

DEVELOPMENT OF A BEDREST MUSCLE STRESS APPARATUS

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ABSTRACT

In attempting further to define the deleterious effects of spaceflight on the human body, measurement systems and techniques were devised to determine the loss of skeletal muscle strength and tone as a result of spaceflight exposure. In order to determine how the muscle degradation process progresses with time during nonuse, a system for measuring muscle stress during bedrest was developed. The Bedrest Muscle Stress Apparatus (BRMSA) is configured to slip snugly over the foot board of a standard hospital bed. Data collected with this device correlated well with pre- and post-bedrest data collected with the original skeletal muscle stress apparatus (SMSA).

Since man first ventured into the strange, new environment created by space travel, medical doctors and physiologists have been trying to determine the basis and extent of the physiological changes which living organisms, particularly the human body, experience in these surroundings. These studies have encompassed experimental systems and protocols covering a wide range of types and complexity. These efforts have progressed from the very simple types of "bungee" exercisers utilized in the early Mercury and Gemini flights to the very sophisticated medical experiment systems flown during the Skylab program. The Skylab equipment was designed to quantify precisely, among other measurements: metabolic rate, cardiovascular function, vestibular response, and sleep effectivity.

During the latter stages of the Skylab program and the Apollo-Soyuz Test Project (ASTP) a group of investigators at Johnson Space Center (JSC) began to reason that another possibly significant aspect of the overall physiological effect of the space environment might be determined by measuring the changes which occur in muscle strength and efficiency during spaceflight. A great amount of one-G research, utilizing various types of muscle stress techniques and electromyographic (EMG) recording systems, had been conducted to gather this type of data, and the applicability to zero-G effects seemed obvious.

A method for developing roughly reproducible stress levels in the gastrocnemius muscle with minimal external devices in the one-G environment was utilized to measure the change in strength and efficiency in the crew of the second Skylab mission during their 59-day flight. The measurement consisted of having the subject balance on the ball of his foot on the leg of interest for a specified period of time both with and without holding an additional 40-pound weight. The gastrocnemius is the muscle located on the back of the lower leg just above the Achilles tendon.

A Skeletal Muscle Stress Apparatus (SMSA) which allows relative isolation

of the muscle or muscle groups of interest such that they can have known forces applied to them was developed to gather muscle strength and efficiency data from the American contingent of the ASTP crew. The basic SMSA consists of chair and pedestal assemblies which are structurally tied together at their bases to form an integral system (see Fig. 1). The pedestal assembly, located in front of the chair, is adjustable fore and aft and to the left and right with respect to the chair for the purpose of accommodating 5th through 95th anthropometric percentile subjects and utilization of either left or right limbs. A treadle which is suspended in the pedestal assembly approximately 16 inches above the floor is coupled to a Statham Instruments Model UL3 universal transducing cell through a model UL4, 0 to 200 pounds load cell accessory. The treadle is also coupled, through a cable and bell crank system, to a wrist strap.

Measurements are made on the gastrocnemius and soleus muscles in the leg by the subject seating himself in the chair assembly and placing the foot of interest in the treadle, the EMG electrodes having been previously located properly on the leg. The treadle is constructed such that the point around which it pivots coincides approximately with the subject's ankle position. The pedestal assembly is located with respect to the chair such that the knee stop may be brought down comfortably on the subject's knee and locked firmly into place on the pedestal assembly for the purpose of inhibiting movement in the subject's leg when the experimental data is being gathered. Pressure against the treadle by the ball of the subject's foot is measured by the force cell and displayed on a meter in the field of view of the subject, usually on top of the knee stop.

Measurements are made on the biceps brachii and brachioradialis muscles by placing the wrist of the properly electroded arm through the wrist strap. The elbow rest and wrist strap tie strap are adjusted to allow the subject to sit in a comfortable, upright position with his forearm at a right angle to his body truck and no input being registered by the force cell. Force applied by the subject at his wrist in an upward direction is measured by the force cell and displayed on the meter. The force measurement system is calibrated with a cantilever weight device which is designed to attach directly to the bell crank in lieu of the wrist strap tie strap.

