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HUMAN RESTRAINT SYSTEMS DEVELOPMENT FOR USE IN ACCELERATION RESEARCH

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SUMMARY

The NASA, Ames Research Center, has a continuing need for pilot-restraint systems suitable for use in research programs designed to investigate the performance and physiological well-being of pilots during severe acceleration. Various concepts in restraint systems have been evaluated at the Ames Research Center and tested under simulated operational conditions (refs. 1,2). Based on the pilots' acceptance of these systems and on those areas requiring improvements, Ames has initiated a development contract to integrate a state-of-the-art pressure suit and a restraint system for use in full space-mission simulations.

Author

INTRODUCTION

With the advent of the Mercury program and subsequent space efforts, special attention has been focused on the effects of large acceleration forces on the occupants of manned orbital or space vehicles (ref. 3). Such effects, if not substantially minimized, can interfere with the pilot's physiological processes and task performance, and thus the overall mission reliability. Ways of identifying and minimizing these basic problems are continually being studied (e.g., refs. 4, 5, and 6).

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Restraint systems for use in Project Mercury were tested in centrifuge facilities throughout the country. Seasoned test pilots familiar with state-of-the-art restraint systems were used as subjects. Their subjective opinions dictated the modifications to the various systems tested. This approach has been used to develop new methods and techniques for restraint systems.

Using pilot opinions to define experimental goals, Ames Research Center has established the following requirements as guidelines for our experimental work in human restraint systems:

1. The system should provide adequate restraint over a wide g range of EBI, EBO, and EBD acceleration,* and any combination thereof.

2. The system should be compatible with the required physiological measurements being contemplated (e.g., refs. 7, 8).

3. A given restraint unit should fit a wide range of sizes of pilots.

4. The system should allow the pilot to be quickly connected to or disconnected from the main support system.

5. Release from the support system should be manually actuated by the pilot.

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*The terms "eyeballs in" (EBI), "eyeballs out" (EBO), "eyeballs down" (EBD), "eyeballs up" (EBU), "eyeballs left, right" (EBL, R), correspond to acceleration fields $\pm A_X$, $\pm A_Y$, and $\pm A_Z$, respectively, where $\pm A_X$, $\pm A_Y$, and $\pm A_Z$ refer to the direction of the acceleration forces measured in the conventional airplane body-axis coordinate system.

6. The restraint system should allow adequate movement for all piloting functions.

7. Ease of ingress and egress from the vehicle should be a prime consideration in the design of the restraint system.

8. Weight and bulk of the restraint system should be held to a minimum.

In addition to these guidelines, it appeared that for later studies it would be advantageous to have a pressure suit as part of the restraint system. The feasibility of this integration was studied by two industrial firms under contract to NASA. They recommended a configuration, a design approach, and the over-all advantages and disadvantages of the integrated system.

The purpose of this paper is to describe the restraint systems developed and to report on the progress of the current attempt to integrate certain desirable features of these systems with a state-of-the-art pressure suit.

DESCRIPTION OF THE RESTRAINT SYSTEMS

Modified NASA Couch

Omnidirectional acceleration protection was considered necessary for a study of a pilot's ability to control a reentry vehicle while subjected to an EBO acceleration (refs. 9, 10). The investigation of the availability and adequacy of existing restraint systems determined that the NASA couch described in reference 1 and shown in figure 1, with certain modifications, could be used.

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Many additions were made to the basic individually formed posterior mold for EBI protection to allow for more effective support for the anterior portions of the body while subjected to EBO acceleration (fig. 2). It was necessary to fabricate adequate head, torso, and extremity restraints which would hold the individual in his body mold and yet permit him to perform the required tracking task efficiently.

As shown in figure 2, the head restraint consisted of a protective helmet with an individually molded face piece which was designed so that the major portion of the load would be taken over the prominences of the maxillary bones of the face. A chin cup was connected to the face restraint to improve restraint stability under "g"; however, the chin, being an unstable support point with poor tolerance to large loads, did not carry an appreciable load.

The torso was held in the mold by two separate supports. The upper torso was supported by crossed nylon straps forming a large load bearing area over the upper rib cage. The upper ends were attached to 4 inch straps which extended over the collar bone and shoulder. A similar type support was fabricated for the pelvic area.

The extremities were restrained by a nylon netting and strap arrangement positioned over each upper arm, thigh, and lower leg. All the restraints were buckled to the structure holding the molded couch.

Each pilot used his own standard "g" suit to increase his tolerance to positive A_Z or EBD acceleration.

Although this restraint system was found to be adequate, numerous shortcomings discovered as the program progressed led to the development of the universal pilot restraint suit.

Universal Pilot Restraint Suit

It was reasoned that a restraint suit which could be donned and worn as a piece of personal gear, in somewhat the same manner as a conventional parachute, would more closely meet the design guidelines listed in the Introduction and would eliminate the problems associated with the modified NASA couch. Such a suit would allow the pilot to walk around with unrestricted head, arm, and leg movements and would satisfy requirements 4, 5, and 7 of the design guidelines.

