied. The Boom Assemblies shall not deflect more than .00953 meters (3/8 inch) under this loading. The length of the extended Boom should be .813 meters (32 inches).
4. The Grip Assemblies should be adaptable to a variety of surfaces (tubing, edges of flat sheet, etc.). The Grips should have a quick-disconnect capability.

The concepts studied during the initial period are detailed in Appendix A. Four concepts of the Boom portion of the System were studied as were various types of Grip Assemblies. During this period the limitations imposed on an astronaut operating in the A7L pressure suit were investigated to determine their effect on the Restraint System design. The desireability of locating controls on the frontal plane of the body was one result of this investigation. This study showed that the maximum forward reach in the suited mode is approximately .508 meters (20 inches).

A technical review of the first month's activities was held at Martin Marietta Corporation. At this review it was decided to concentrate the design efforts on the rigid boom concept and the three-rod boom concept (Fig. A-4, Appendix A). Two of the grip assembly concepts (Fig. A-8 and A-10, Appendix A) were to be studied further. The following four items also resulted from this review:

1. It was decided that the .813 meter (32 inches) boom length and load capacities requirement should be studied further and modified if they are proved to be more than required.
2. Simplicity was again underscored as the chief requirement of a successful design.
3. When not in use, the Restraint should fit compactly at the astronaut's side between the hip and the knee. It must present no possibility of snagging in narrow passages.
4. With regard to the grip assembly, it was established that in most cases the astronaut would secure these devices to appropriate structural members and then

maneuver himself into a suitable work position. This left remote control of the "grippers" as potentially desirable but not required.

In the period following the technical review, a model of the three-rod boom was built and evaluated with the result that it was not considered worthy of further effort. Several variations of the three-rod boom were also considered. One of these was a flexible center rod with recessed cables running longitudinally from end to end. With clamps at each end, any curvature of the center rod can be locked easily. Further effort on this concept was not considered justified.

Another concept investigated was a pneumatic tube with incremented collars. Here the core tube can be pressurized with the tube in a given curve. The result is the force of the tube on the collars locks the position. The development required for the tube and pneumatic system was considered to be excessive for this effort.

In addition to the work described above, a Litton Hard Suit was evaluated. The suit was available at Martin Marietta. It was pressurized and measurements were made, photographs against a grid pattern were taken, and a physical pattern was made of the suit in the zero-g relaxed position.

As a result of the efforts in this period, it was decided to concentrate exclusively on the rigid boom concept. Fig. 2 shows the results of this effort with a description of the design presented in Appendix B. Detailed design drawings of this concept were prepared and presented in a design review at MSFC. It was decided that the push-button mechanism for controlling the telescoping boom was not good. A redesign was made and submitted as part of the preliminary design package at the completion of Phase I.

A preliminary stress analysis of this design was made and presented as part of the Phase I package. This analysis showed that the present design meets loads imposed by the contract with ease.

The preliminary weights analysis also presented as part of the Phase I package resulted in the following.

Total weight of boom assembly is 19.1 newtons (4.305 lb) per boom if it is steel; and 6.4 newtons (1.44 lb) per boom if it is aluminum. If aluminum tubes are used with the rest of the boom being steel, the weight is 11.2 newtons (2.525 lbs) per boom.

The total Phase I package was submitted and approved by NASA prior to the commencement of Phase II.

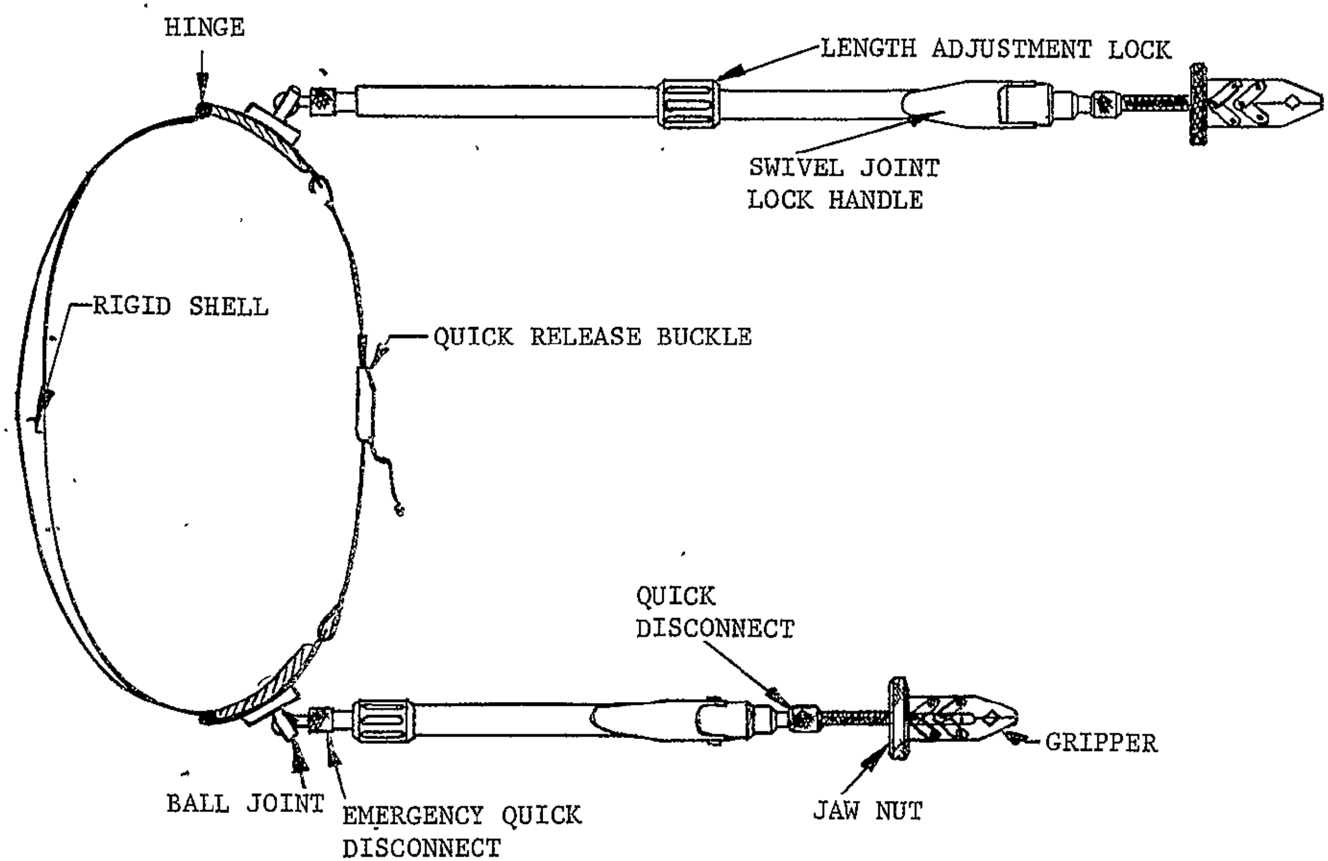



Fig. 2 Restraint System Layout

Phase II

The second phase was to fabricate and assemble the test hardware from the drawings approved during Phase I and to develop a test procedure for use during Phase III. The initial Phase II effort was the fabrication of a Boom Assembly to the Phase I drawings. During this time a new concept in a small vise grip was found. The new grip required no adjustment through its range of operation. It was decided to hold up on the fabrication of the Grip Assembly until this vise grip could be evaluated.

During the boom assembly fabrication, the detailed Test Procedure was prepared. After completion of the boom assembly (Fig. 3), a technical review was held at MSFC. The Boom Assembly and vise grip were reviewed and then the Boom Assembly was tested in the pressure suited mode. This resulted in the following:

1. The direction of the grooves on the handle portion of the Boom would be changed to run perpendicular to the Boom axis.
2. The handle portion would be changed to provide a "shaped" configuration and a reduced size.
3. The weight of the Boom would be reduced.
4. The trigger for the telescoping mechanism would be

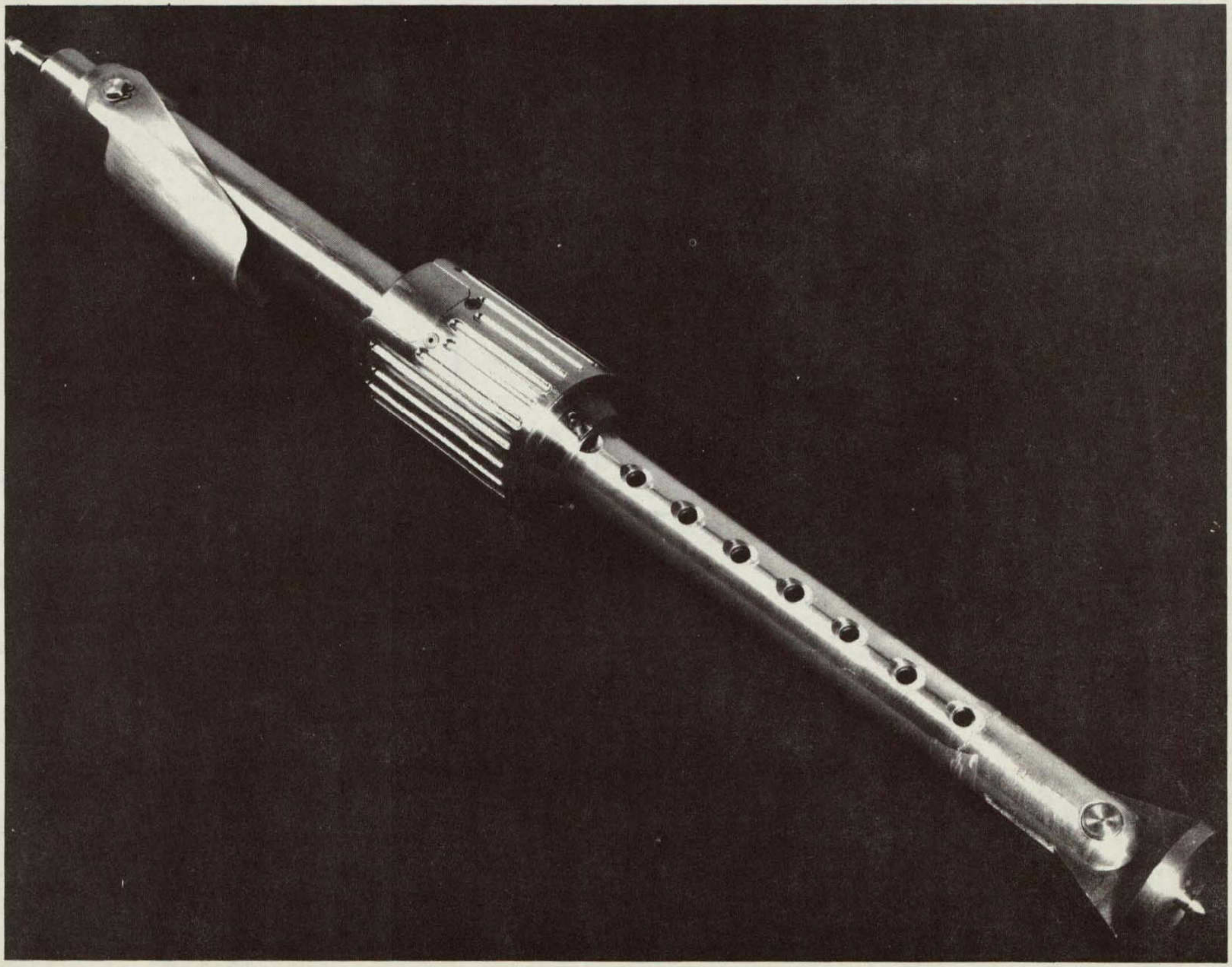


Fig. 3 First Boom Assembly Model

changed to give a "free-wheeling" effect which will allow the Boom to follow the user without actuating the release. The trigger would be shaped and knurled.

5. The grip assembly would be redesigned completely to incorporate the action of the new vise grip.
6. The existing Boom Assembly would be modified to incorporate some of the design changes.

The draft of the Test Procedure was presented and reviewed. The Procedure was subsequently submitted formally and approved by NASA. 35 mm slides of the Boom were made and forwarded to NASA.

Following the technical review the Boom Assembly was redesigned. The initial boom assembly consisted of two tubes, an aluminum tube sliding inside a stainless steel tube and locked by means of a .00635 meter (1/4 inch) diameter pin passing through the outside tube into the inside tube. The lock assembly that operated the pin was a stainless steel cylinder with a flush-mounted lever. The entire boom assembly weighed 25.1 newtons (5.64 lbs). In an effort to permit easier operation of the telescoping lock with the pressure suit glove and reduce the total weight of the assembly, the following changes were made. The telescopic adjustment lock was changed from a single action lever to a double action lever pivoted in the center. One direction retains the lock open while the other direction locks the tubes; thus permitting the operator to unlock the adjustment, work himself into the desired position, and then lock the telescoping adjustment. Both tubes are made from aluminum and the outside diameter is reduced from .0317 meter (1-1/4 inches) to .0254 meters (1 inch). Two Boom Assemblies were fabricated to this new design.

It was decided to coat the outside of the inside tubes of the Boom Assemblies with a teflon penetrated anodize (Nituff) to augment the sliding action.

The grip assembly design of Phase I was replaced by the new vice grip concept. In the new design the grip attaches to the end of the Boom Assembly with a quick disconnect and fold along the boom when not in use. This presents a minimum profile and length when the unit is not in use (Fig. 4). The retracted length is .356 meters (14 inches) with the grip folded on the boom. The length with boom and grip extended is .775 meters (30-1/2 inches). Two of the vice grips were modified to the design (Fig. 5).

The Belt Assembly design was completed and fabricated. The Boom Assemblies were fitted to the Belt Assembly (Fig. 6). The complete system with Grip Assemblies is shown in Fig. 7.