The SMSA was successfully utilized on the American ASTP crewmembers for preflight measurements, but the exposure of this crew to toxic gas during descent and the subsequent concern for crew health prevented muscle characteristic data from being collected on all but one of the crewmembers post recovery.² The SMSA was also utilized as an onboard experiment in a simulated dedicated Life Sciences Spacelab mission in January 1976.³

EMG data reduced from the studies conducted during the second Skylab and ASTP missions indicated that the anti-G muscles become very susceptible to fatigue when subjected to weightless conditions. These effects apparently start early in the weightless period and increase in severity as the weightlessness continues. The time course of these characteristics was not, however, easily definable with just the two sets of data - the second of which (post-ASTP) was rather sketchy anyway. It became obvious that the only way to get good information relative to the time sequence of changes in the anti-G muscle characteristics was to devise a system to determine these changes in real-time.

The best currently known analogy to spaceflight conditions relative to physiological changes which can be easily implemented in ground-based testing is bed rest. Although many investigators argue - probably correctly - that various phenomena which significantly affect specific physiological changes during spaceflight are absent from bedrest situations, the overall deconditioning effect is still strikingly similar. Since no U.S. spaceflights were being scheduled following the ASTP mission, and since in the interim several bedrest studies were, it was determined by the investigators that a device to determine muscle degradation in bedrest subjects would be very useful.

Since one very important requirement of bedrest studies is that the subjects must remain in a supine position at all times, a basic design constraint for any type of Bedrest Muscle Stress Apparatus (BRMSA) would have to be that it must be usable without requiring the subjects to arise from bed. It also seemed desirable to provide a device which could be easily moved from one bed to another so that minimal disturbance of the bed-resting subjects would be required while performing the muscle stress tests. The initial response to these requirements was a concept of a system which could easily be slipped onto the footboard of the bed on which the subject was lying. Although this is the concept which was incorporated into the final BRMSA design, actual utilization of the equipment turned out to be not as simple as originally conceived and the ease of movement between beds concept was essentially negated during operational use.

After careful study of the beds utilized by the hospital in which the initial bedrest study was to be conducted, the basic BRMSA design was developed. The basic frame is devised to fit snugly over the footboard with one end placed directly over the main supporting corner post of the bed. The frame is symmetrical so that it can be placed at either side of the footboard to allow the subject to be tested on either his right or left limbs.

A treadle almost identical to the one utilized in the original SMSA, particularly with respect to subject interface, is suspended in the middle of the frame and coupled to a load cell and transducer identical to that utilized in the SMSA. The treadle is configured with multiple holes around the perimeter to interface with the load cell force bar such that adjustment of the treadle base angle relative to the orientation of the subject's leg can be accomplished (see Fig. 2). The Principal Investigator desired this adjustment in order to allow testing to be accomplished with the subject's foot placed at various angles relative to his leg - in particular, toe-down angles.

The arm stress interface with the treadle load cell system is accomplished by providing an adjustable-length rod which attaches to a cloth strap around the subject's wrist on one end and one side of the treadle on the other end. Multiple holes are provided in the treadle side for this interface, also to allow adjustment relative to the angle of the rod, determined by the subject's forearm length, with respect to the treadle height above the top of the mattress. The direction of pull on the rod exerted by the subject's wrist was to be kept perpendicular to a line from the treadle pivot point to the rod attach point.

One of the most perplexing aspects of the BRMSA development program was devising a method for restraining the subject's body against the isometric forces he would be exerting. Several concepts were examined and discarded before the final configuration was developed and implemented. The restraint

system had to be reasonably comfortable on the subject while he maintained his supine position during the test period, and fairly easy to don in this position also. It could not interfere significantly with the various physiological sensors placed on the subject's body, and still had to withstand the reaction to the isometric forces applied by the subject which were to range up to 300 pounds and more.

