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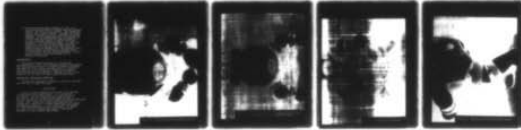
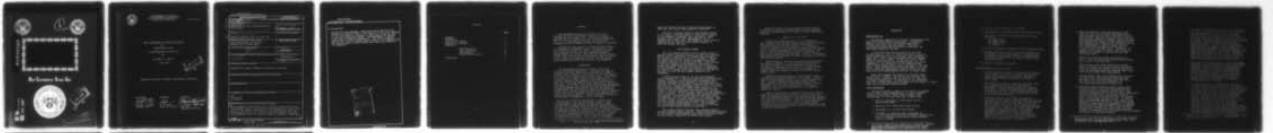
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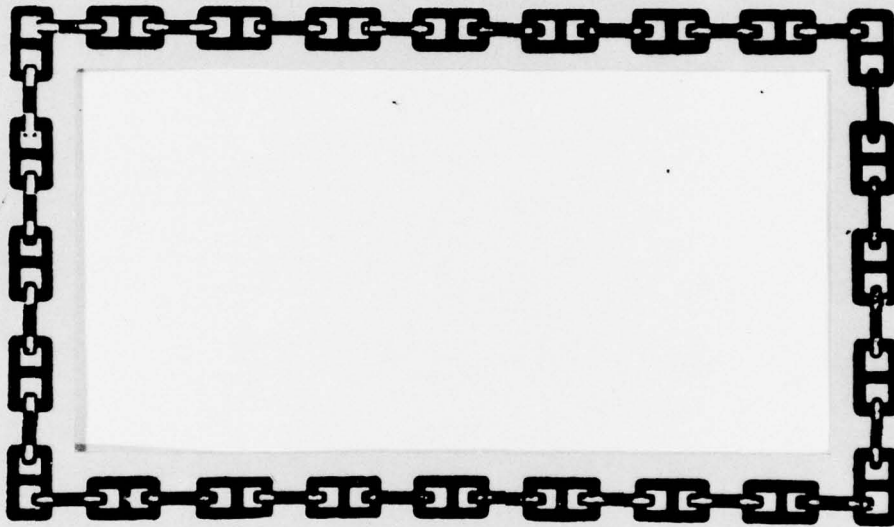
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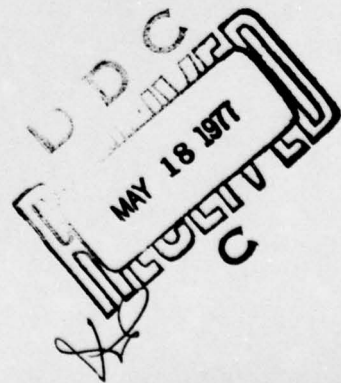


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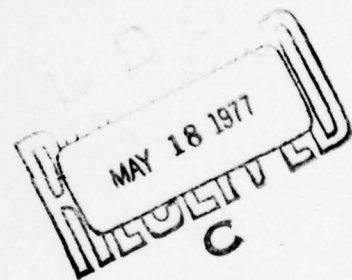
EVALUATION OF JIM:

A One-Atmosphere Diving Suit

By

LT Robert C. Carter

July 1976



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ABSTRACT

The atmospheric diving suit (ADS) "JIM" was evaluated at Navy Experimental Diving Unit during a two-week period in June, 1975. The suit was shown to meet many of the expectations that the manufacturer had for it. It could keep an aquanaut dry and at one atmosphere while he worked in water to depths of 1000 FSW.

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BACKGROUND

The atmospheric diving suit (ADS) "JIM" is an articulated manned submersible. Although this type of undersea vessel has been under development for about a century, JIM, constructed by DHB Ltd, is the first ADS to have joints that remain supple to 1000 FSW.¹ The purpose of an ADS is to create a barrier which protects the operator from the high pressure of the deep ocean, yet does not prevent the operator from doing useful work in the ocean. Of course, the barrier inhibits the operator's performance so the user must weigh the decreased performance of an ADS compared with a diver, against the saving of decompression time and possible long-term physiological damage to the divers, transportability and ease of handling at the dive site of the ADS, and low cost compared with other deep diving systems. In some instances, JIM may be the best way to accomplish a job in the ocean.