The restraint system which resulted is illustrated in figures 3, 4, and 5 and is described in detail in references 2 and 11. So that the suit would fit a wide range of pilot sizes (guideline no. 3), aluminum back frames were made in large, medium, and small sizes. They were contoured to the approximate shape of the human body to provide structural support for the posterior portion of the torso. The frame is covered with heavy-gage nylon. Between the shell and the pilot are a series of inflatable bladders which conform closely to the shape of the individual pilot, thereby providing suitable support for a range of pilot sizes. Anterior support is provided by an individually molded face restraint for the head, a restraint bib secured to the back frame for the upper torso, an integrated pelvic restraint and modified "g" suit for the lower torso, knee restraints for secondary support of the lower torso, and forearm restraints (the unique design and function of the forearm restraint will be discussed later in this paper).

The pilot dressed in the mobile restraint suit, figure 4, connects to the support structure in the centrifuge gondola by mating tapered pins on the back frame, thigh supports, and helmet with correspondingly located spring loaded receptacles on the support structure. His feet are restrained by a latching arrangement on the foot controller which serves the same control function as toe pedals in a conventional aircraft. To compensate for the wide variation in trunk length, thigh length, lower leg length, etc., among pilots, the restraint system support structure, figure 5, is adjustable.

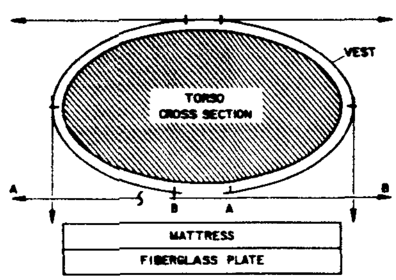
Soft Torso Restraint

Another design approach for providing positive omnidirectional restraint was to use only soft materials wherever practical. For example, instead of using the contoured hard shell or molded couch for lateral torso restraint, a cloth "vest" with appropriately located straps served the same function.

This restraint system is shown in figures 6 and 7. Certain features of the previously described mobile restraint suit were left unmodified and used in conjunction with the soft torso restraint. The major changes in this restraint are the anterior and posterior supports for the upper and lower torso.

The posterior portion of the torso and buttocks-thigh region is restrained in the EBI and EBD acceleration directions by two mattresses filled with miniature styrofoam balls. These mattresses are secured to flat fiber glass plates which, in turn, are secured to the support structure in the same manner as the mobile pilot restraint. After the pilot makes his body impression in the mattresses, a vacuum pump evacuates the air from the mattresses causing them to become very rigid. Essentially, each pilot molds his own couch. However, this couch is shallow so that it provides no lateral support for the torso. If a pressure point occurs while immersed in a high "g" field, a solenoid valve arrangement allows the pilot to "dump" the vacuum, reposition his body to remove the pressure point, and remold his couch.

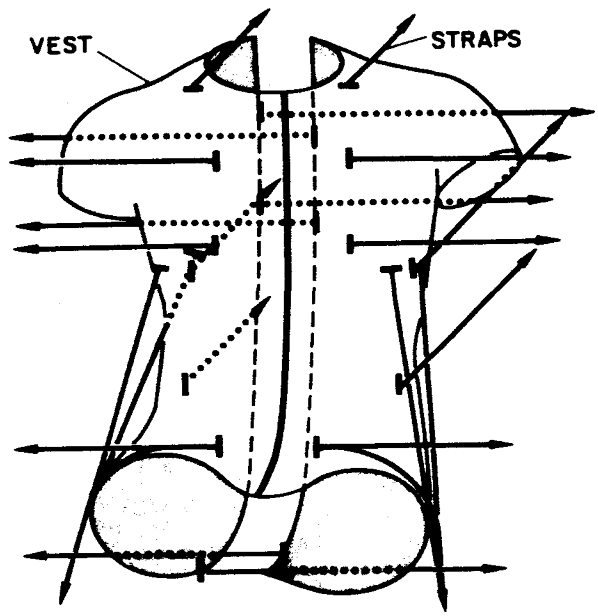
To restrain the subject in the EBO, EBU, and EBL and EBR, a vest was tailored to completely cover the torso from the shoulders to the pelvic area. This vest, however, is open over the back of the torso, so that the harness can be adjusted as illustrated in the following sketch.



Straps A and B can be adjusted to accommodate various torso sizes.

The same method of adjustment and positive restraint is provided over the shoulders for EBU, and over the shoulders and under the armpit for EBO. The loads from the straps are distributed throughout the vest by appropriate reinforcement of the nylon material used.

The harness arrangement is shown schematically in the following sketch.