Anthropometric data indicated that a restraint system which would distribute the force at both the waist and shoulders would be the most efficient and the most comfortable for the subject. The waistband portion of the final restraint configuration was a custom-built unit based on the concept of a backpack waistband, but with longer pads to extend entirely around the subject's waist. Attach points were very securely sewn into the top and bottom of the band to accept the shoulder straps and subject restraint cables, respectively. The shoulder straps were of a padded adjustable type - lengthened versions, as a matter of fact, of the shoulder straps developed for the Skylab bicycle ergometer restraint system. These straps were crossed across the subject's chest in use and when they and the restraint cables were cinched down to allow minimal movement of the subject against the isometric forces he exerted during testing, the entire restraint system felt reasonably comfortable and quite secure. The restraint cables attached to each side of the BRMSA frame close to the top with pip pins which passed through a multi-hole metal strap on the end of the cables.

The inside surfaces of the frame "legs" which contacted the footboard were covered with a hard, slick rubber-like material to facilitate installation and removal of the BRMSA on and off the footboard. The instrumentation package which contained the electronic circuitry to perform the force and EMG measurements was mounted on a flat plate which had hooks at one end to engage mating holes located on the top of the BRMSA frame, allowing this package to hang down along the outer side of the BRMSA.

The muscle force output from the universal transducing cell was fed into a Statham Instruments Model SC1100 bridge amplifier. An additional stage of gain was added so that the output from the bridge amplifier could be optionally increased when measuring low force levels. A meter, with scales calibrated in pounds of force, was mounted on a small metal box. This box was then placed in a location from which the subject could easily monitor the reading and thus maintain the fixed force levels required by the test protocol.

Captured pins, the ends of which fell approximately 1 inch below the main box section of the BRMSA frame, were located at each end of the frame between each pair of "legs" such that the pin at the end of the frame located at the extreme end of the footboard would engage the hole located on the top of the footboard at this point. This arrangement prevented any possible lateral movement of the BRMSA along the footboard. Two handles located at each end of the BRMSA frame to facilitate placement and removal of the unit on and from the footboard complete the BRMSA design configuration.

Calibration is accomplished through the use of a calibrator arm which hooks under the treadle pivot point on each side and rests on the force cell linkage in a horizontal position. The distances between the pivot point and the effective center of gravity of the calibrator arm are calculated to impart the known 100-pound calibration force to the force measurement system.

A typical use sequence of the BRMSA would proceed in the following manner:

Sensoring - EMG and sensors for other measurements which may be made before, during, between, or after stress sequences which require electrical contact with the body are attached at appropriate locations on the body. These other measurements may include electrocardiogram, vectorcardiogram and/or electroencephalogram. Also, sensors which will be located in proximity to or underneath the restraint system are usually applied at this time. These may include a pneumogram strain gauge, a phonocardiogram sensor, leg volume cuff assembly, and other trunk or leg-mounted sensors.

System configuring - The BRMSA is mounted at the appropriate side of the footboard. The instrumentation package is hung on the outboard side of the BRMSA, appropriate power and signal connections are made, and the system is turned on. Other instrumentation appropriate to the particular investigation being conducted will probably be connected and powered up at this time also.

Calibration - The calibration arm is placed on the BRMSA in the appropriate location and all systems and real-time readouts are adjusted to reflect the 100-pound calibration value. Other systems utilized in the particular investigation are usually calibrated as appropriate at this time. The calibration arm is removed from the BRMSA at the conclusion of this sequence.

Restraint donning - The subject is rolled to one side or the other as convenient and the restraint belt and shoulder straps are placed on the bed in such a manner that they can easily be wrapped around the subject and secured when he rolls onto his back again. The shoulder straps are loosely attached to the belt and the restraint cables are adjusted to give a good pull against the isometric forces. The restraint cables can most easily be attached to the BRMSA (after being attached to the belt) if the subject allows his knee to bend up slightly, then be straightened back out to check the cable length adjustment. The shoulder straps are then cinched down snugly and the entire restraint system is checked for tightness and comfort and further adjusted as necessary.