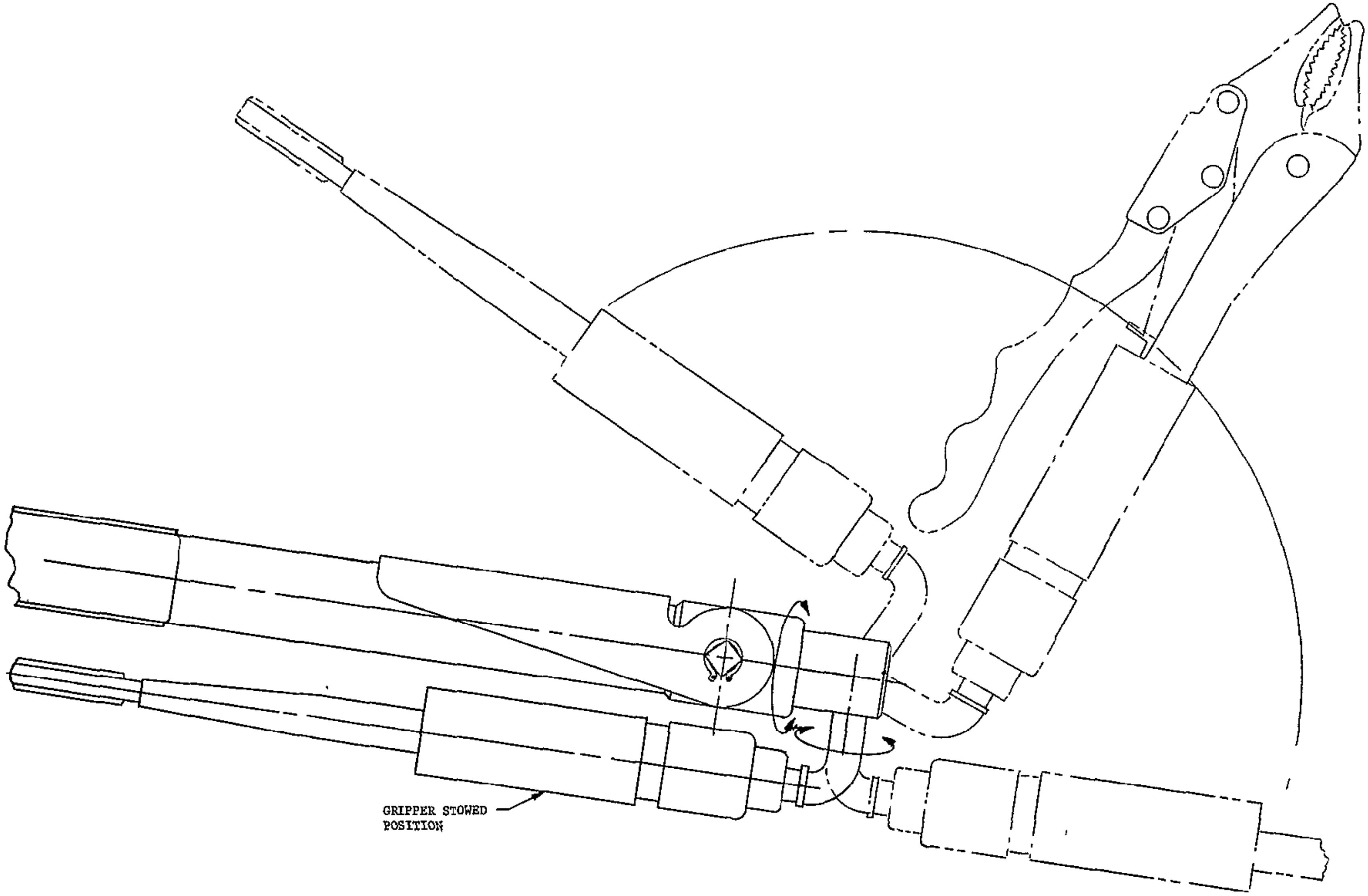



Fig. 4 Grip Assembly Movement

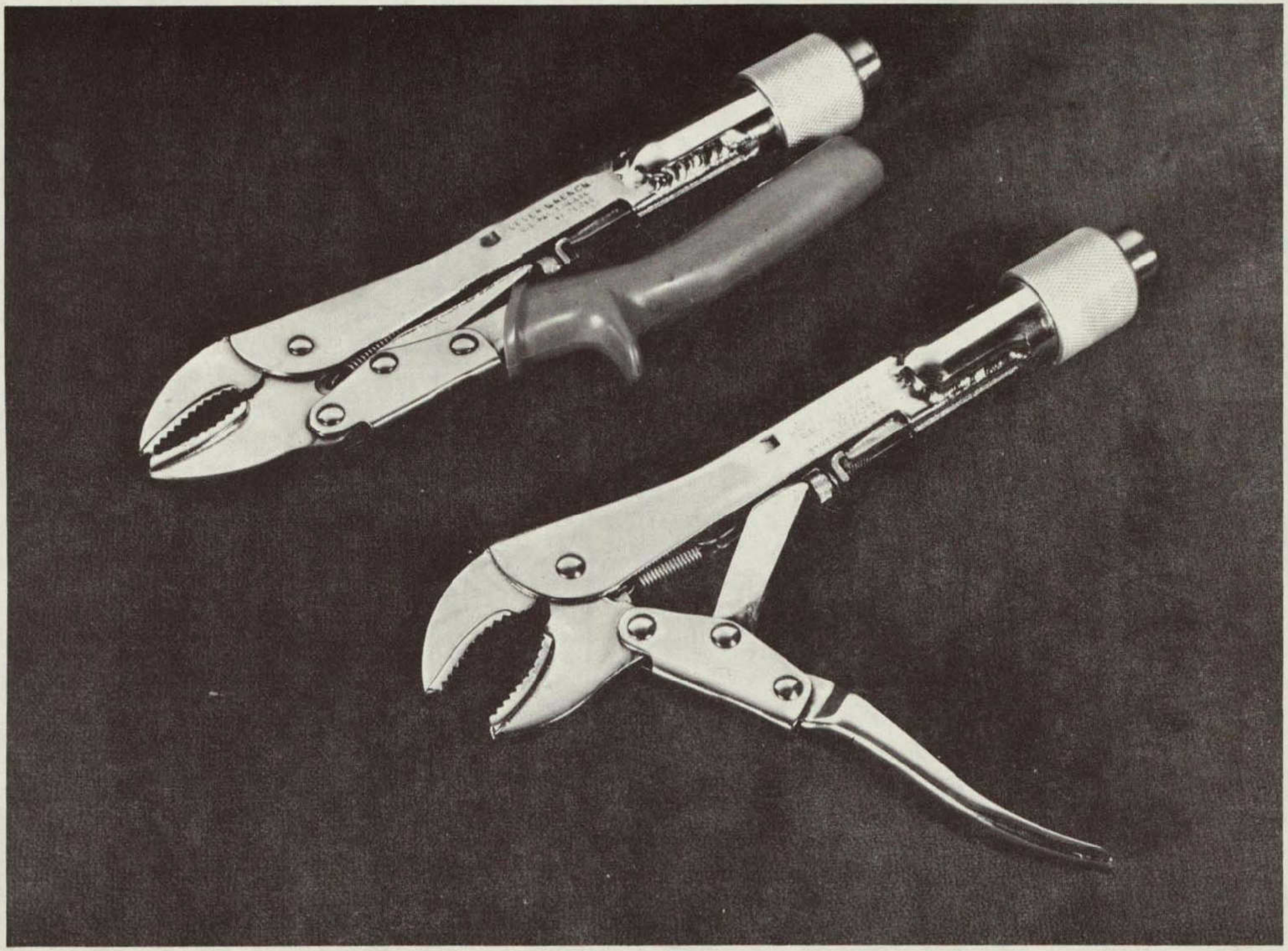


Fig. 5 Grip Assemblies

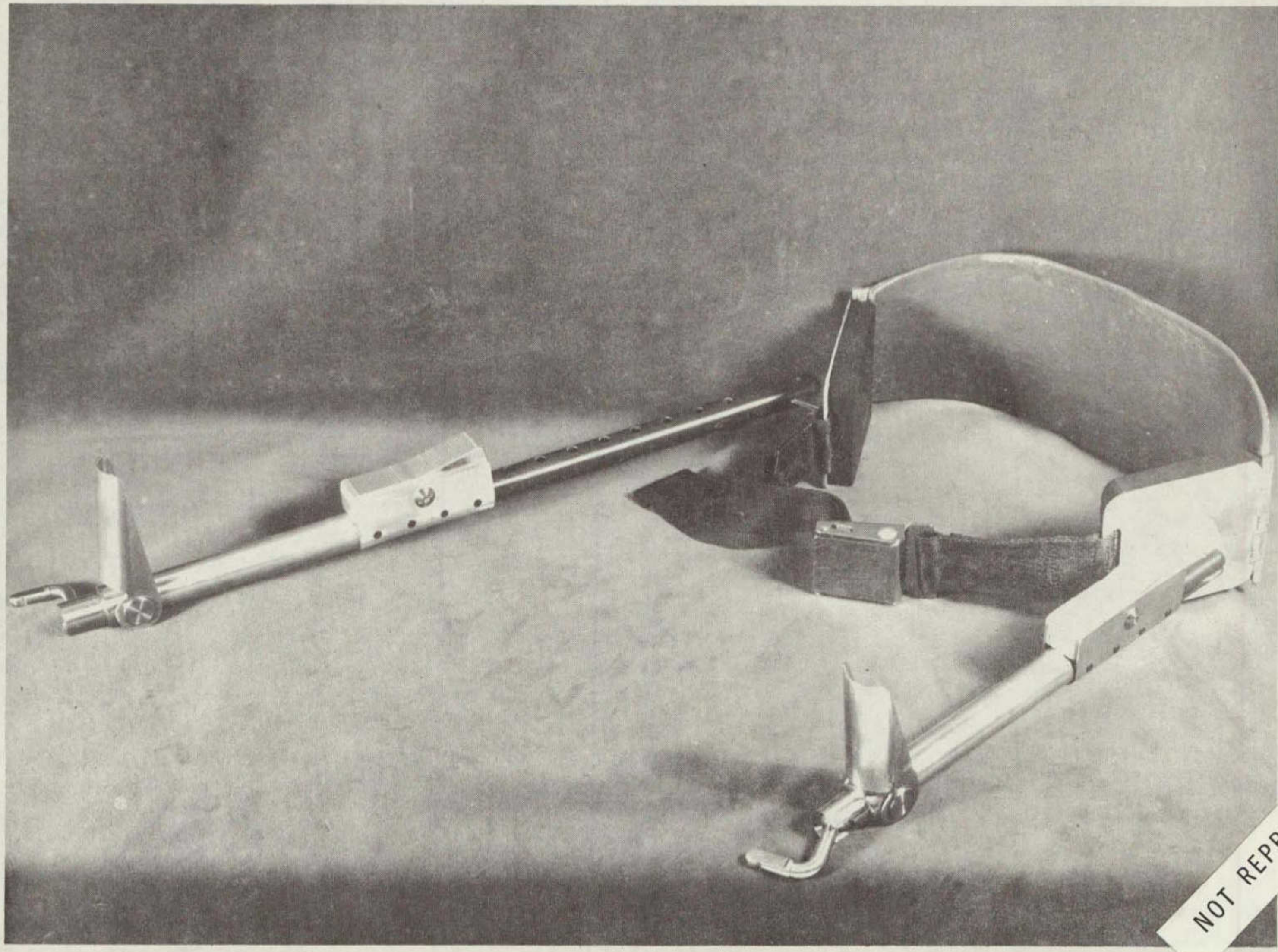




Fig. 6 Belt and Boom Assemblies

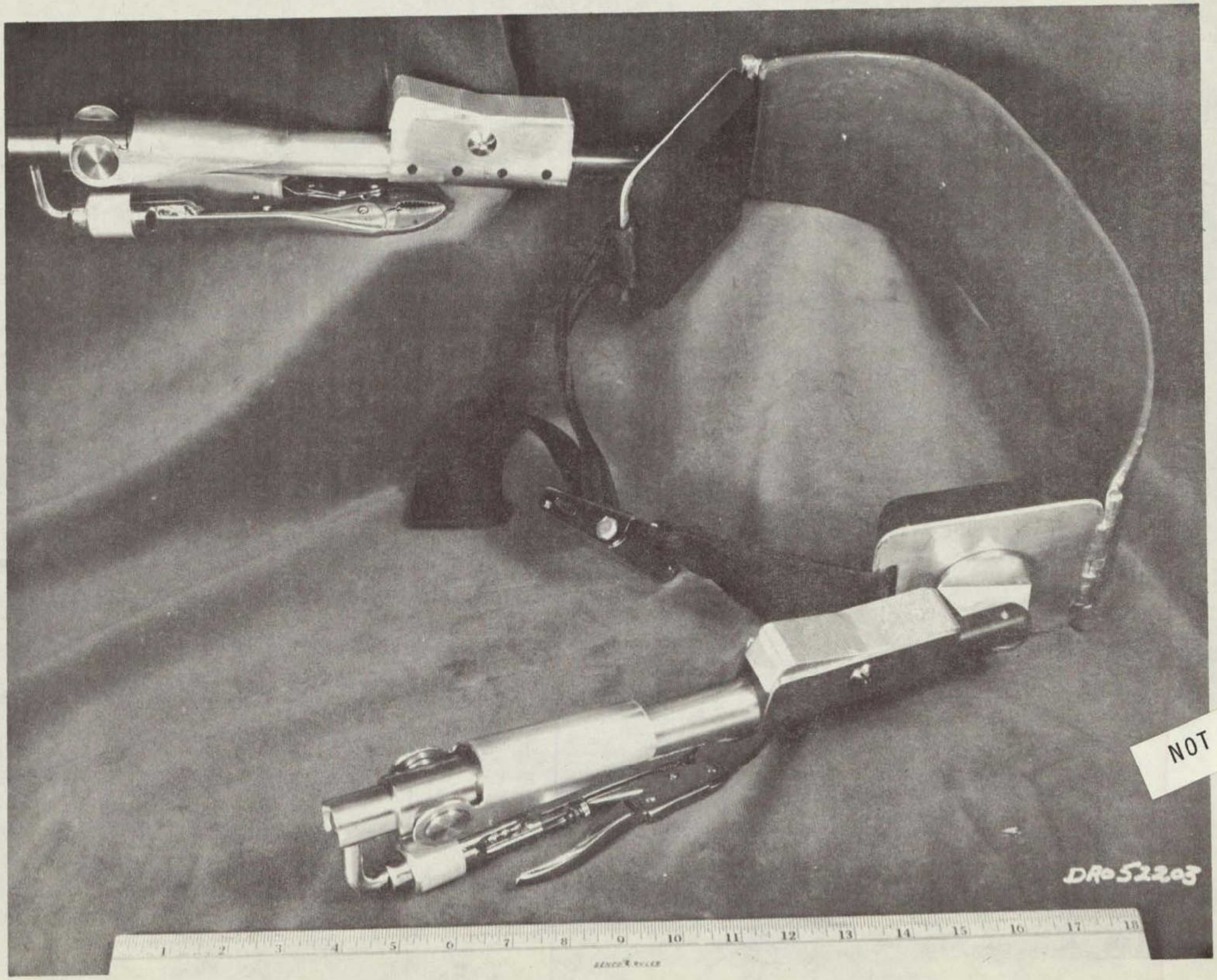





Fig. 7 Restraint System

Phase III

Phase III was to perform testing in accordance with the Test Procedure developed and approved as part of Phase II. The first effort was a weight check of the system which follows.

| | |
|---|---|
| Belt Assembly | 11.85 newtons (2.67 lbs) |
| Grip Assembly #1 | 3.02 newtons (0.68 lbs) |
| Grip Assembly #2 | 3.07 newtons (0.69 lbs) |
| Boom Assembly #1 | 8.72 newtons (1.96 lbs) |
| Boom Assembly #2 | 8.67 newtons (1.95 lbs) |
| Total | 35.33 newtons (7.95 lbs) |

A 65% reduction in weight of the Boom Assembly was achieved with the new design.

Prior to the planned test program, two demonstration tests were performed at MSFC. The demonstration tests were zero-gravity simulations performed in the Mechanical Simulator (air bearing) and in the Neutral Buoyancy Facility.

A NASA-MSFC test subject was used for the Mechanical Simulation. He performed the demonstration test in both the unsuited and pressure suited modes. Both still and movie film coverage of the test was obtained. The test was in conjunction with the test of the Portable Astronaut Test Kit. A comparison between a flexible (strap) tether and the Restraint System was achieved. Fig. 8, 9 and 10 show the restraint on the Test Subject. Fig.