The hull of the ADS is essentially a cylinder with a hinged dome at the top for operator access. Four anthropomorphic limbs project in appropriate places. The suit has a backpack which houses two oxygen bottles intended to endure for 20 hours, and as much as 60 pounds of adjustable weight for buoyancy control. Another 70 pounds of balancing weights are mounted on the front of the suit between the penetrators for the arms. The hull is cast of magnesium alloy RZ5 in order to achieve an optimum strength to weight ratio. JIM 3, which is described

1 Thomas, V., "The Trials of JIM", Journal of Naval Sciences, 1(2), p. 125-135, 1975.

here, was designed to have a maximum working depth of 1000 FSW, and a proof test pressure of 2000 FSW.

This suit's unique feature is the moveable joints in its limbs. There are eight of these joints located at the shoulders, forearms, hips, and knees. These aluminum alloy joints allow approximately 20° of movement about their axes. The design of these joints is proprietary, but they do allow useable movement at 1000 FSW (Thomas, Op. cit.)

LIFE SUPPORT SYSTEM

The life support system of JIM is closed circuit, and the interior volume of the ADS is used as a reservoir. Exhaled air is piped from an oro-nasal mask through a CO₂ scrubbing cannister to the suit interior. Inhaled air comes from the suit interior through another CO₂ scrubbing cannister to the oro-nasal mask. The pressure in the suit momentarily decreases as the operator metabolizes oxygen, and the resulting CO₂ is absorbed by the scrubbers. This drop in pressure is compensated by addition of oxygen from oxygen bottles on the back of the suit, so that the suit always remains at one atmosphere.

Carbon Dioxide levels in the suit were measured using a Beckman LB-1. The CO₂ levels were monitored during operator training, including periods of moderate work. Scrubber cannisters were refreshed at the beginning of each day's diving, so that they rarely had more than three hours of use. Oxygen consumption rates of up to 1.8 liters per minute were attained. Under these conditions, CO₂ levels in the suit were kept below two percent, and CO₂ levels in the gas breathed by the operator were maintained below .1 percent. In one instance, when the tubes connecting the operator's oro-nasal mask with the scrubbers became disconnected, the CO₂ level breathed by the operator rose to eight percent in twenty minutes of mild activity. This critical incident points out the importance of checking the life support system before diving. The scrubbers are located behind the operator so it would be difficult for him to make repairs during an operation.

The oxygen levels in the suit were measured using a portable teledyne oxygen analyzer. Oxygen percentages breathed by the operator varied between twenty and thirty-two percent, and was usually twenty-one to twenty-three percent.

Installed battery-operated gauges displayed percent of oxygen and percent of carbon dioxide to the operator. Additional gauges displayed internal pressure and external pressure.

TRAINING OF OPERATORS

During the testing period, Mr. A. B. Gisborne, test engineer from the Royal Naval Physiological Laboratory, who is the world's most experienced JIM operator, conducted training for two operators. Mr. Gisborne's training program for each operator consisted of one session per day, which included about forty-five minutes in the water. He felt that additional training would be too much for the operators to assimilate. Five to ten sessions were required for operators to become proficient at walking, and attitude control.

The attitude of the suit was controlled by shifting the operators weight. A shift upward and forward put the suit's center of gravity above and in front of its center of buoyancy, so the suit fell slowly forward. A shift down into the suit would put the center of buoyancy above the center of gravity so the suit would right itself.

Walking is accomplished by a weight shift to one side while thrusting the opposite leg forward. The suit, like any other buoyant object, has a natural period for roll. Operators became accomplished walkers when they learned to walk with this natural period. Walking was found to be the most strenuous activity for an operator. Fast walking required about 1.8 liters of oxygen per minute.

Use of JIM's hands, or manipulators, is the critical path for application of the device. Training for this skill proceeded throughout the two-week evaluation period. Each task attempted required a new approach by the operator, or a new type of manipulator. Work with the manipulators required attitude control to maintain proper distance from the task as well as control of the manipulators. Ten to twenty training sessions are required to acquire ability to use the manipulators.