Although the system appears quite complicated, once the straps are secured to the structure, quick ingress and egress is accomplished by a zipper in the front of the vest. The head and extremity restraints are the same as those in the mobile pilot restraint, except that the knee restraints are mounted on a common tubing structure which fixes the distance between the knees.

Restraint Harness-Pressure Suit System

Certain desirable features of the universal pilot restraint suit were next integrated with a state-of-the-art pressure suit. The objective was to protect the wearer against reduced pressures and both sustained and impact accelerations. As to the configuration of the proposed system, the contractors were free to pursue any practical approach. However, to comply with the original guidelines, the integrated system was not to compromise or lose any of the advantages or performance of the restraint harness and pressure suit as independent units.

From a number of design configurations, the lobster shell concept (figs. 8 and 9) was selected as most practical for further development. Although the detailed design of components may change during the course of the effort, the NASA-Ames has contracted for the construction of a functional mock-up of the lobster shell system for further development and testing.

For EBI, EBL, and EBR protection, the lobster shell concept consists of individual hard shells located on the back of the pressure suit torso. These hard shells are linked together by a heavy nylon cover and are fastened to the cover by rivets and metal backup plates. In order to facilitate suit maintenance, the complete cover and hard-shell assembly is laced to the pressure suit.

The system attaches to the support structure by two harness-to-structure connector keys located on each hard shell. These keys attach to quick-release retention rails in the centrifuge cab, thus providing couch contour and a means of retaining hard shell alinement. The retention rail system provides lateral and longitudinal clearance which facilitates noncritical alinement of the attachment keys. Once the keys are seated in the rail grooves, the locking bar is held in the locked position by cam plate linkage units.

Anterior restraint for the torso and extremities will be provided by restraint straps which are adjusted by take-up buckles on the front of the suit torso and on the front of the thighs. In addition to the take-up straps, heavy nylon netting joined to the front of the take-up straps provides additional support for the torso. Head restraint will be provided by additional padding in the existing pressure suit helmet.

DISCUSSION

Except for the lobster shell restraint, the systems described herein have been tested and used routinely by NASA and Air Force test pilots familiar with state-of-the-art restraint systems on centrifuge facilities located at the University of Southern California, Aviation Medical Acceleration Laboratory (AMAL), Johnsville, Pennsylvania, and NASA, Ames Research Center. Since results in restraint systems development are based primarily on subjective impressions of pilot subjects, their comments have been used as the basis for acceptance or rejection of restraint methods and techniques. Significant advances in human restraint development are perhaps best indicated by the higher magnitudes of sustained accelerations that pilots tolerate.

Using the modified NASA couch, pilots were subjected to accelerations of 7 g EBI, 5 g EBO, and 7 g EBD. They were able to perform control functions without undue discomfort, but numerous shortcomings noted throughout its use laid the groundwork for further restraint development.

The primary disadvantages of a contoured body couch are twofold. There are various methods of molding a couch to an individual, but none yet for molding the body shape while it is in a high acceleration environment. That is, the forces due to acceleration cause the posterior of the body to move into the mold and, in most cases, cause pressure points by the compression of the fleshy parts of the back. The other disadvantage is the lack of universal fit. This, in itself, contributes to inefficient operation of the facilities both because of the down time required to change couches for various subjects and also because of the lead time to allow for individual couch fabrication.

The universal pilot restraint suit has performed admirably in alleviating the above mentioned problems. Pilot subjects have performed meaningful tasks while subjected to accelerations of 14 g EBI for 2 minutes, 10 g EBO for 1-1/2 minutes, and 7 g EBD for 1-1/4 minutes. However, its somewhat inadequate provision for lateral restraint at high EBL and EBR accelerations has led to the development of the soft restraint.

For EBO, EBL, and EBR support, the soft torso restraint is considered to provide more positive support than the universal pilot restraint suit. However, the lack of rigid support from the axilla to the waist allows the rib cage to flatten under EBI acceleration, causing difficulty in breathing. Further imporvement could be obtained from a combination of the soft torso restraint with the hard shell and bladder system of the universal pilot restraint suit.

The most significant development in enhancing pilot's control of a vehicle in an EBO condition has been the forearm restraints shown in figures 3, 4, and 5. In the first attempt to determine EBO acceleration performance, the upper arm restraints used with the modified NASA couch allowed excessive fore and aft movement of the arms and wrist relative to the side-arm controller, thereby causing erroneous control signals. To compensate for the acceleration field, the arm is counterbalanced by a counterweight arrangement tied to a forearm restraint which embodies the "Chinese magic chain principle." That is, the tension of the cuff around the forearm increases with an increase in the applied load. This counterbalanced forearm restraint makes it possible for the pilot to move his arm under acceleration in the fore and aft directions with little more physical effort than is required in the earth's 1 g field.