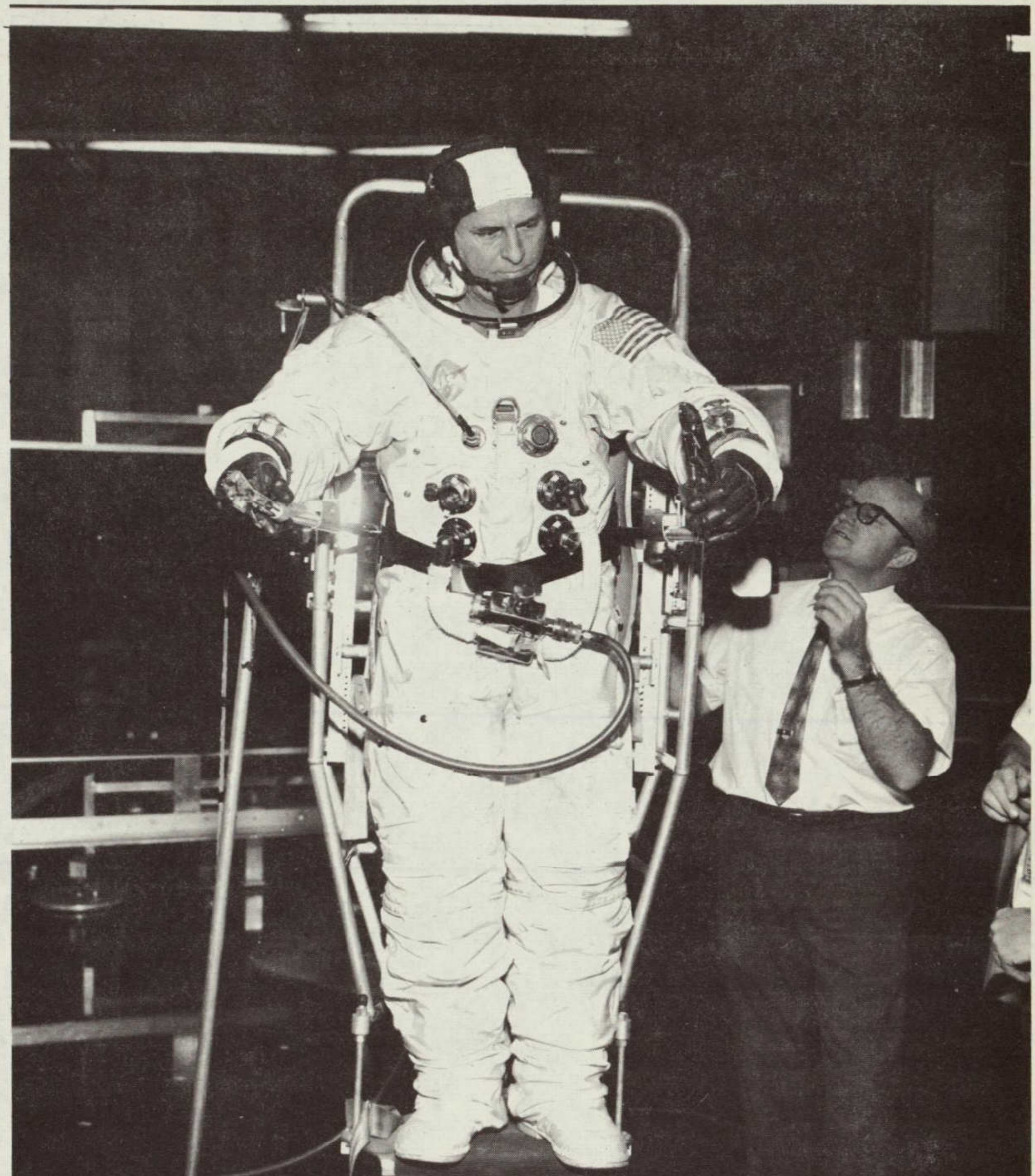


Fig. 8 Pressure Suited Subject with Restraint System

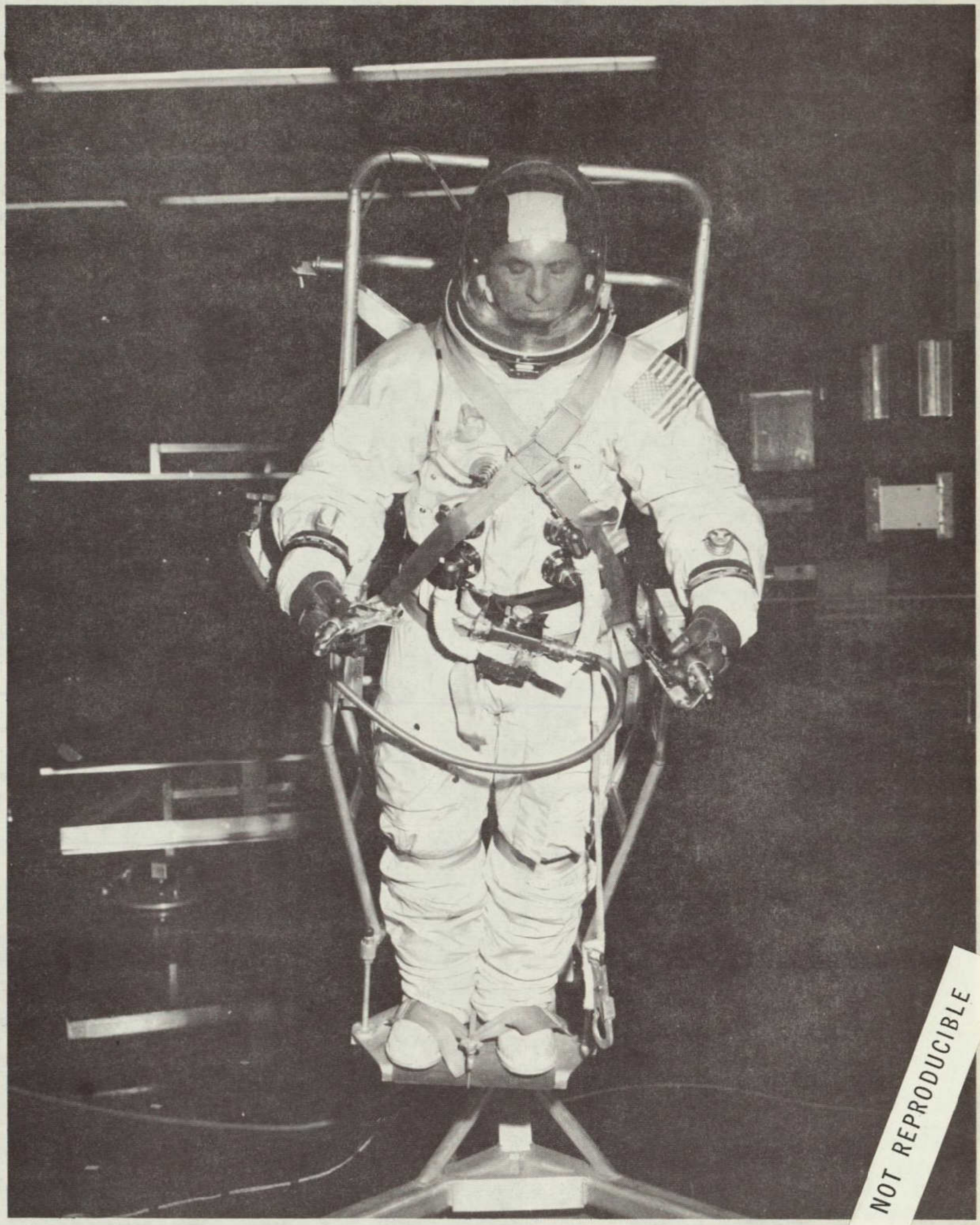




Fig. 9 Pressure Suited Subject with Restraint System

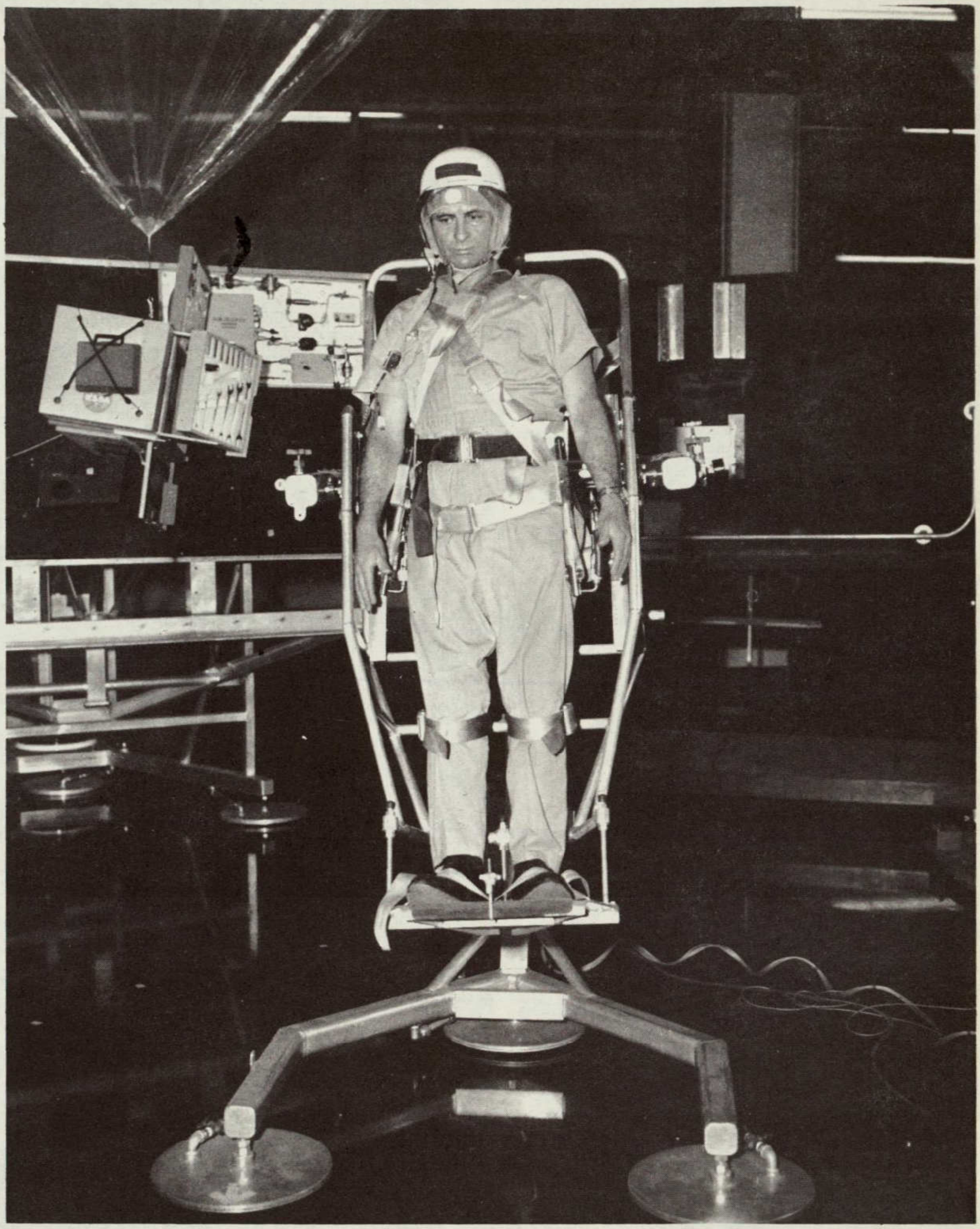


Fig. 10 Unsuited Subject with Restraint System

11 through 20 show the Restraint at various points during the test. The results of this test follow.

1. The flexible strap tether provided almost no restraint as compared to the rigid restraint.
2. The Restraint System was easily manipulated in both the suited and unsuited modes with the exception of the Grip Assembly. In the suited mode, it was hard to attach the grip to the structure with one gloved hand.
3. The restraint allowed a great deal of freedom of movement in the unlocked mode. When locked, it afforded more than adequate restraint against the work forces imparted. The high inertias of the simulators taxed the restraint severely.
4. In the suited mode, a one-tether operation was tried. This performed satisfactorily.
5. The test subject's comments were very favorable toward the Restraint System.
6. The two Grip Assemblies had different length and shaped handles. The handle with the greater length and the shaped lever was the easiest to use.
7. The quick disconnects operated easily.
8. The telescoping lock mechanism functioned well.
9. The forward ball joint lock performed well; however,