EVALUATION

Maneuverability

The walking capability of JIM was investigated by the Royal Naval Physiological Laboratory². Comparisons between a hard-hat diver and JIM were made using a 350-yard test basin for ship models. Additional investigations were made of walking in currents, and safe towing speed for the ADS.

It was found that JIM could walk the 350 yard straight-away at a rate of 50 feet per minute, with an oxygen consumption of 1.5 liters per minute (moderate to heavy work). This compares favorably with the maximum speed of a hard-hat diver: 80 feet per minute. RNPL inferred that the diver would become slower, due to the impediment of his umbilical, if the comparison were made in water deeper than 18 feet, the depth of the test basin. They concluded that the walking speed of a diver and JIM would be approximately equal in water 150 feet deep, with JIM out-performing the diver in deeper water.

RNPL also compared the ability of JIM and a diver to walk into a current. The ADS and the hard-hat diver could sustain forward motion in currents of 1 knot and 1.5 knots, respectively. In addition, it was determined that JIM is stable when towed at speeds up to at least 1.7 knots, which was the maximum speed attempted.

Task Performance

JIM was evaluated at NEDU for its ability to perform certain simple tasks representative of those regularly required in the ocean. These tasks, staged in the 15-foot deep, 15 x 30-foot test pool at NEDU, were:

1. Use of a hack saw on a steel plate and on a nylon braid hawser.
2. Operation of a "come-along" manual winch.
3. Adjustment of a 14-inch valve handle.
4. Placement of a wing-nut and a hexagonal nut on a one-inch bolt, bolting pre-aligned flanges, and use of a standard wrench and an impact wrench on nuts on a flange.

2 Royal Naval Physiological Laboratory, Alverstoke, England, Preliminary Report on ADS Walking and Current Trials, Report 674, by Gisborne, A.B., Morrison, J.B., and Butt, W.S.

5. Pulling a sled loaded with 50 pounds.
6. Demonstration of maximum lifting force with one arm.
7. Operation of tools from the Supervisor of Diving Tool Kit:
 - (a) Ramset Gun
 - (b) Impact Wrench
 - (c) Cable Cutter
 - (d) Grinder
8. Use of the installed compass to walk a straight course.
9. Attaching recovery lines to a 12-inch diameter pipe by putting hooks through padeyes on the pipe, and by passing a sling under the pipe and then passing the sling through one of its eyes, to form a lasso around the pipe.
10. Tests of emergency procedures.

Task performance was as follows:

1. JIM was capable of cutting 1/4-inch into a 3/8-inch steel plate in 5 minutes. The ADS was also able to cut the hawser with a hack saw. The type of short, gross movement exemplified by sawing is JIM's forte.
2. The ADS was also able to swing the foot-long lever of a "come-along" manual winch through the approximately thirty degrees required to operate the winch. Although the operators were only able to complete a cycle of the lever once every three to five seconds, they could, nonetheless, use the winch to move heavy objects.
3. A 14-inch circular valve handle attached to a mounted vertical shaft was used to test JIM's ability to adjust such a handle. The handle was horizontal about 18 inches above the deck of the test pool. JIM was unable to turn the valve handle by grasping its outside rim. However, the ADS was able to turn the handle by grasping its hub. This method represents a considerable loss of mechanical advantage compared with turning the handle by applying force at its rim. Alternate strategies, such as use of a lever, may have to be used by JIM to turn recalcitrant valve handles.

4. Some nuts-and-bolts tasks were devised to test JIM's abilities to use these common fasteners. Operators were able to align a hexagonal nut and a one-inch bolt, and take an initial turn on the nut after several minutes of repeated trial-and-failure. The operators were unable to make further turns of the hexagonal nut because of the limitations of the ADS's manipulators. Operators were unable to use conventional wrenches to tighten the nut on the bolt for the same reason. Similarly, JIM operators were unable to use an impact wrench to tighten nuts because of inability to pull the activating lever.

Winged nuts were much easier for operators to turn. A nut with three-inch wings could be placed and turned on a one-inch bolt.

JIM was able to put bolts through pre-aligned holes in flanges, but could not fasten the flanges with nuts because the flanges were too narrow to allow use of winged nuts, and hexagonal nuts could not be handled with JIM's manipulators.