CONCLUDING REMARKS

Experience with these systems has indicated the problems and methods of solution for steady acceleration fields. Although some experience has been gained with rapidly varying acceleration fields (such as would be encountered in vibration and capsule tumbling), extension of our knowledge in both steady and vibratory acceleration fields must await further analysis of the problem areas.

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FIGURE LEGENDS

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Figure 1.- Modified NASA couch.

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Figure 2.- Pilot seated in modified NASA couch.

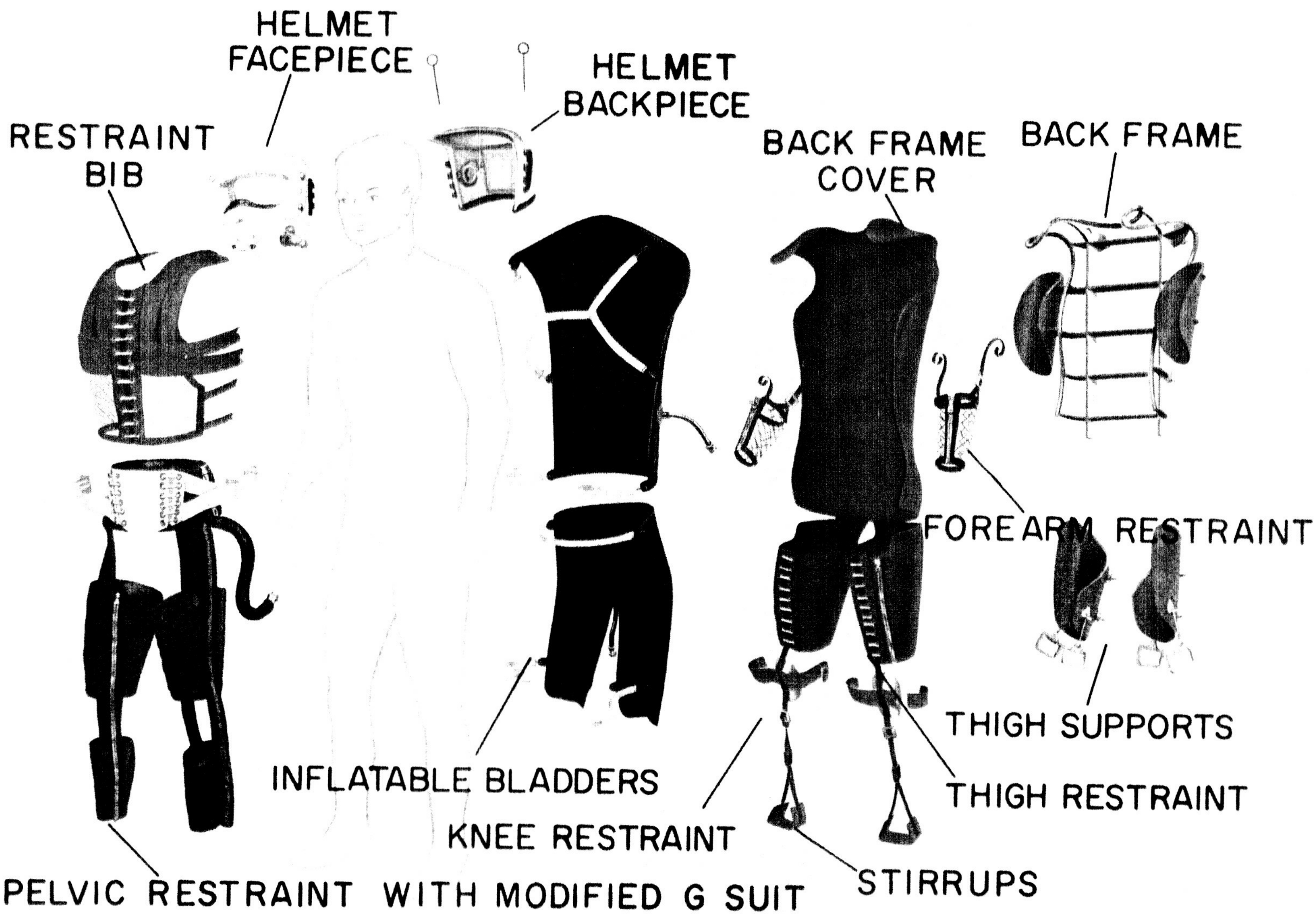

Figure 3.- Universal pilot restraint suit.