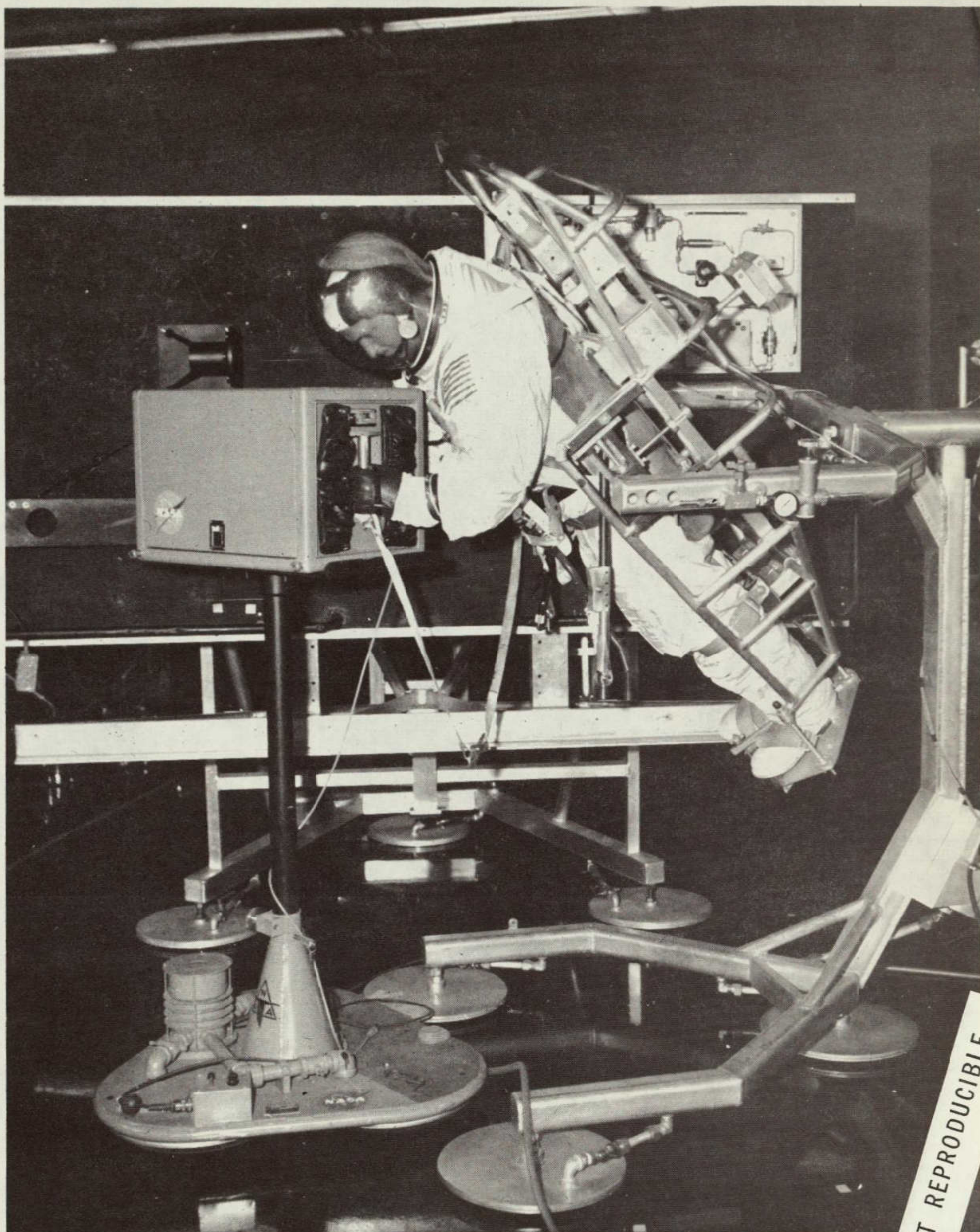




Fig. 11 Pressure Suited Subject Untethered

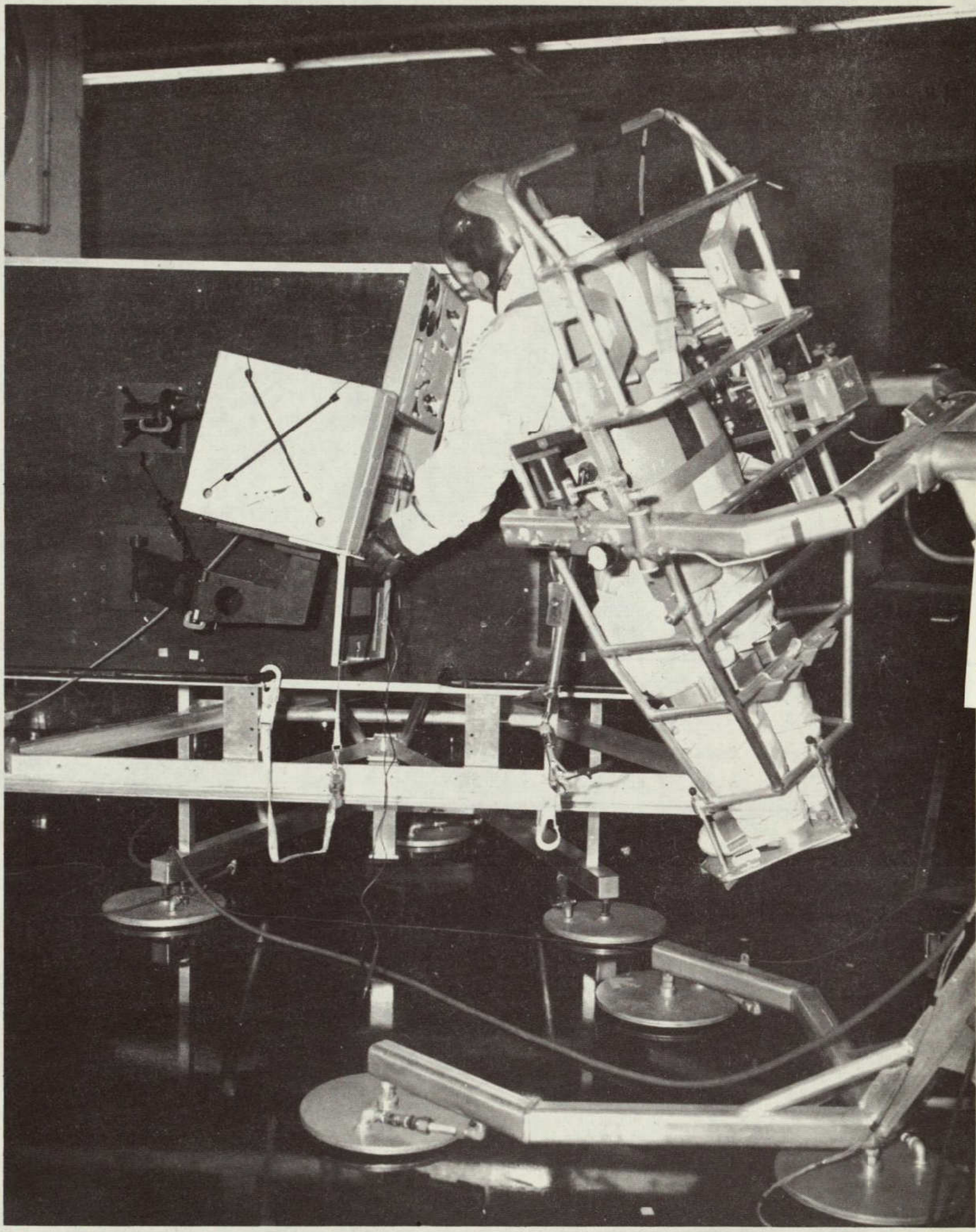




Fig. 12    Pressure Suited Subject Working with Single Tether

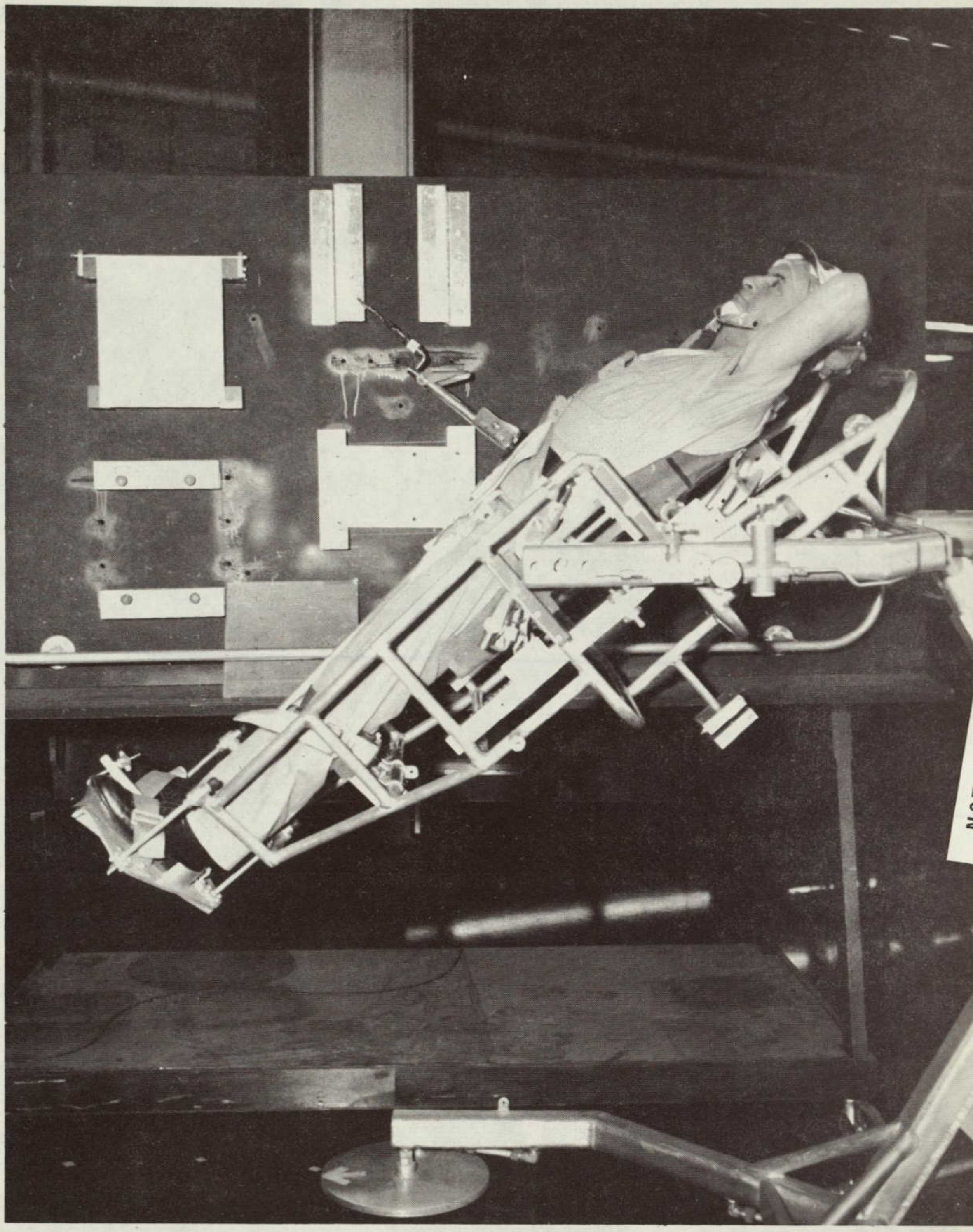




Fig. 13 Subject Demonstrating Resting (Sleeping) Application

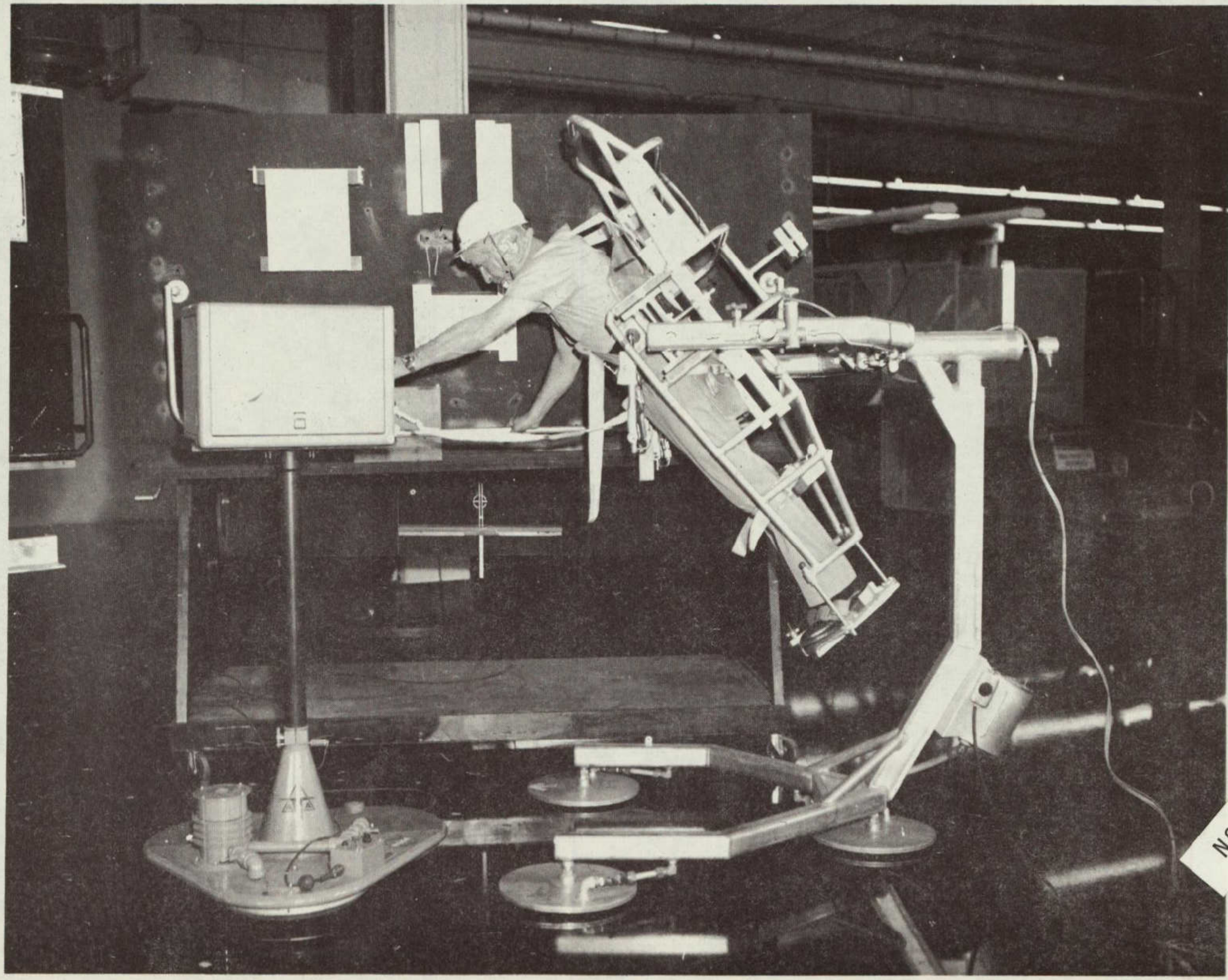


Fig. 14  Unsuited Subject Translating Prior to Tethering

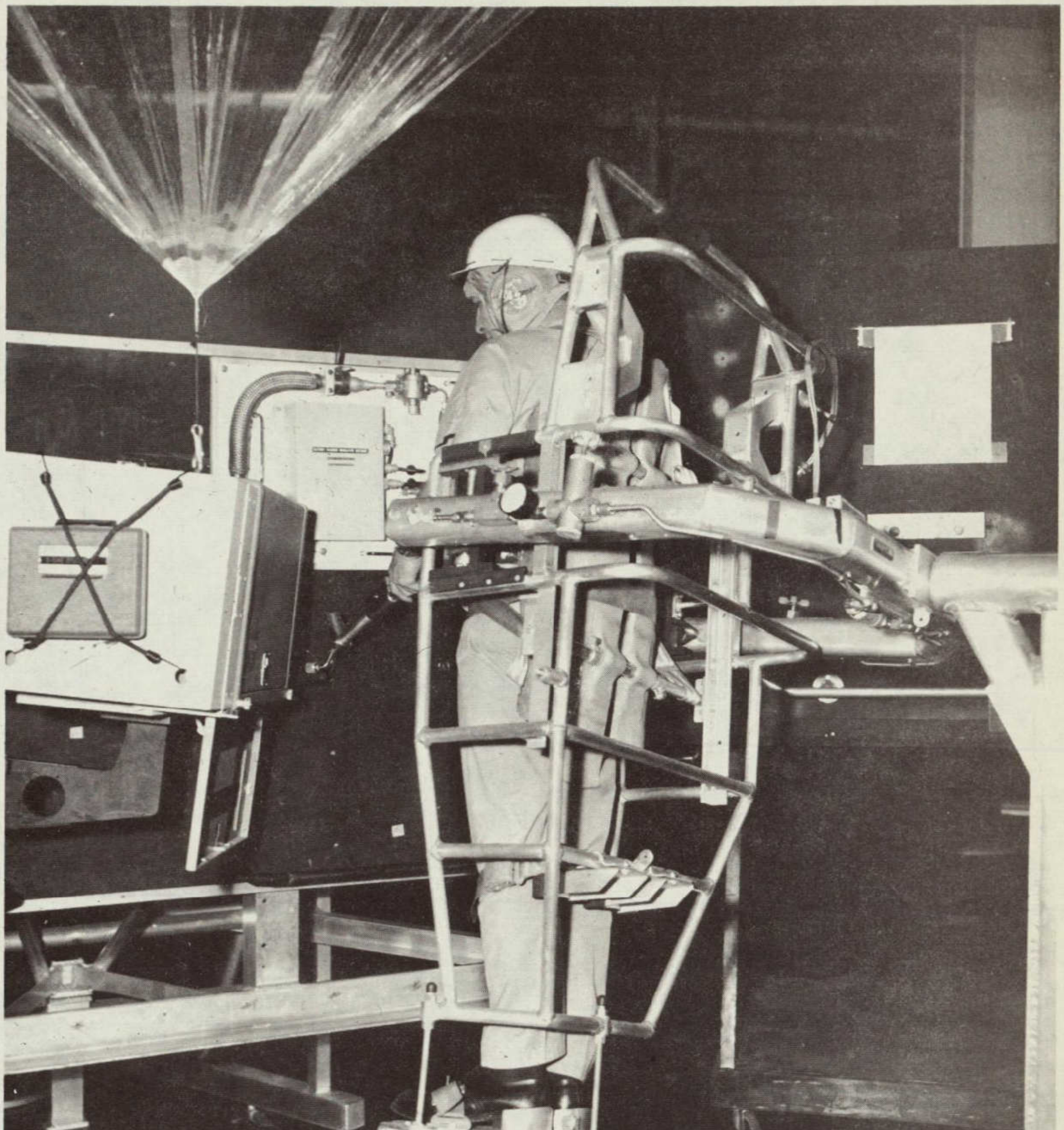


Fig. 15 Subject Tethered Prior to Locking-Up

Fig. 16 Subject Working While Tethered

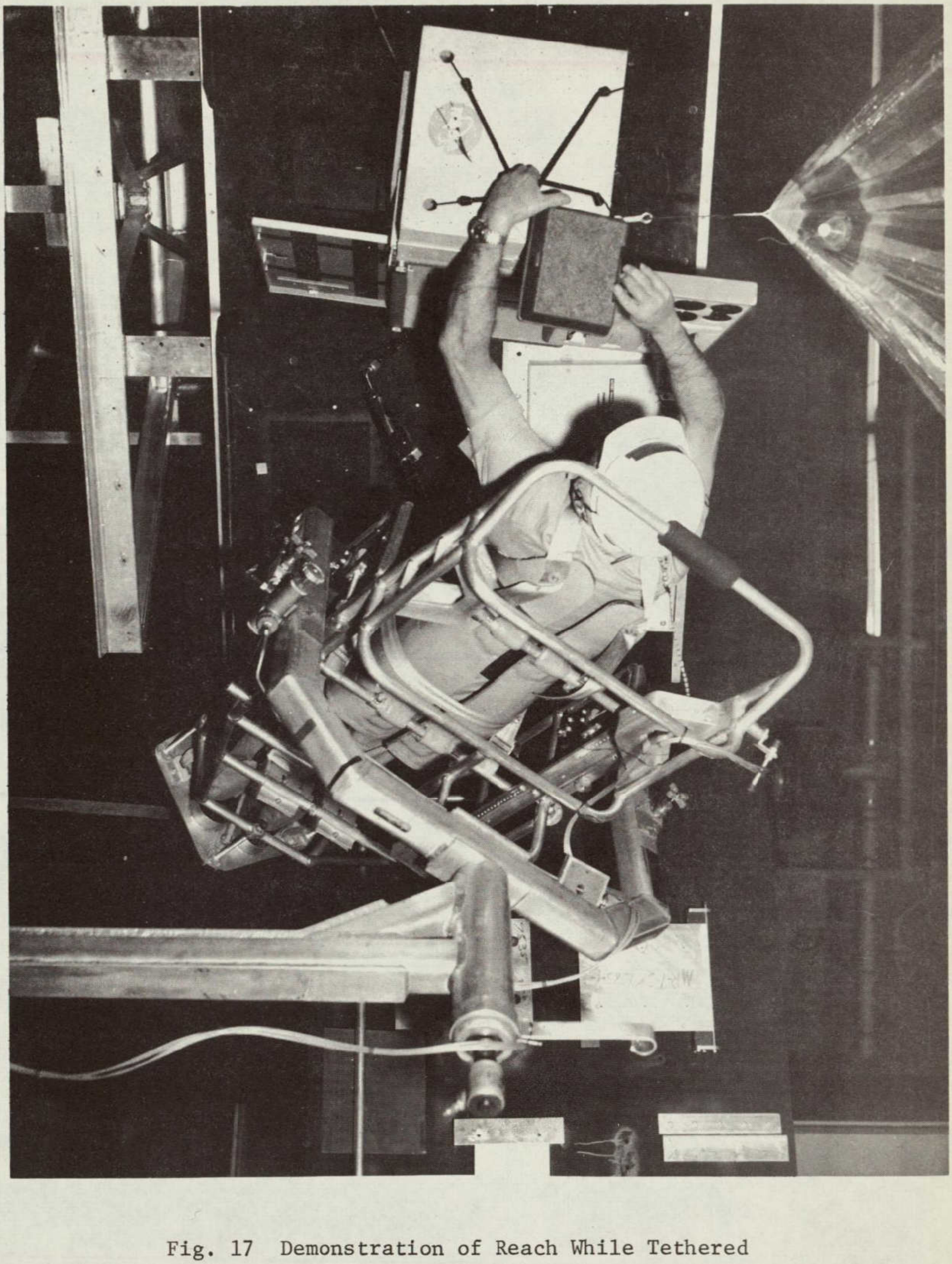


Fig. 17 Demonstration of Reach While Tethered

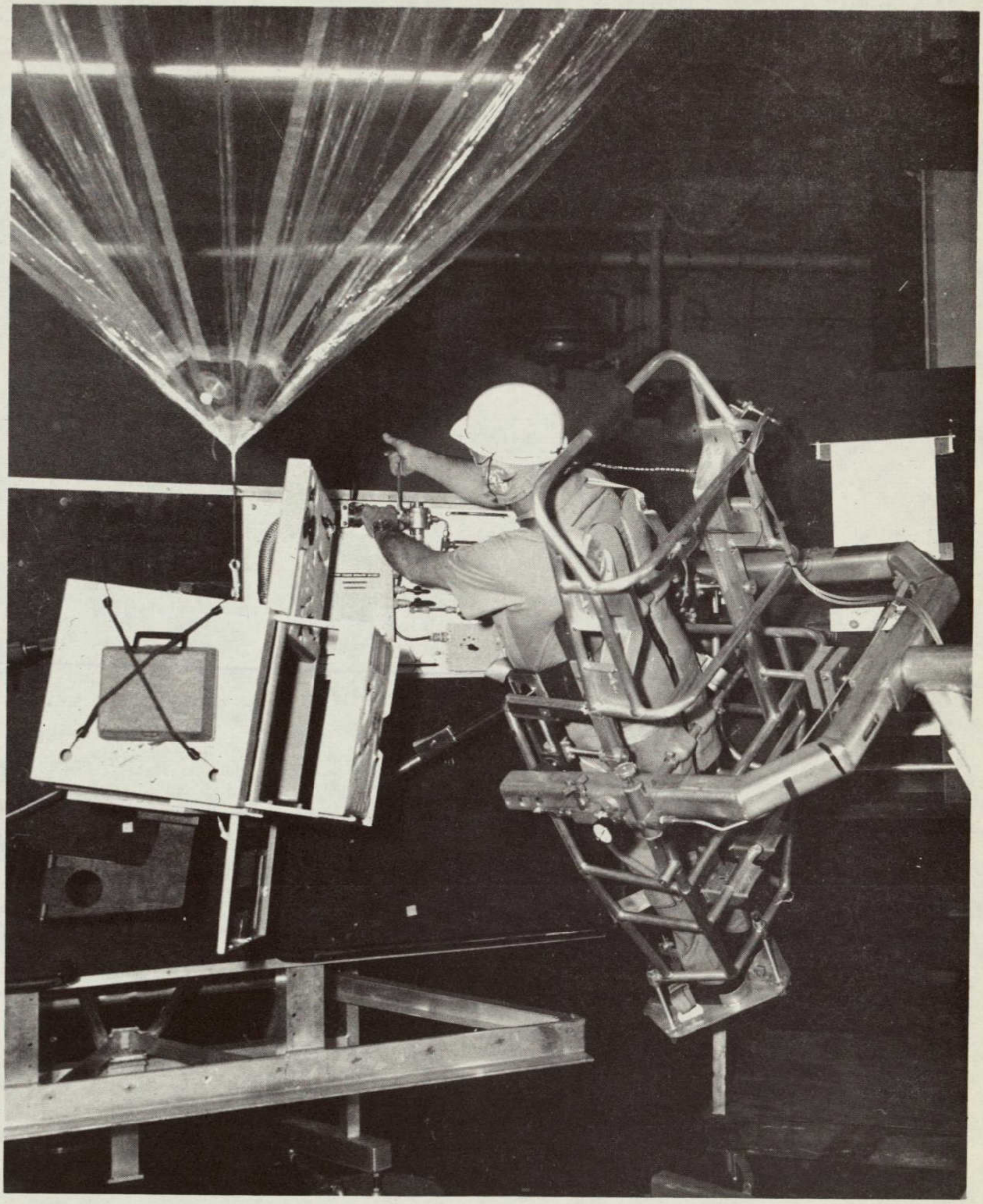


Fig. 18 Subject Working While Tethered

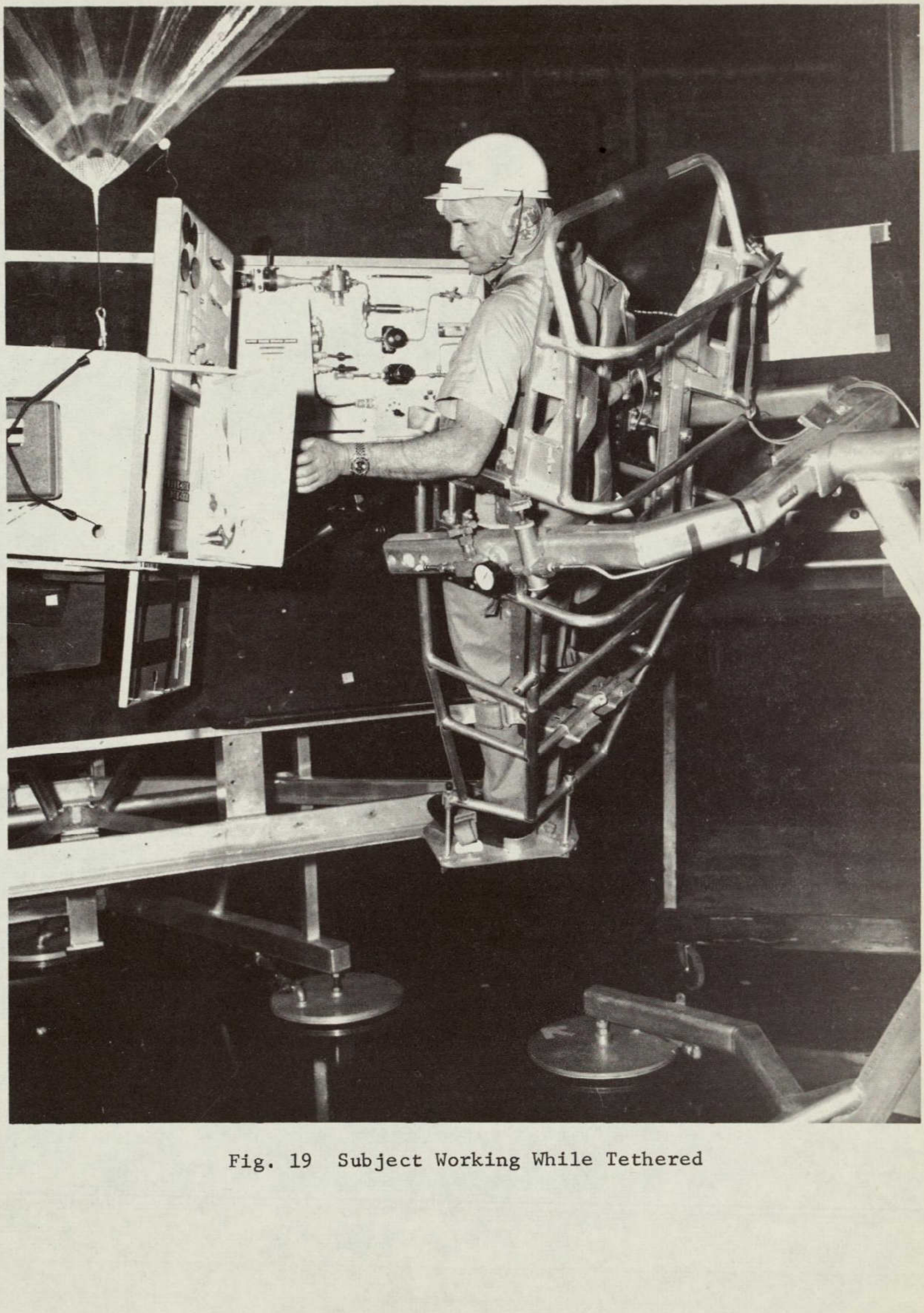


Fig. 19 Subject Working While Tethered

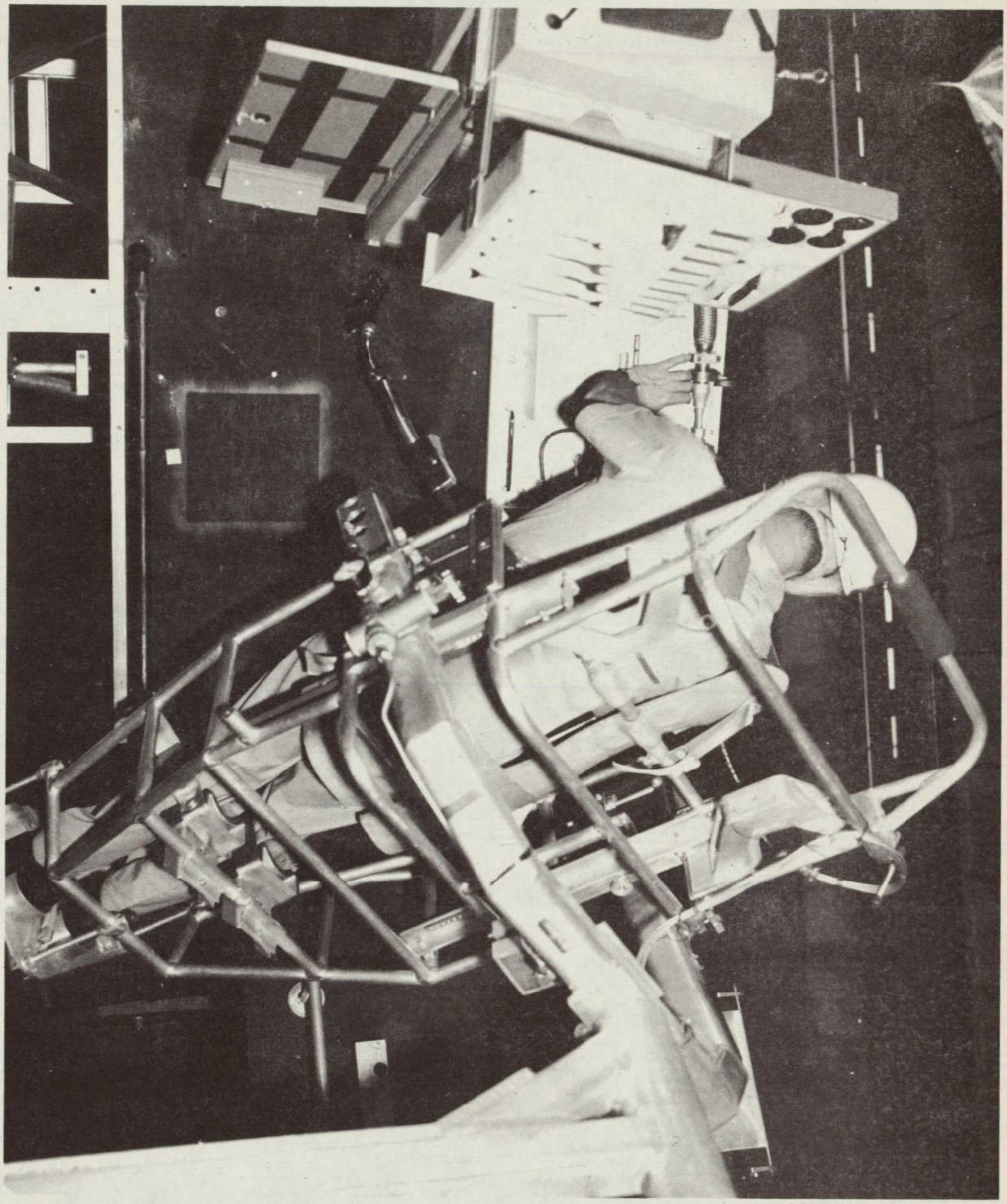


Fig. 20 Subject Working While Tethered

the lock handle could be partially closed by accident which would impede the unlocked maneuverability.

Following the Mechanical Simulation, the restraint was tested in the Neutral Buoyancy Facility. A NASA-MSFC test subject donned the restraint and took it under water and locked on the OWS mockup structure. He then evaluated the unit for maneuverability, support, and operation. Following his evaluation, one of the astronauts present donned the unit and performed similar tasks. All operations were observed through the TV monitor system. The following are the test subject's, astronaut's, and observer's evaluations.

1. With the Grips attached and all controls unlocked, the maneuverability was limited only by the length of the Boom. The subject rotated $180^{\circ}$ in the vertical plane, both perpendicular and parallel to the structure. He moved up until he was against the structure. The same was true for down and to both sides. He appeared to have all of the mobility of a flexible tether. Both the subject's and the astronaut's comments were favorable on the maneuverability of the system.
2. The system could be locked at any position and different orientations were tried. The comments were that the system slipped a little due to the subjects' being

negatively buoyant. Both commented that the holding force of the system should be adequate in zero-g.

3. The grip assemblies were hard to use one-handed. The quick disconnects worked well. Comments were that the grip assemblies should be lined to protect the structure being used. A conclusion was that a better grip should be developed.

4. The telescoping mechanism worked well but the lock could be inadvertently hit with the arm. A guard should be provided.

The general conclusions from the testing were that the Restraint System performed well in simulated zero-gravity and that the tether is good and the approach is correct. The tests demonstrated the need for some further development and several design changes. The remainder of the Phase III testing was deleted by a contract modification which is detailed in the Phase IV description.

Phase IV

As a result of these tests, a modification to the basic contract was processed which redirected the remainder of Phase III and Phase IV. The modification extended the period of performance to 30 July 1970. In addition, the remainder of the Phase III testing and test report were deleted in lieu of a redesign effort to incorporate the results of the demonstration tests. The test hardware was to be refurbished to include the design changes. The modification provided for the following:

1. Redesign the Grip Assembly and line the jaws with a resilient material.
2. Fabricate two grip assemblies to the new grip design and existing quick disconnect design.
3. Redesign the Ball Joint Handles to provide a flaired edge and end for easier gloved-hand operation. Also relocate the handle to the side of the Boom Assembly.
4. Redesign the telescoping locking mechanism to provide shielding against inadvertent actuation. Investigate relocation of mechanism and providing a larger spring force on the lever.
5. Fabricate and install the quick disconnect mechanism at the belt/boom interface.
6. Fabricate and install the parts necessary to modify the existing Boom Assemblies to the new design and refurbish (new Nituff coating) the parts which will be re-used.
7. Deliver the prototypes which reflect the redesign and refurbishment.

The redesign was completed and the final design is reflected in the design drawings presented in Volume II of this report. The following is a discussion of the design changes.

The new grip assembly concepts were designed, fabricated and delivered. These concepts are shown in Fig. 21 and the design drawings are included in Vol. II. The concepts utilize spring loaded jaws which require squeezing to open.

The ball joint handles have been redesigned to:

a. provide a flaired edge for easier operation, and;

b. latch in the unlocked position to prevent unintentional partial locking. New handles have been fabricated. The handles have also been relocated from the top to the side of the boom and new outer tubes have been fabricated to accomplish the change.

The design of the telescoping locking mechanism has been changed to extend the sides to shield the lock against inadvertent actuation. The locking pins were changed in length and angle of entry to prevent any slip of the tubes when under heavy load. New components have been fabricated for this design. The locking mechanism actuator has been relocated from the top to the bottom side of the boom and a larger spring force has been provided.

The quick release actuator on the swivel plate hip joint subassembly has been redesigned from a button release to a lever

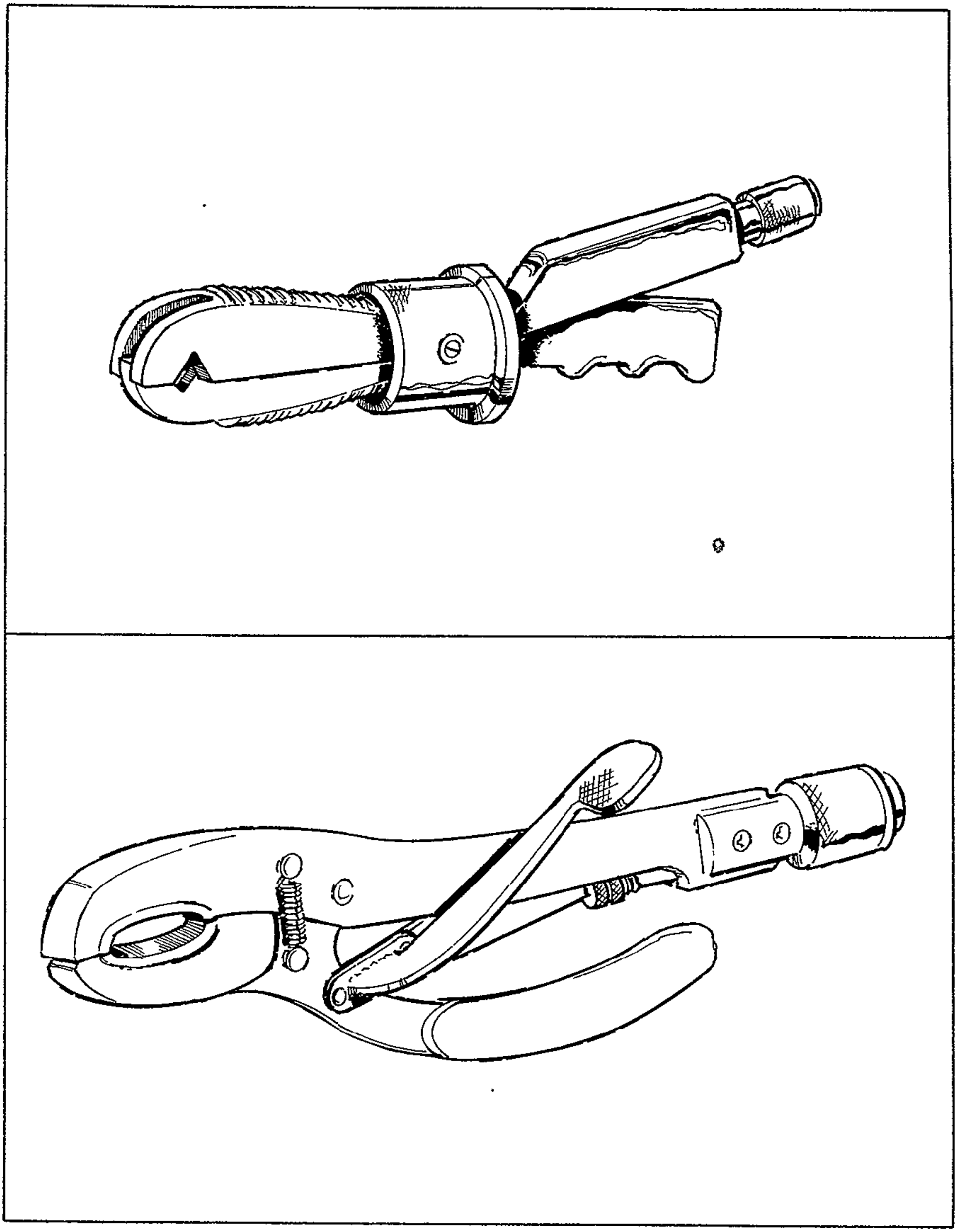


Figure 21 Grip Concepts

release to prevent inadvertent actuation. The boom can be released by $90^{\circ}$ rotation (forward) of the lever. The new design also incorporates an attachment to hold the boom at the stowed position when it is not being used. Complete new swivel plate hip joint subassemblies were fabricated.

The decision was made to coat the sliding surfaces of both telescoping tubes for the boom assembly with NITUFF (a teflon penetrated hard anodize coating). The outside of the outside tube would not be coated. This has been accomplished and the Belt and Boom Assemblies have been fitted and assembled.

During Phase IV a test of the torque resisting capability of the boom assembly was made. The forward ball joint with the friction lock is the only portion of the boom assembly in question. This joint (smooth surfaces and lubricated) presented a resistance of 20.3 meter-newtons (15 ft-lbs) breakaway torque before slipping. The total restraining moment for the Restraint System (2 Boom Assemblies) would therefore be 40.6 meter-newtons (30 ft-lbs). The axial loading capability (restraint to a push-pull force) is calculated to be 1070 newtons (241 lbs).