5. JIM operators pulled a sled loaded with 50 pounds of lead weight. The operators found that the best way to do this was to face the sled, hold the towing loop, and walk backwards. No difficulty was encountered in this task.
6. Operators exhibited maximum steady lifting force using JIM's arms. This force was measured with a spring scale tied between the deck and a T-bar which the operators held in JIM's vice-grip manipulator. Maximum force was about fifty pounds, which is about 75 percent of the maximum force the operators could attain without wearing the suit. A similar type of measurement was made at RNPL, where it was determined that JIM could lift a seven pound weight with the standard hand-like manipulator.³ Heavier weights could not easily be held by the manipulator. The difference between the fifty pound lift force measured here and the seven pound force measured at RNPL is accounted for by the inability of the standard manipulator to hold heavy objects.

3 Royal Naval Physiological Laboratory, Alverstoke, England, Preliminary Report on The DMB Armoured Suit, Report 873, by Gisborne, A.B. and Morrison, J.B.

7. JIM operators attempted to use some standard tools from the Supervisor of Diving Tool Kit. As already mentioned, operators were unable to activate the starting lever of the impact wrench, although they were able to place the socket over a nut or a bolt head. Operators were able to use a ramset gun on the deck, but were unable to place the gun against a bulkhead because of inability to grip and balance the tool. The kit includes a hydraulic cable cutter which operates with a pumping action like that used to propel a railroad hand-car. This motion is impossible for JIM, so operators were unable to use this tool. The grinder was another tool that JIM operators tried to use. Although they could hold the tool, both operators expressed doubt that they would be able to grip it well enough to do underwater grinding while aboard JIM.
8. One report (Thomas, OP. CIT.) of JIM's sea trials conducted by the Admiralty Underwater Establishment describes operators as having a confused sense of direction. Since JIM had an installed compass, it was decided that it would be reasonable to test the operator's ability to walk a straight course, using the compass, in zero visibility. It was found that JIM operators could not walk within 90° of a pre-assigned course using a magnetic compass. This might be attributable to the steel in the test pool.
9. JIM has been used as a salvage tool to recover two super tanker anchors and chains from 375 feet of water near the Canary Islands.⁴ The ADS was used to pass a leader through the end link of the chain. The leader was then used to attach lifting cables. The recovery of the two anchors was successful and JIM returned to Great Britain within three weeks of its deployment. To test the ADS's salvage capability, a six-foot section of 12-inch diameter pipe was placed on the deck of the test pool. Recovery of the pipe was easily accomplished by attaching hooks to padeyes on the pipe, or by passing a sling under the pipe, and then pulling one eye of the sling through the other eye. This task required no fine manipulation or gripping, and was accomplished with little difficulty.

⁴ Hughes, D.M., "JIM Goes To Work", Ocean Industry, 11(4), pp. 377-380, April 1976.

10. The standard emergency procedure for JIM is to jettison about 60 pounds of weight used for buoyancy control, and float to the surface. This system was tested, and it works reliably. Because JIM allows operators limited visibility, and almost no tactile feedback, it was hypothesized that the operator of the ADS might have difficulty freeing himself if he were to become tangled in cables like those encountered in the SEA-LINK tragedy. To test this capability, one bight of DUCS cable was passed around an arm of the ADS and another bight was passed around the opposite leg. The operator tried to free himself, and had made no progress after 15 minutes when the test was discontinued. Fouling cables present a difficult problem for the unaided JIM operator.

Anthropometry

The maximum voluntary motion of a JIM operator was documented on film. The following pictures show maximum horizontal shoulder flexion, horizontal shoulder extension, hip abduction, hip flexion, and knee flexion. Operators were able to use all the motion allowed by JIM except in horizontal shoulder extension. Because of this, future models of JIM will have the arms placed farther apart.

Water-Tight Integrity at 1000 Feet

JIM was left overnight, unmanned, in water at 1000 FSW. The suit did not admit any water.