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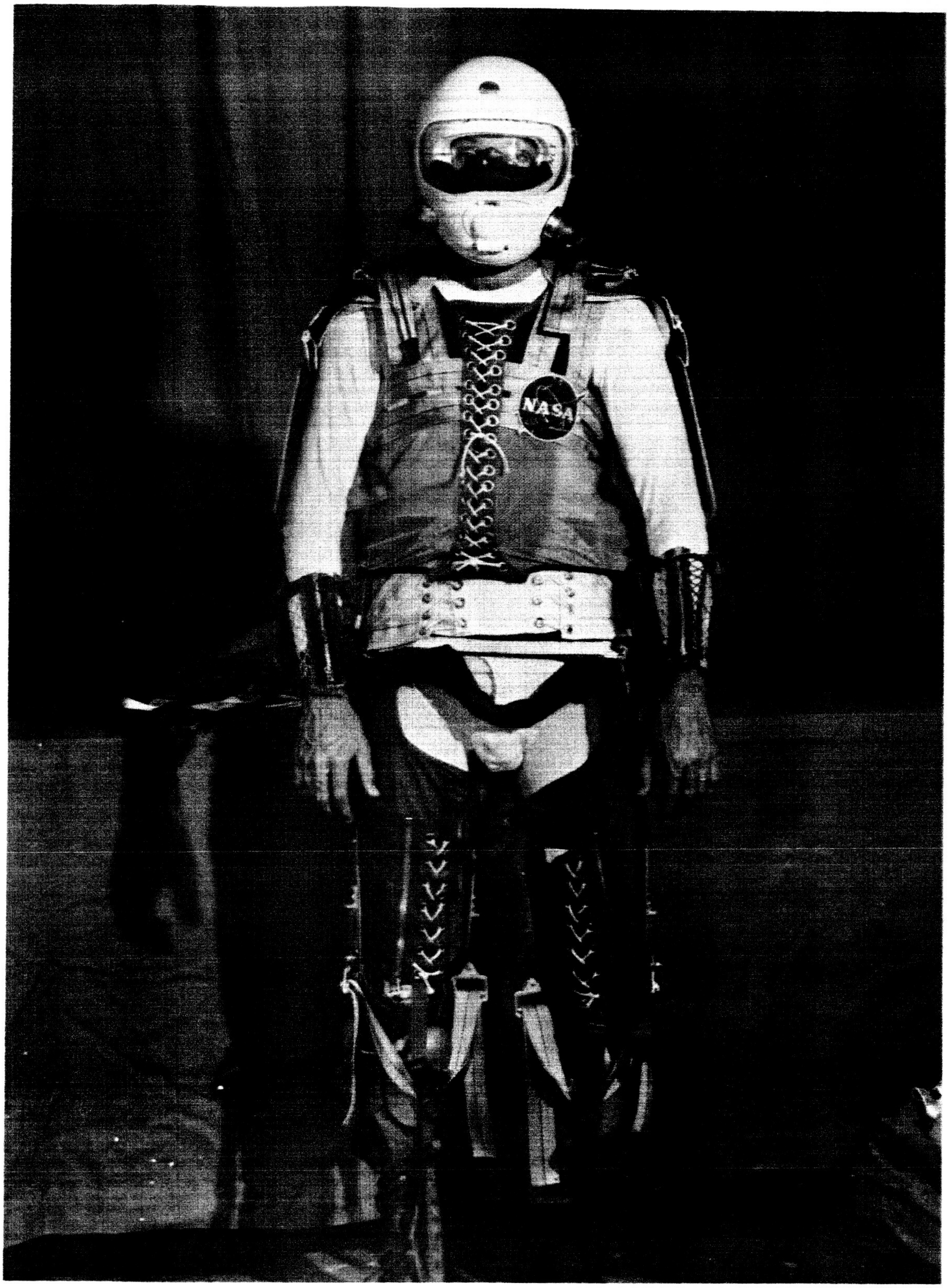

(a) Front view.