Also during this phase the Restraint System was tested in a zero-gravity simulation in the KC-135 aircraft. The following are the comments of the test subject.

1. The jaws of the Grip Assemblies should be lined to protect the structure to which they are attached.
2. The telescoping lock mechanism would slip under a heavy load.
3. The slot in the forward ball joint collar was hard to find when returning the Grip Assembly to the stowed position.
4. It was felt that the hip plate swivel joint should have provisions for locking. It was suggested that if this joint were lockable, the forward joint may not need to be lockable.
5. The rigid back plate on the Belt Assembly is not needed for suited operations. A flexible belt to connect the hip plates is all that is required. The flexible belt becomes very rigid when the suit is pressurized and provides all of the necessary support.

Item 5 is most significant for future design of the Restraint Device. Items 1 and 2 were disclosed in previous tests and have been corrected. Items 3 and 4 appeared for the first time and could be the results of the characteristics of the test vehicle, i.e., the forces encountered in the transition from negative to positive g and the short duration of the zero-g field. It is felt that further study is warranted before design changes are recommended for items 3 and 4.

## III. CONCLUSIONS AND RECOMMENDATIONS

### A. Conclusions

The primary conclusion resulting from this effort is that the rigid boom approach to provide positioning and restraint is superior to other concepts. The Restraint System design resulting from this study provides a free mobility which approximates a flexible or fabric tether. In addition to the freedom of movement, the design allows the system to be rigidized or locked-up at any position. The resulting restraint is 40.6 meter-newtons (30 ft-lbs) in rotation and 1070 newtons (241 lbs) in axial loading. This restraint is considered adequate for all inflight maintenance tasks requiring restraint of this nature. Larger restraint forces can be easily obtained by using the legs or arms for bracing. The use of a limb or limbs with the Restraint provides an excellent truss arrangement.

The useability of the Restraint in the zero-gravity environment has been determined through the use of the simulation mediums of the six-degree-of-freedom Mechanical Simulator at MSFC, Neutral Buoyancy, and the parabolic trajectories of the KC-135.

The weight of the prototype system is less than 35.5 newtons (8 lbs). This weight can be reduced for a flight article with a further reduction for pressure suited application. The rigid back plate of the Belt Assembly is not required when the system is used with a pressure suit.

The configuration of the system provides a minimum profile, both in length and width, when it is not activated. The system is easily operated and provides three independent methods of release in the event of emergency. These are:

1. Belt-to-Boom Quick Release
2. Grip-to-Boom Quick Disconnect
3. Belt Buckle Release

Each of these methods will effect release.

B. Recommendations

The Restraint System development should continue to insure its availability for the Skylab Program. A tether of this type should be a portion of either the operational hardware or the experiment hardware. To achieve this position, the following is required.

A more comprehensive study of different types of Grip Assemblies compatible with the anticipated Skylab structure should be accomplished.

An end item specification for a flight qualified Restraint System should be prepared.

The current prototype system should be subjected to more simulation testing and astronaut review. Any redesign indicated by these evaluations should be accomplished.

A belt assembly for pressure suited application should be designed and fabricated. A quick change-over from suited to unsuited application should be considered. A possibility is a removeable back plate.

The design should be subjected to a materials study to insure flight requirements will be met.

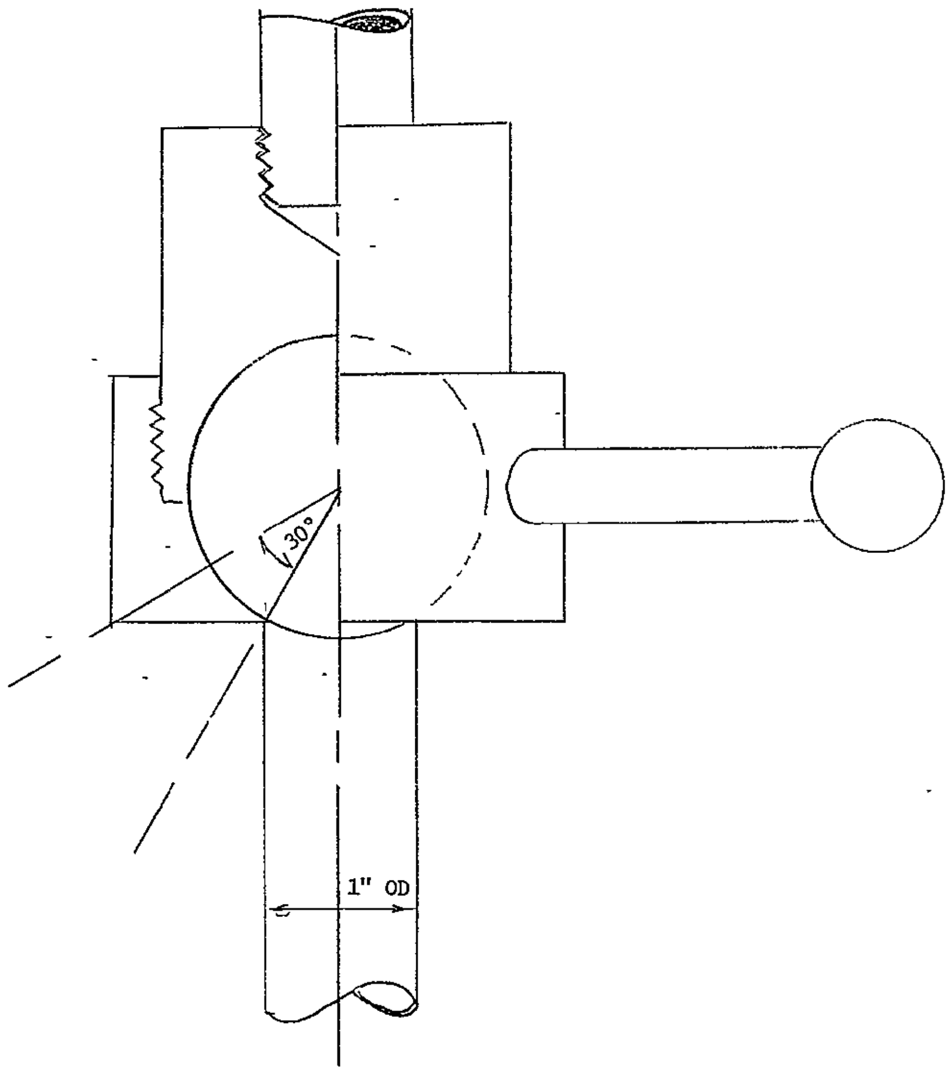
# APPENDIX A

The Restraint System can be divided into three sub-problems: 1) the boom assembly itself, having extension/retraction and rotation capabilities, 2) the belt and belt-to-boom interface, and 3) the attachment device with its interface to the boom assembly. The following are discussion of various boom concepts studied.

1. Rigid boom concept:

a) The ball-joint is preferred over a universal joint since it offers three degrees-of-freedom controlled by a single locking mechanism. The joint design described in the Martin Marietta Corporation proposal could only swing through a cone $30^{\circ}$. By adopting the modification described in Fig. A-1, the range of movement can be expanded to a $60^{\circ}$ cone. The proposed method of locking the telescoping tubes is acceptable as described in the proposal.

b) It was recognized that any controls located at the waist attachment point would be outside the reach envelope of an astronaut operating in the pressurized mode. By attaching to the suit at an angle, the controls can be brought to the frontal plane of the body, well within the reach envelope. This approach is diagrammed in Fig. A-2.




BALL LOCK TO PROVIDE 30° DISPLACEMENT
ANY DIRECTION FROM CENTERLINE

Fig. A-1 Locking Joint

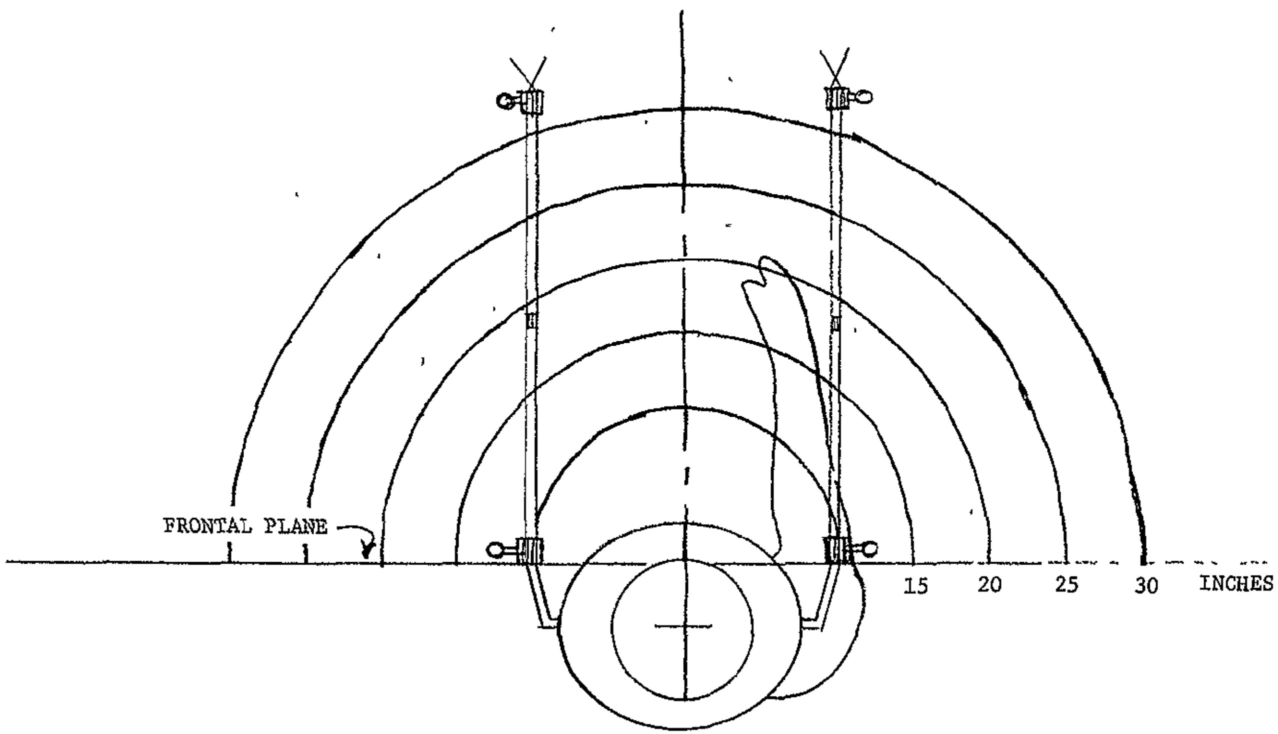



Fig. A-2  Arm Extension in Pressure Suit

The proposal concept was greatly improved by the incorporation of the above modifications. However, it is still limited by the number of locking operations required in positioning and re-positioning. The following alternatives have been considered in an attempt to reduce these operations to a few natural movements.

2. An ideal restraint would provide the astronaut with the same degree of flexibility as the human arm. The attachment to a structural member and the subsequent achievement of a comfortable work position should be accomplished with a minimum number of controls operated from a single point. An initial design satisfying these objectives is depicted in Fig. A-3. Like the human arm, this device is hinged near its mid-point. The "forearm" portion is divided into two members; by manipulating the control handle, the astronaut causes the gripper "hand" to assume a position corresponding to the position of his own hand. The gripper can then be locked or unlocked remotely from the control handle.

3. A modification of item 2 realized some additional benefits. Each telescoping boom is divided into three booms. A joint having three degrees-of-freedom is attached to each end of the boom; the orientation of these joints can be adjusted by controlling the relative lengths of the three telescoping members. This method gives the astronaut single point control of:

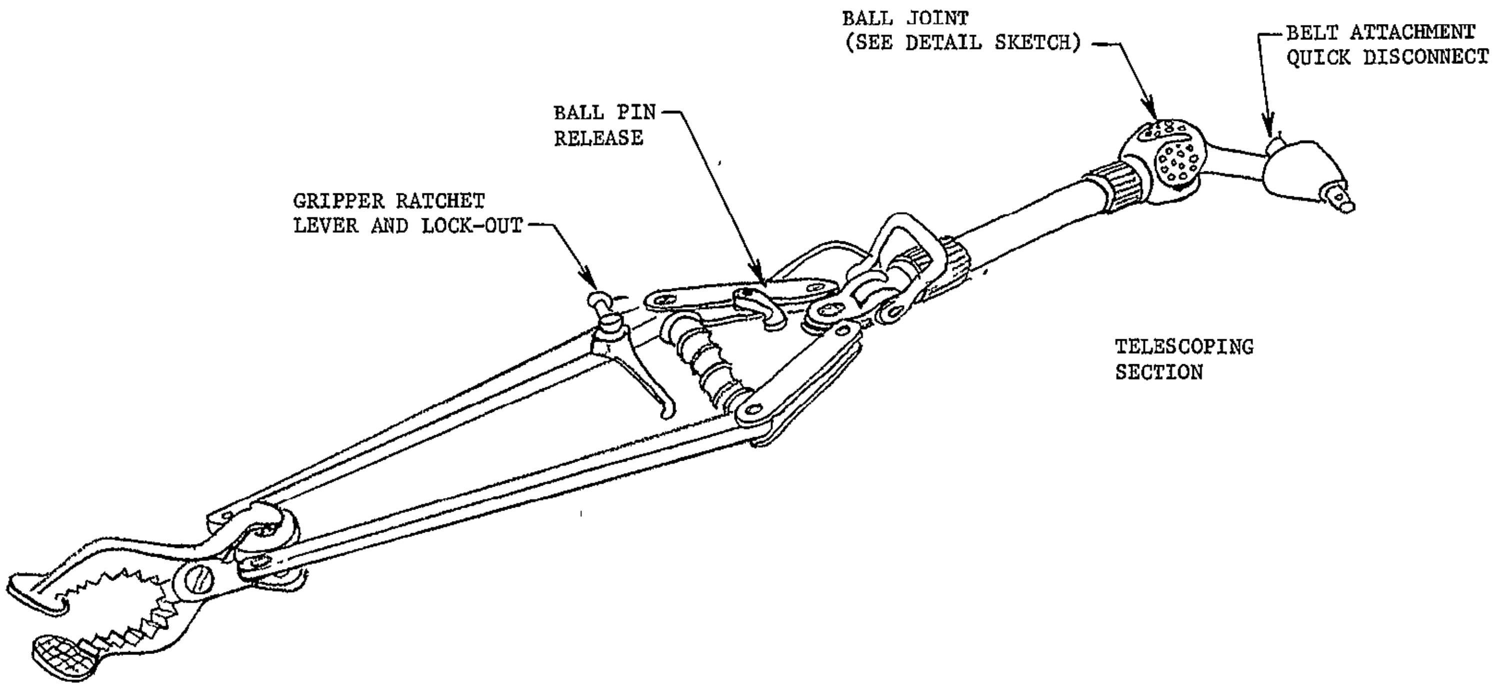



Fig. A-3  Remote Grip Control

a) extension-retraction capability, b) right-left movement, c) up-down movement. Each boom can rotate in an approximate $60^{o}$ cone. The astronaut simply maneuvers himself into the desired position and secures this position by squeezing a trigger with each hand. This concept is illustrated in Fig. A-4.

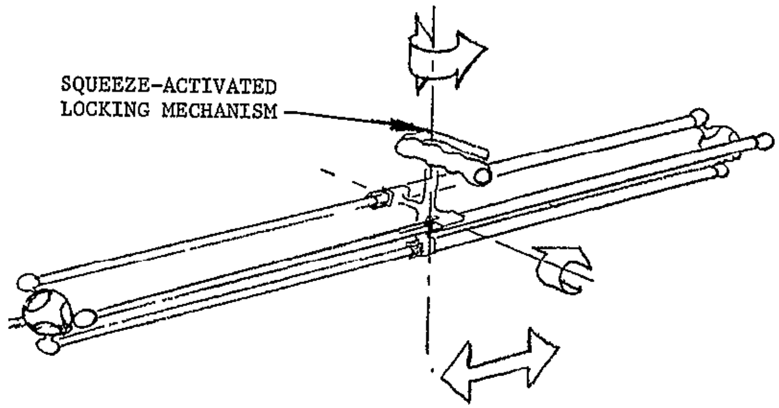
4. A concept based on a series of interlocking beads has been considered but not carried into the development stage. Multi-faceted hemispheres would be strung on a strand of steel cable. When tension is applied to the cable, the beads would be locked in the particular position they have assumed. This concept is diagrammed in Fig. A-5.

The grip assembly concepts studied are discussed below:

1. A ratchet-operated clamp is a very secure although somewhat time-consuming method of attachment. The mechanism would be similar to the conventional reversible ratchet wrench. The use of such a device is illustrated in the proposal.

2. Fig. A-6 illustrates the addition of a fast-lead screw to the ratchet mechanism of item 5 to facilitate its operation.

3. Fig. A-7 shows an attachment device which utilizes a sliding collar to close the jaws around the anchoring point. Depressing the lever then introduces a mechanical advantage for a more positive grip.