CONCLUSIONS

JIM is a viable underwater tool which can be handled and maintained with relative ease. It is watertight to 1000 feet, and has been shown to be maneuverable at that depth. The suit's most salient asset is that it obviates the expense and danger of compressing and decompressing divers. Some of the suit's liabilities are unwieldy manipulators, inability to escape entanglement, and limited navigational capability. It is an ideal tool for salvage of a pre-located object in clear, deep water. It would be a poor tool for location and repair of underwater equipment in cable riddled turbid water.

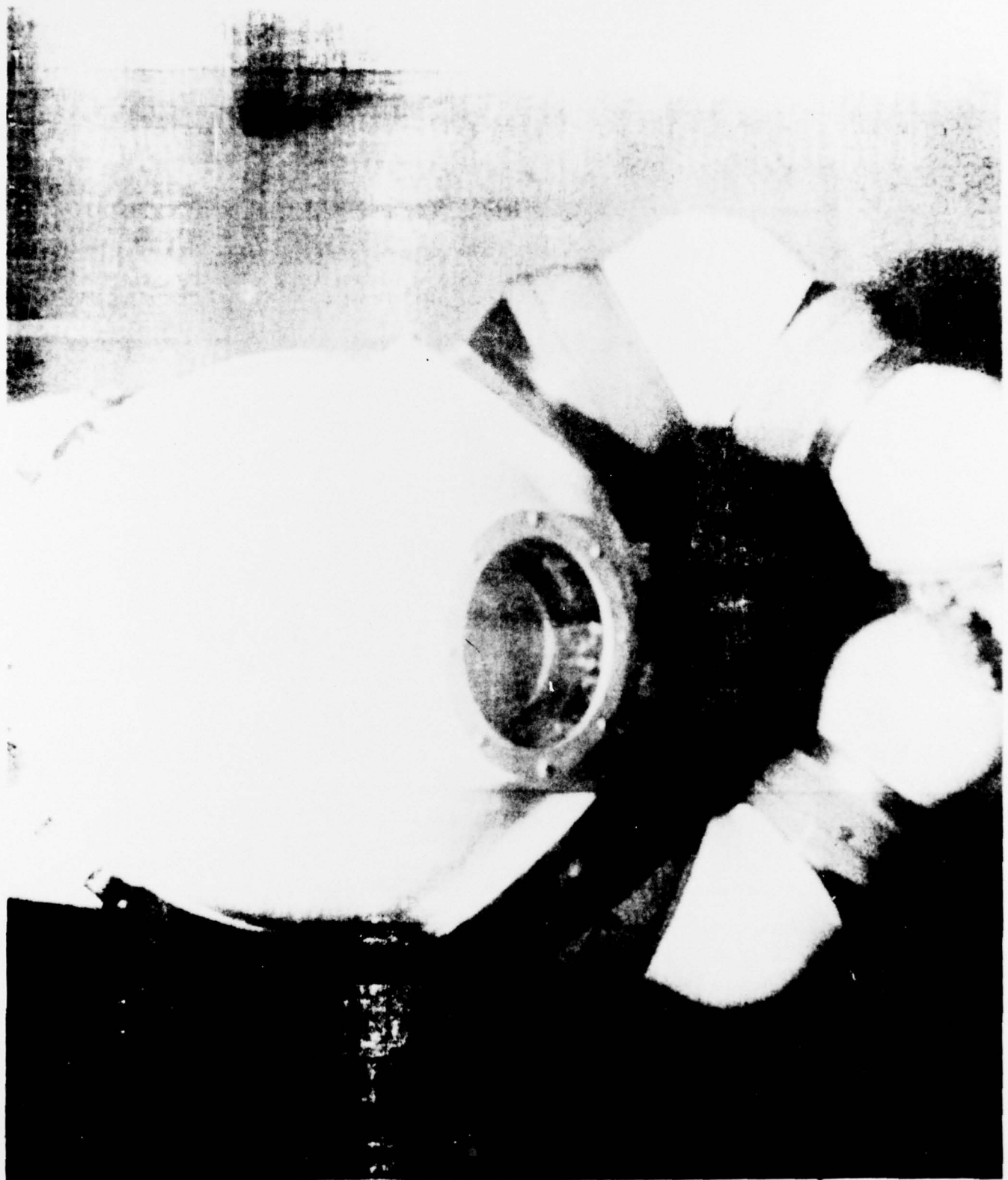


Figure 1. Maximum horizontal shoulder flexion.