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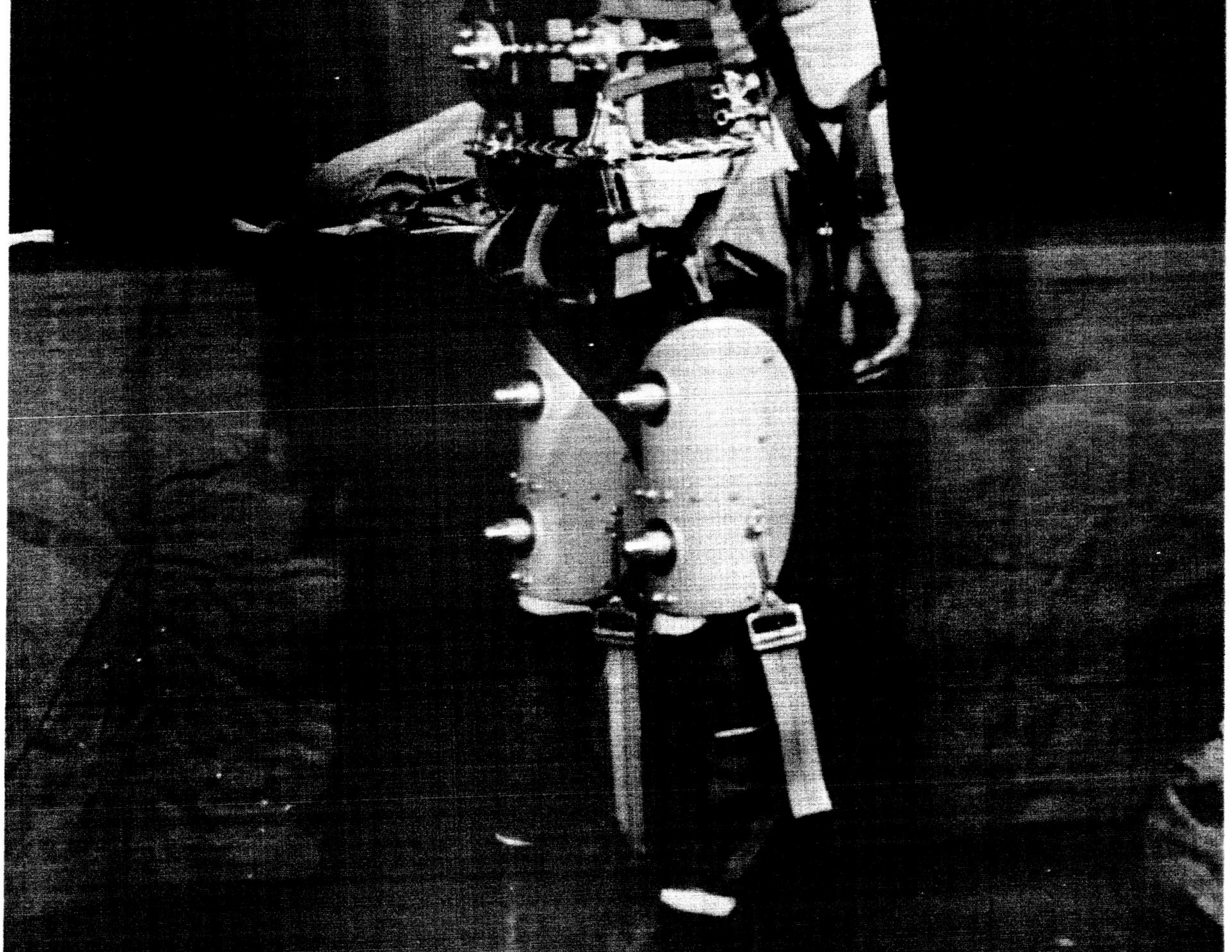
Figure 4.- Pilot wearing universal pilot restraint suit.



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(b) Rear view.

Figure 4.- Concluded.

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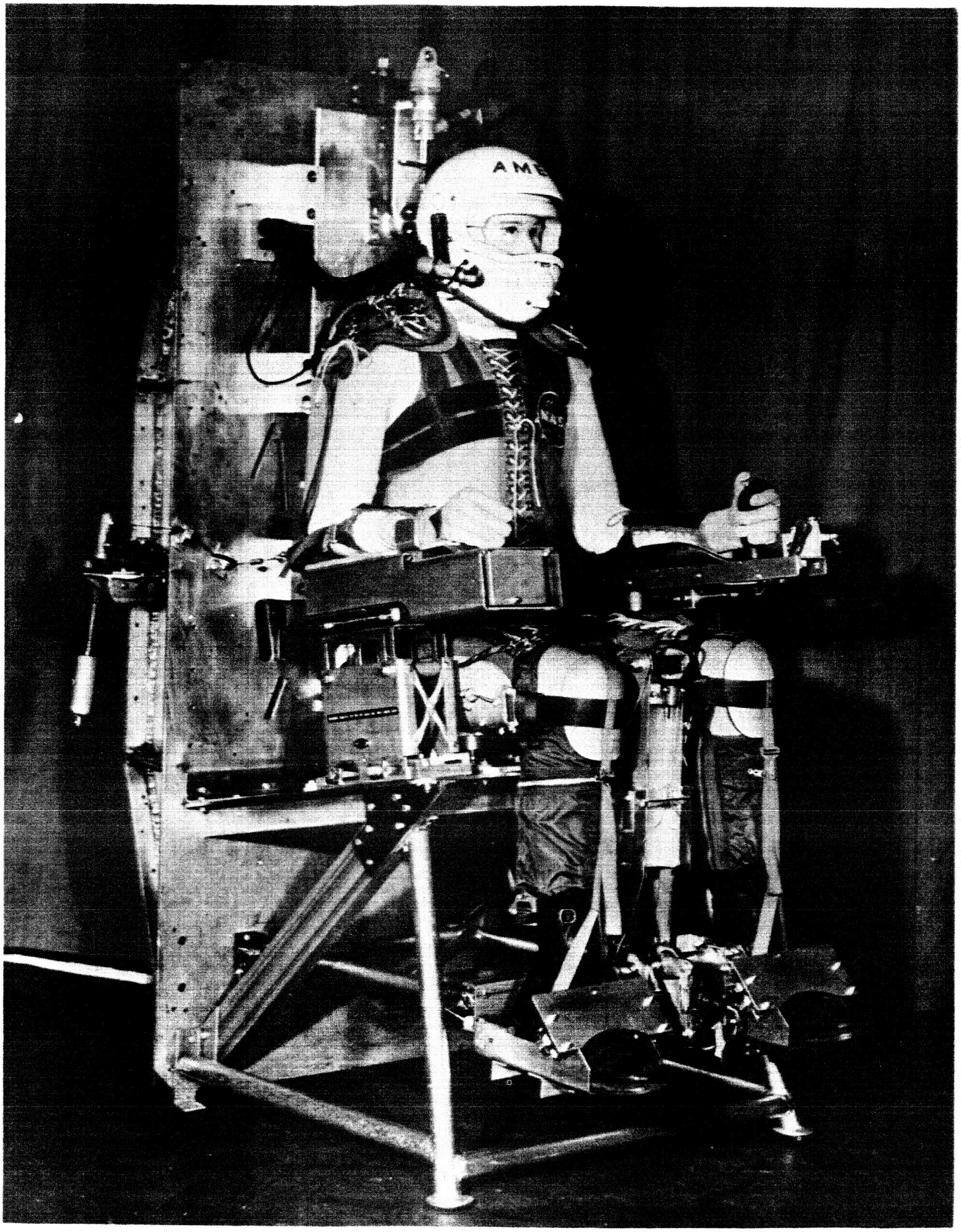