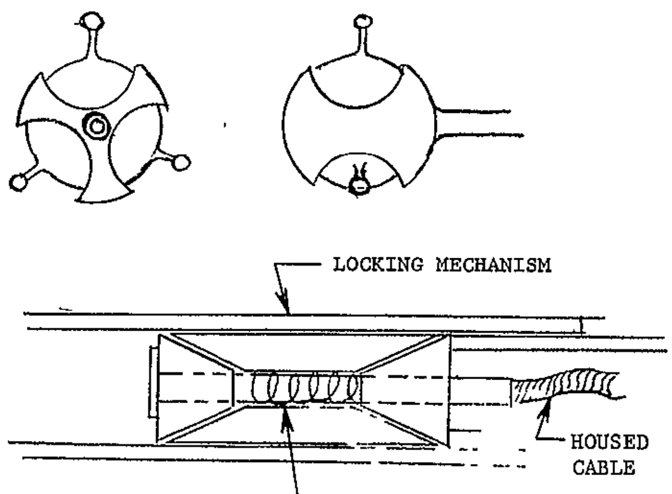




Fig. A-4 Three Rod Boom Concept

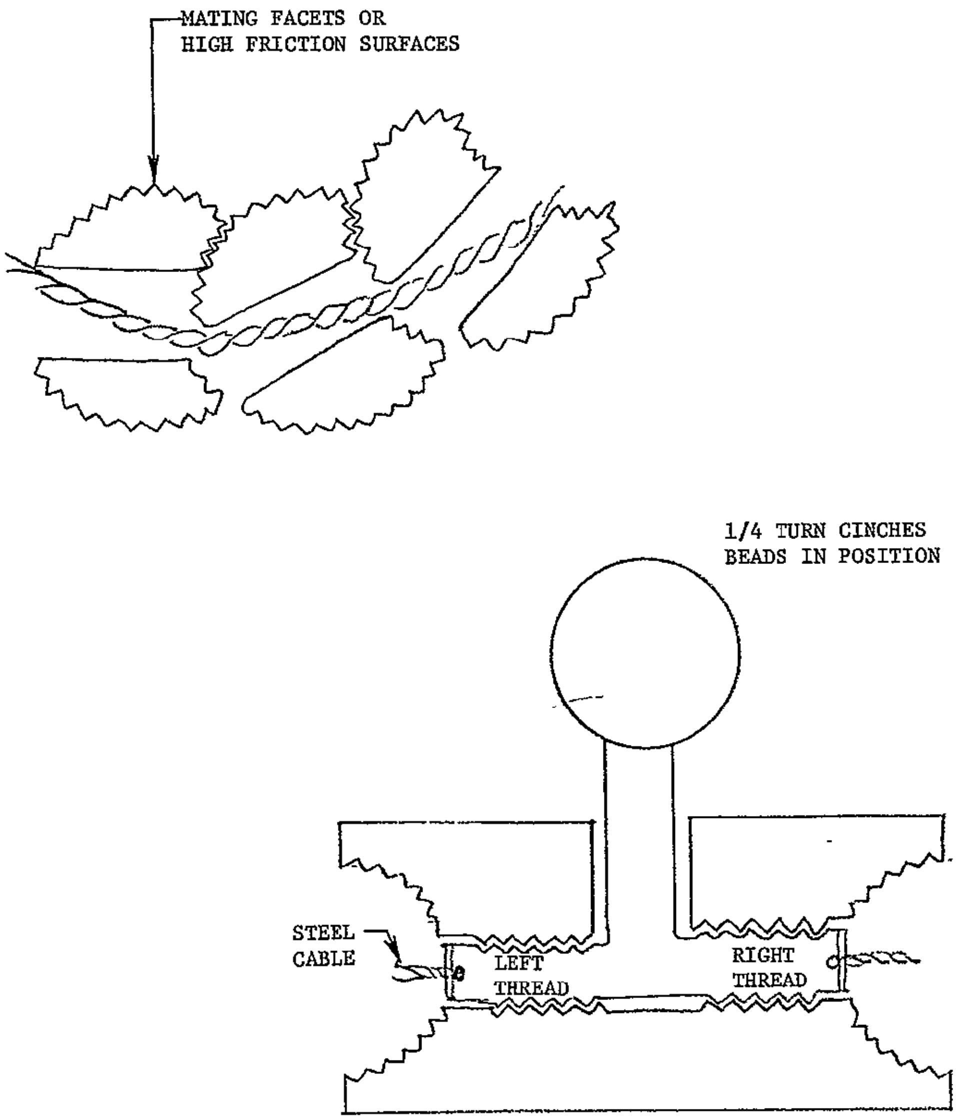



Fig. A-5 Rough Ball Concept

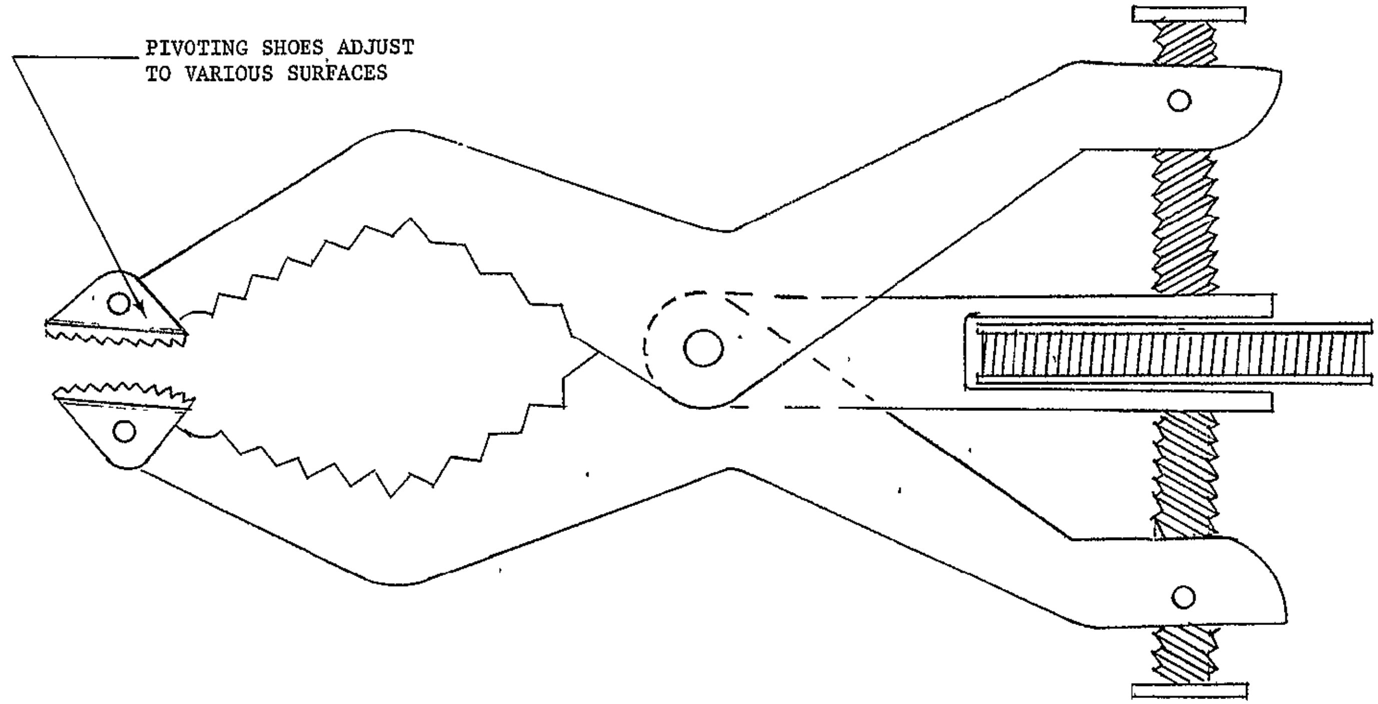



Fig. A-6 Grip Concept

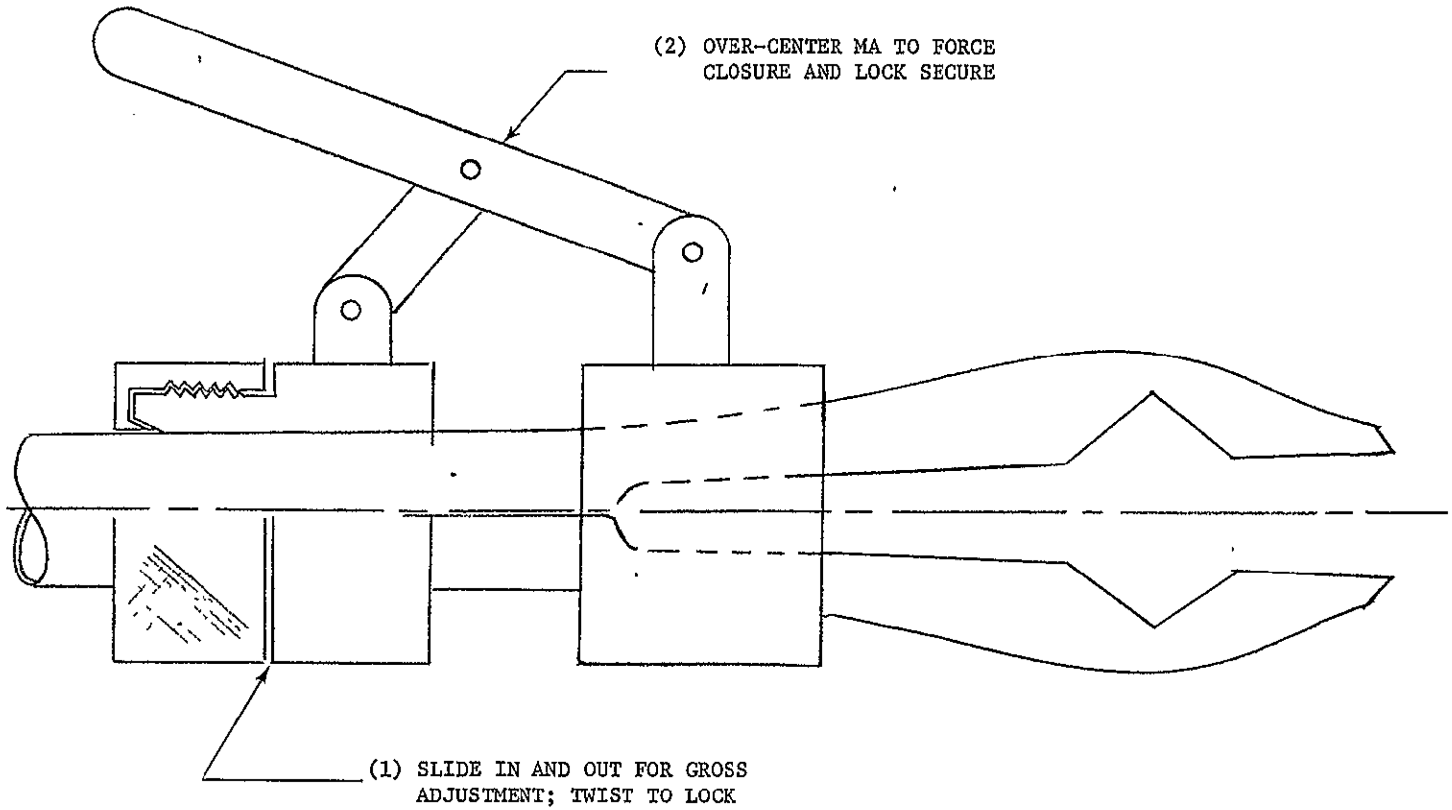



Fig. A-7 Grip Concept

4. A "fish clamp" device, similar to the clamps used in attaching electric cables to battery terminals, is shown in Fig. A-8. This is a relatively simple concept; but, as shown, does not incorporate any locking features.

5. The use of modified vice-grips has been suggested and actually employed in the initial MSFC prototype. The strong reaction force associated with the release of this type of grip makes its use questionable.

6. The application of a direct pull on the mechanical linkage illustrated in Fig. A-9 brings the jaws together into the closed position. A cable or rod can be used remotely to apply an axial force along the centerline of the restraint boom.

7. In Fig. A-10, a lever-operated cam is used to close the jaws about the anchor piece; the lever is then given a quarter-turn, engaging a slotted screw which provides the mechanical advantage to complete the locking action.

8. The preliminary report for NAS8-30069, Feasibility Study of Experimental Material Handling Devices was reviewed. The study on attachment devices does not appear to fit this situation. They are too large and gross for this application.