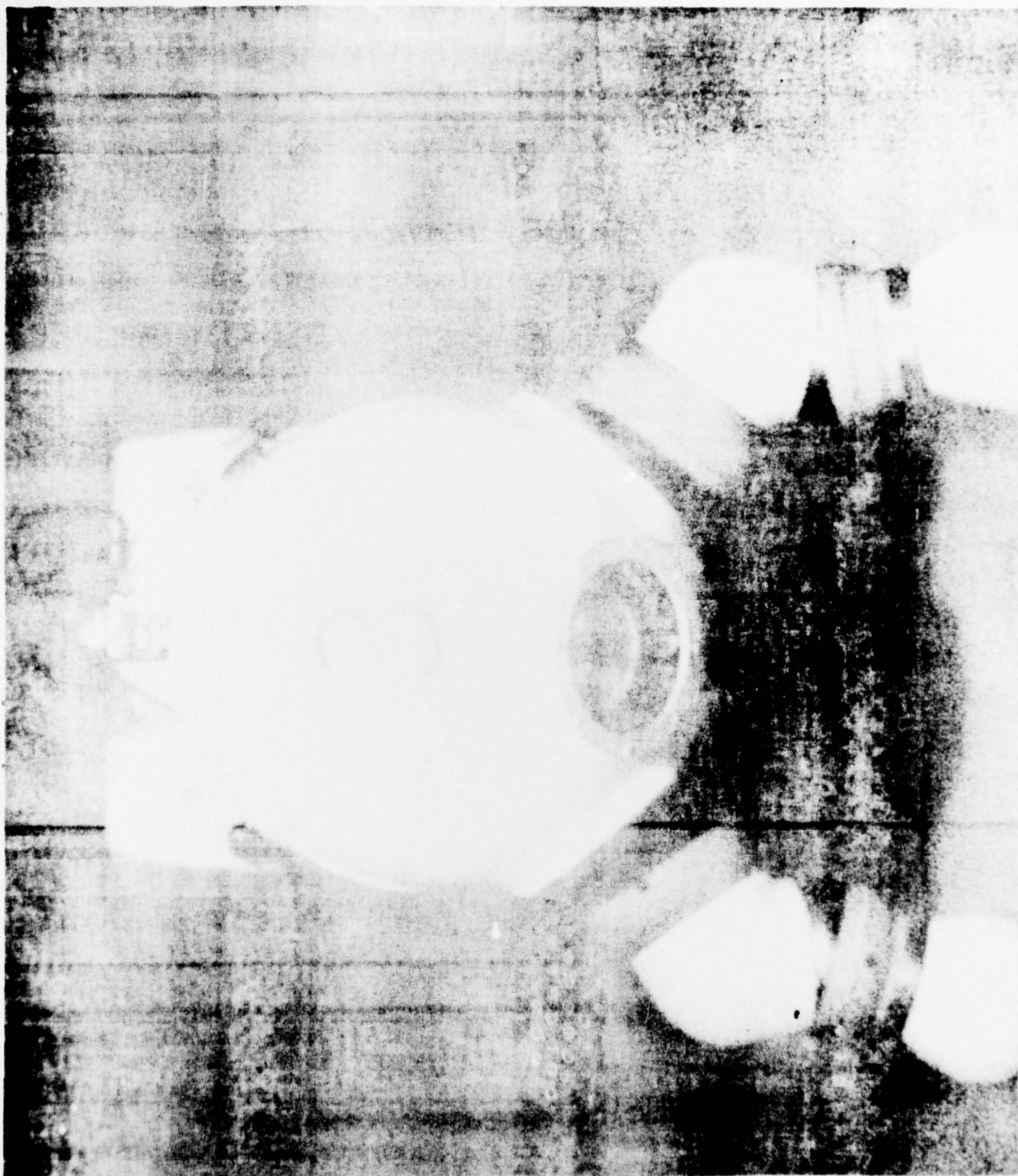


Figure 2. Maximum horizontal shoulder extension. Note incomplete use of the mechanical joint.



Figure 3. Maximum hip abduction.



Figure 4. Maximum hip flexion and knee flexion.