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Figure 5.- Universal pilot restraint suit attached to support structure.

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Figure 6.- Front view of pilot wearing soft torso restraint.

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Figure 7.- Strap arrangement of soft torso restraint.

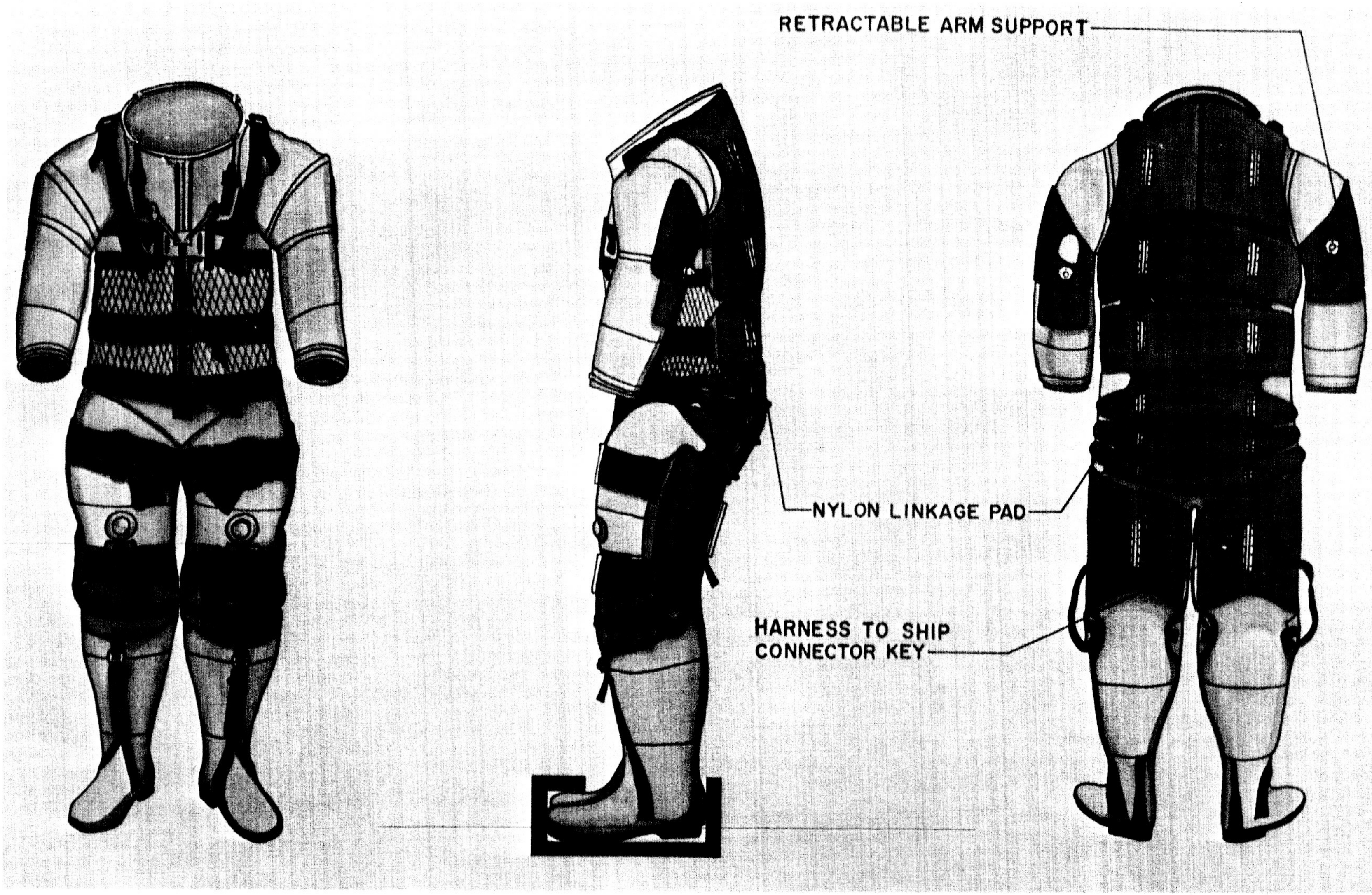

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Figure 8.- Lobster shell restraint.

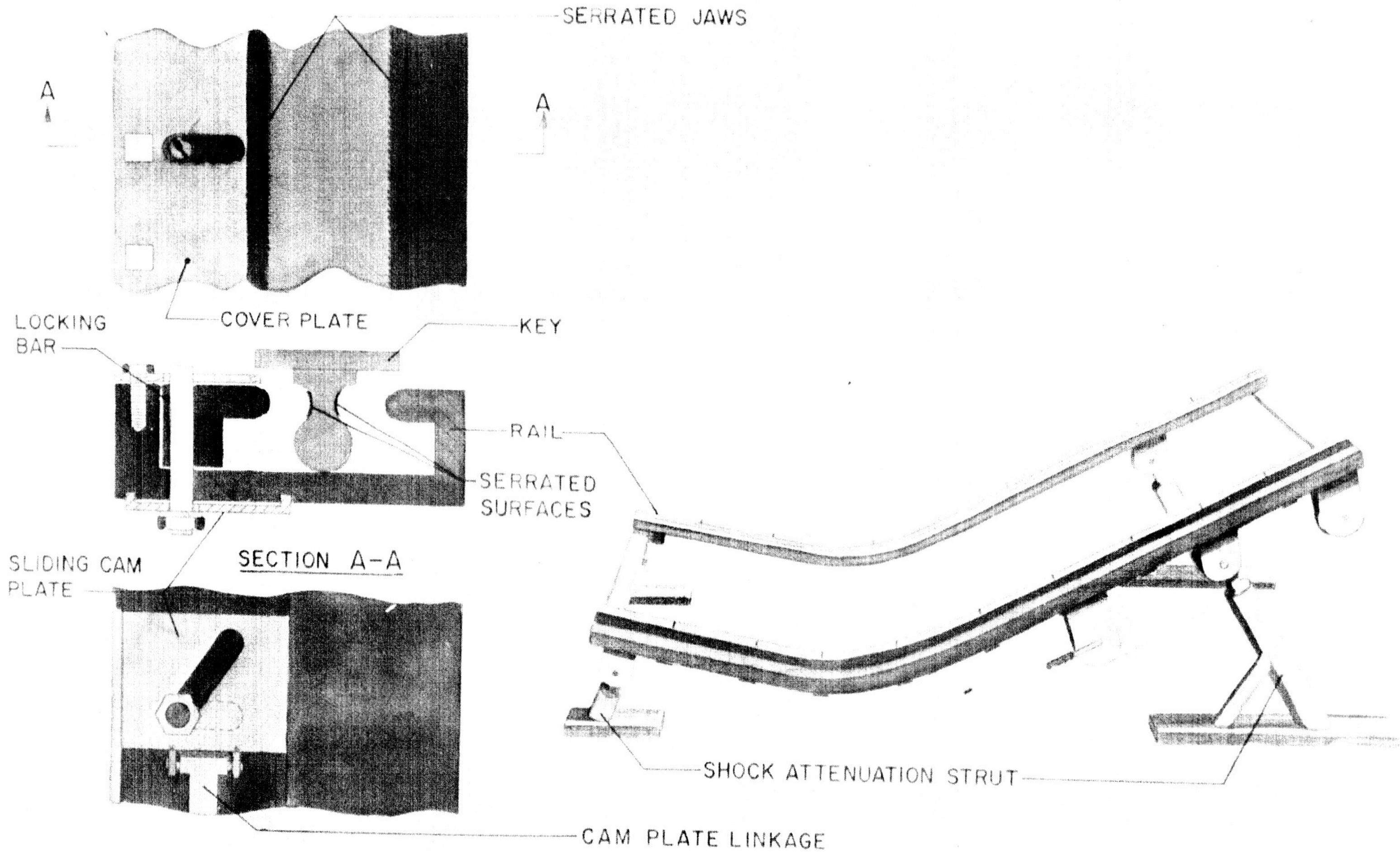

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Figure 9.- Attachment mechanism - lobster shell concept.

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