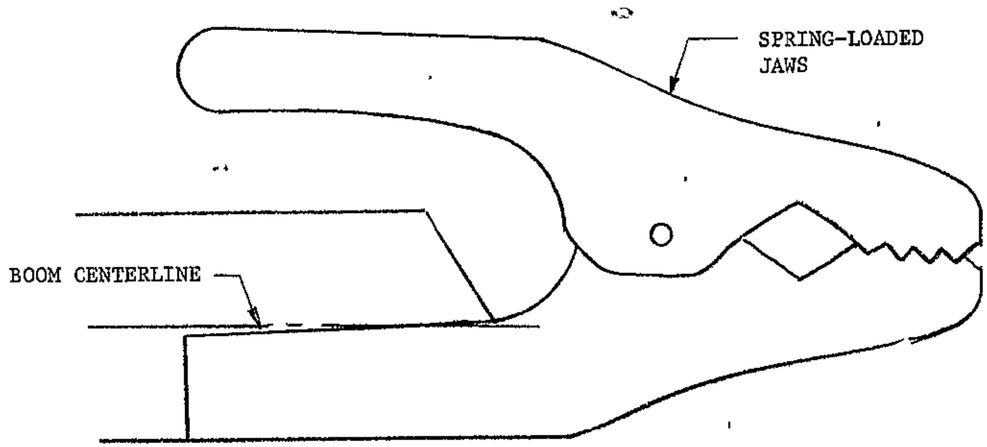



Fig. A-8 Grip Concept

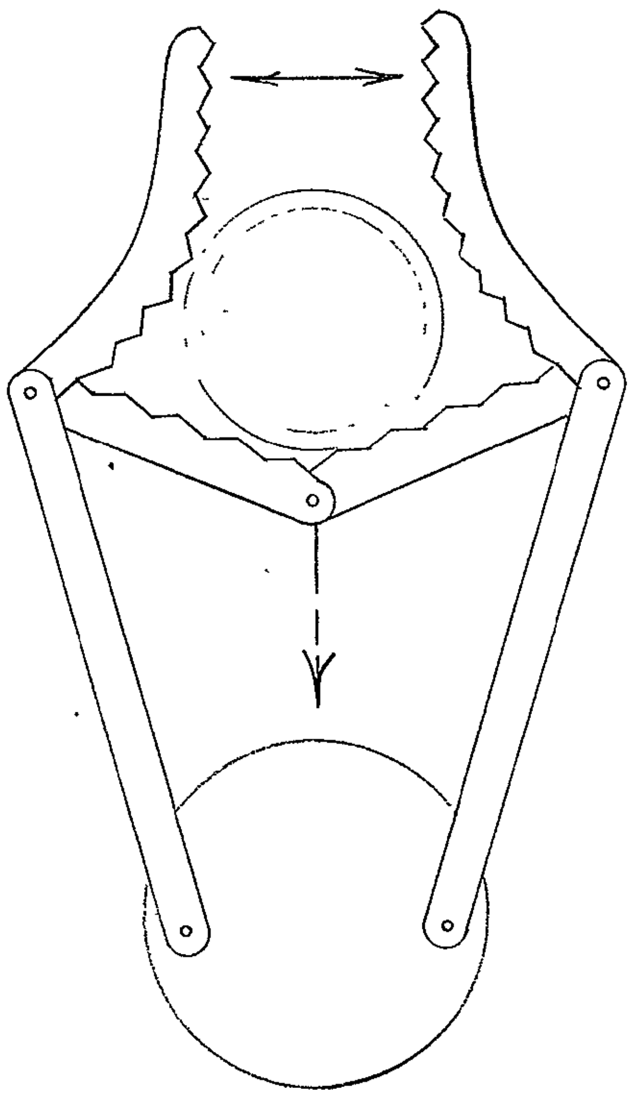


Fig. A-9 Grip Concept

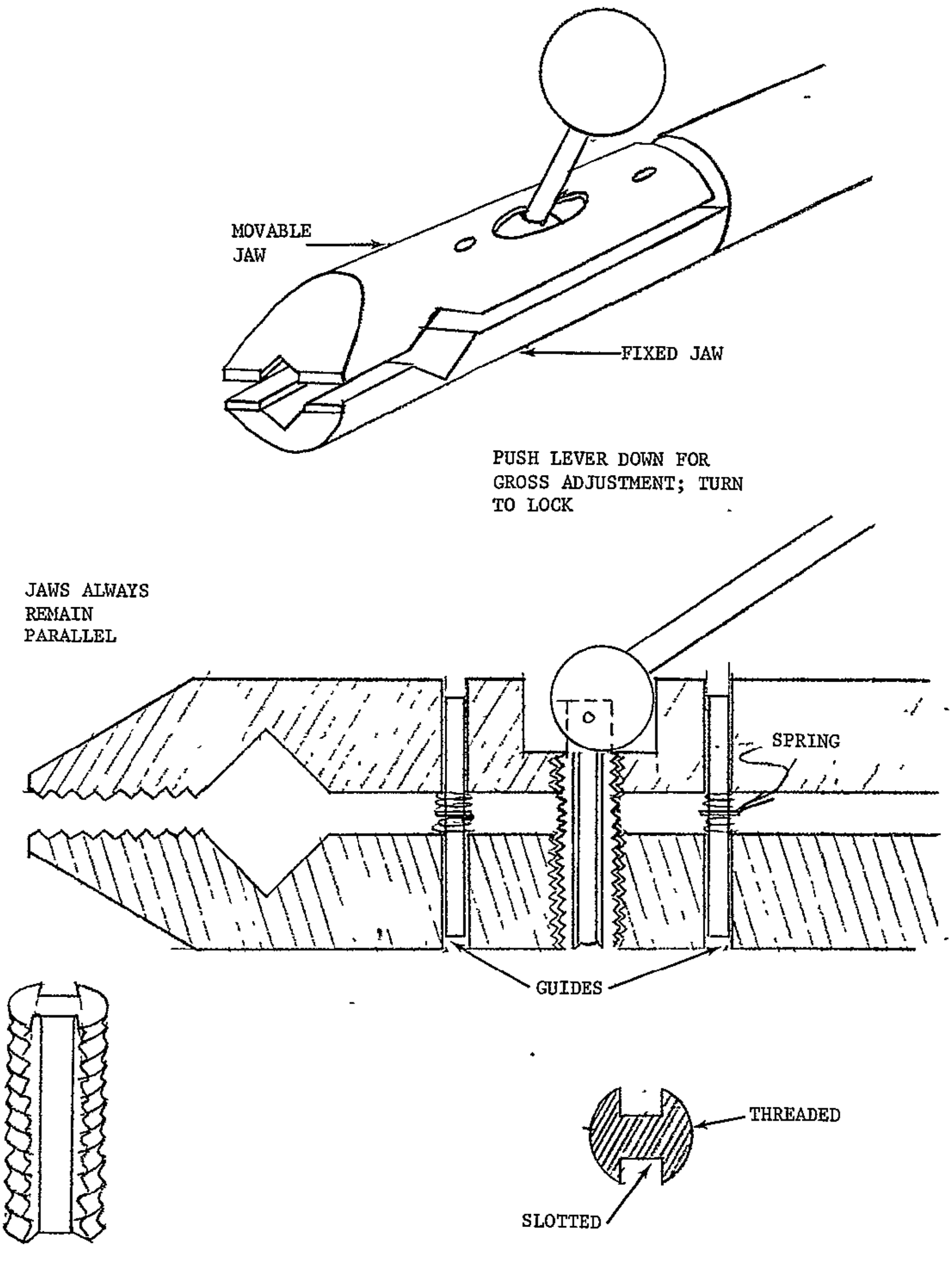



Fig. A-10 Grip Concept

## APPENDIX B

A discussion of the rigid boom concept is presented here.

Three successive designs of the telescoping boom control mechanism were made. The first was a modified version of a basic, friction type lock (Fig. B-1). Positive locking is achieved by sliding a collar over spring fingers forcing them into shallow grooves cut in the inner tube. These grooves are equally spaced at one-inch intervals giving boom length adjustments in one-inch intervals. Should test results indicate, the grooves could be more closely spaced and/or the collar threaded for possible increased closure force. The second design was a straight-forward, push-button, lock mechanism. The third, that which was included in the design package is described as follows.

The overall length adjustment of the restraint boom can be varied in one-inch increments from approximately .356 meters (14 inches) to .609 meters (24 inches). This is accomplished by a counter-clockwise motion of a sleeve or thimble (Fig. B-2). Maximum rotation of $45^{\circ}$ of the thimble causes rotation of a profile cam slot, driving a cam follower through a rise of approximately .00407 meters (.160 inches). The cam follower is attached by way of a flat spring to the tube locking plunger so that a similar movement of .00407 meters (.160 inches) is imparted to the plunger. This withdraws it from its locking

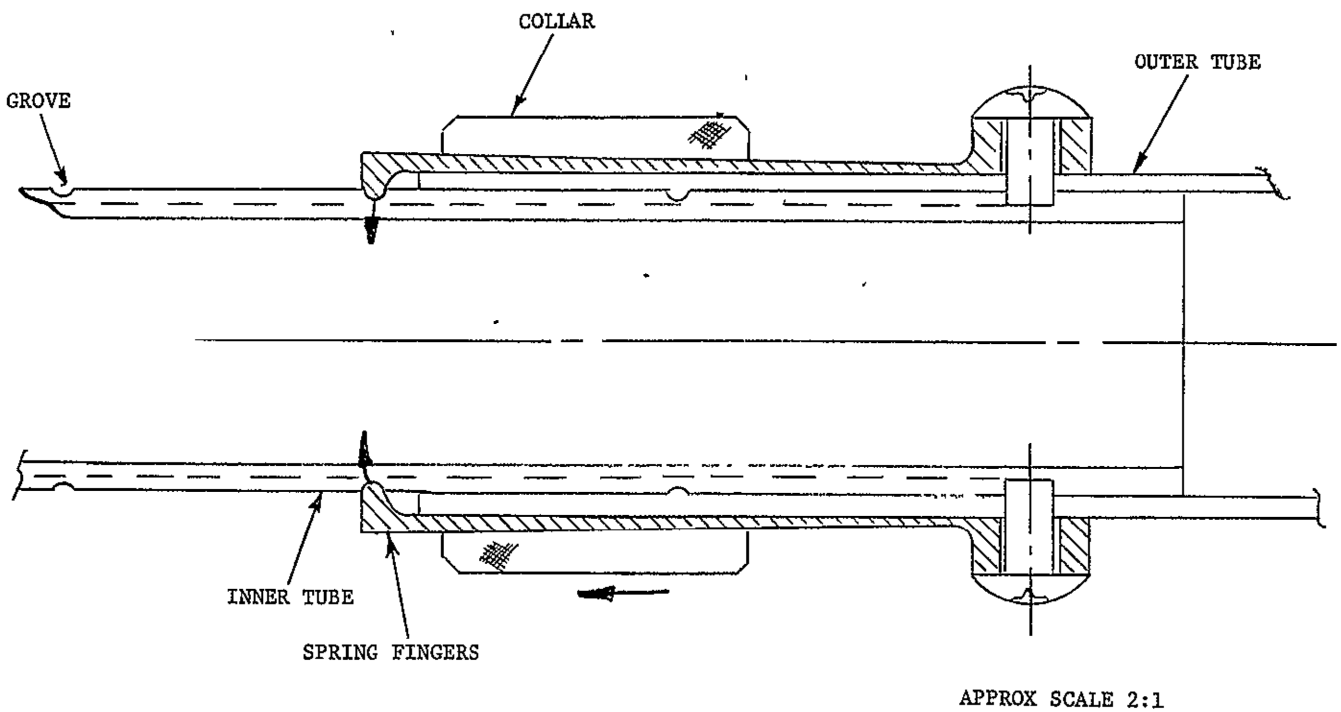



Fig. B-1 Telescoping Joint

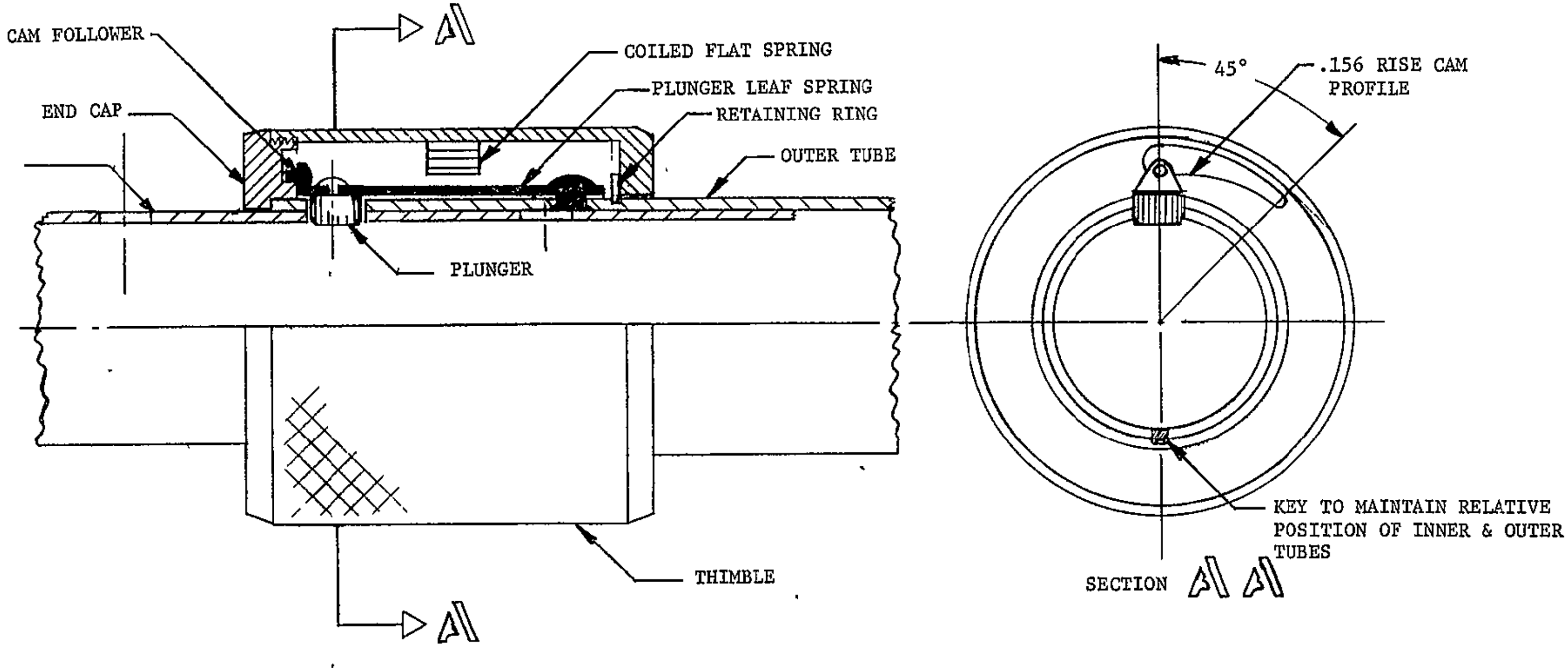
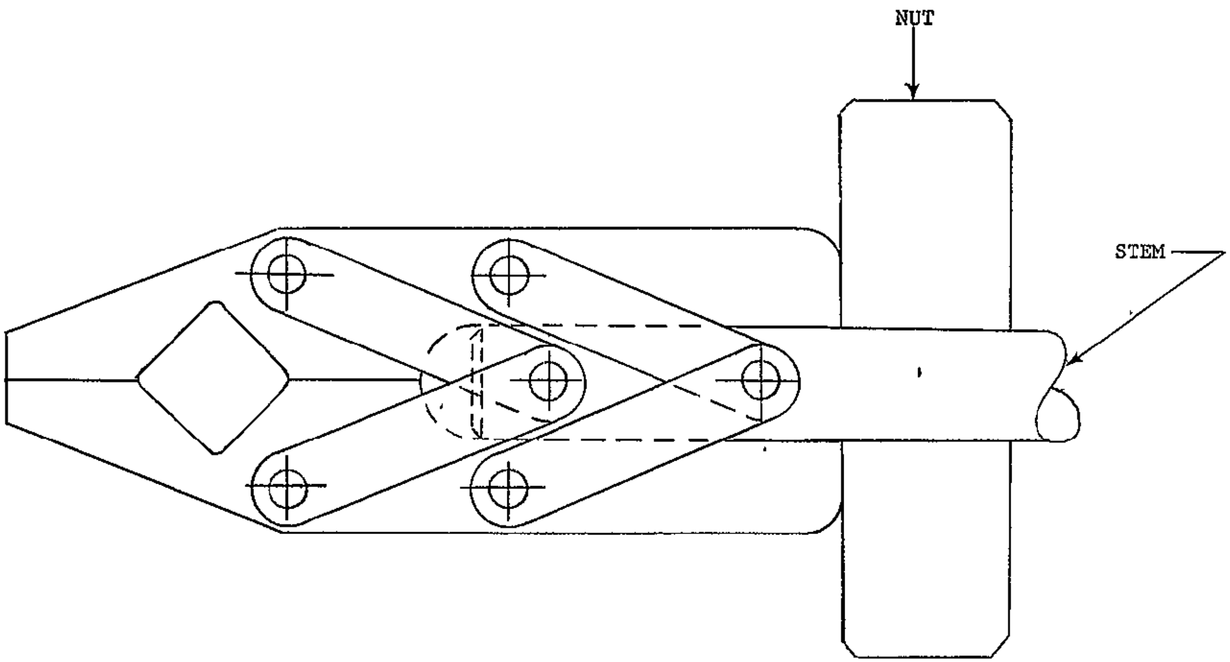



Fig. B-2 Telescoping Boom Adjustment

position in the two tube walls, allowing relative axial movement between them. Since the thimble is an integral part of the outer tube, lengthening or shortening of the boom is controlled without any further hand movements other than to extend or retract the tube. When the desired boom length is obtained, the thimble is released and under the influence of a coiled flat or torsion spring returns to its original ($0^{o}$) position. The two tubes are locked together in the new extended position when the flat spring snaps the plunger into the aligned holes in the tube walls. The tubes are radially aligned at all times by a key so that final minor axial movement of the outer tube to achieve plunger hole alignment and subsequent locking is easily obtained.

Continuing the discussion of the restraint system, the boom assembly attaches to a swivel joint on the belt assembly through a quick disconnect. The extended length with grip assembly installed is .737 meters (29 inches). The retracted dimension is .356 meters (14 inches) without the grip assembly. The grip assembly attaches to the boom assembly through a quick disconnect.

The grip being presented is an all-purpose type which retracts upon itself to reduce overall length. The grip design is made up of two parallel jaws connected by links to a center stem (Fig. B-3). The jaws are spring loaded to the open position by torsion springs located at the link pivot points. A




GRIPPER (FULLY CLOSED)

APPROX SCALE 2:1

Fig. B-3 Grip Concept

driving nut behind the pair of jaws is used as the closing and clamping force. When the boom is in the stowed position, the jaws are allowed to open past maximum position so that the overall length of the boom is foreshortened by one and a half inches. This allows the stowed envelope dimension of .305 to .356 meters (12 to 14 inches) to be achieved. As a part of the gripper assembly design, a fully adjustable ball joint has been provided. This enables the gripper jaws to be positioned anywhere within a 180° spherical area. The ball and swivel joints are locked simultaneously by one handle, this handle is faired into the boom assembly when in the locked position (Fig. B-4).

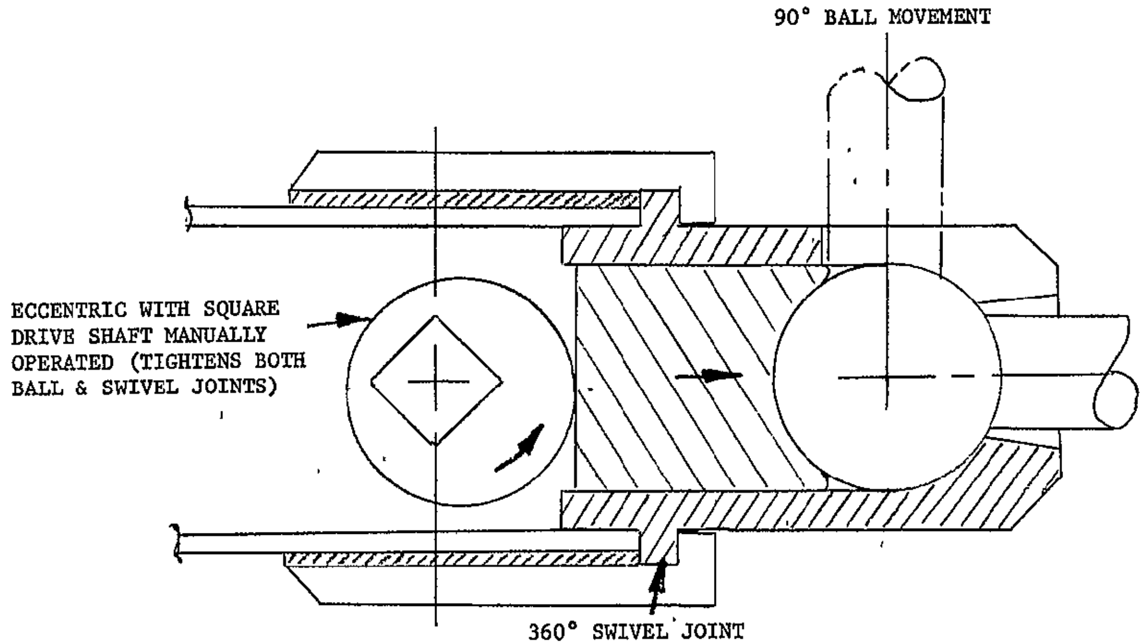



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Fig. B-4 Ball Joint Concept