Final configuring - Any additional sensors appropriate to the investigation being pursued, such as a blood pressure cuff and microphone, are placed on the subject and all sensors are connected to their appropriate instrumentation systems. The subject places his appropriate limb in place, his foot in the treadle or his wrist through the wrist strap, which will have been connected to the treadle via the adjustable rod. With the subject relaxed (to the extent possible), any force values being registered in the system due to the tightness of the restraint system is nulled out.

Force application - Force is applied against the treadle with the foot by the subject pushing with the ball of his foot only. Force is applied with the arm by the subject pulling straight up (toward his head) with his elbow only. Force is usually applied for a few seconds up to a minute in a sequence of percentages of a previously-determined maximum voluntary contraction (MVC) value. The MVC value is determined by the subject pushing with the maximum force possible for a very short length of time in each of the test configurations desired. The MVC is many times re-checked at the conclusion of a stress sequence.

A typical sequence for leg muscle stress levels might be as follows:

10 seconds at 30% MVC
20 seconds rest
10 seconds at 40% MVC
20 seconds rest
10 seconds at 20% MVC
20 seconds rest
60 seconds at 50% MVC
60 seconds rest
MVC
Relax

The subject maintains these fixed percentage MVC levels by monitoring the force level meter at the levels prescribed by the test conductor.

Initial utilization of the BRMSA showed all of the basic concepts incorporated into the system design to be sound. There were, however, a few shortcomings which had to be rectified before the system could be utilized to its fullest extent. When pressure was first applied by a test subject against the treadle, it became immediately obvious that the backplate against which the heel rested came up too far from the soleplate and caused interference by bearing against the Achilles tendon. This problem was rectified for the "foot flat" test position (the foot approximately perpendicular to the leg) by placing a piece of foam rubber between the subject's leg and this plate. This situation, however, rendered the BRMSA totally useless for any type of toe down testing.

A couple of MVCs by the (fortunately) rather large test subject during initial checkout of the BRMSA quickly revealed several less than adequate components in the initially-devised subject restraint system. The hooks which attached the restraint cables to the subject restraint harness had to be upgraded considerably, and the restraint waistband attach points had to be strengthened also.

As the first of the actual in-bed tests were being accomplished, it was observed that, despite the apparent sturdiness of the hospital beds being utilized and the theoretical offsetting of the forces being generated by the subject with the subject restraint system, there was indeed considerable movement being effected between the footboard and the bedrails. It therefore became necessary to devise an additional restraint system for use between the footboard and the bedrails to prevent movement between these components of the bed. Two cables with turnbuckles at one end and terminations which could be attached quickly to the footboard (one actually attached to the BRMSA frame) and the rails were fabricated and installed. This extra bracing effectively eliminated a large portion of the footboard-to-bedrail movement.

As the procedures and techniques for setting up and operating the BRMSA and other systems associated with the bedrest study became more coordinated and streamlined, it became apparent that setting the system up on one bed and then shifting subjects in and out of that bed, rather than moving the equipment from bed to bed, was a much more efficient mode of operation. This was due mainly to the quantity of equipment to be moved rather than any problems with moving the BRMSA itself from one bed to another.

Data collected with the BRMSA correlated well with pre- and post-bedrest

data collected with the original SMSA. The absolute values of the data obtained from the BRMSA were slightly higher than the SMSA data due to a better mechanical advantage for the subjects in the supine position, but all frequency and trend data correlated very well between the two units.⁴

In addition to its proven value for gathering in-test muscle stress data during bedrest simulations of the zero-G environment, it would appear that the BRMSA might also have definite application in certain clinical situations. Since long-term confinement of patients in bed does have the precise deleterious effect on the cardiovascular and skeletal muscle system which makes it a valuable corollary to the zero-G environment, it would seem that a system of this type would be useful at least to keep track of a long-term bedridden patient's muscle strength deterioration, if not also to provide therapeutic assistance in maintaining a minimal level of skeletal muscle and cardiovascular system tone. It is the contention of many cardiologists that isometric exercise is one of the best adjuncts to building and maintaining a health cardiovascular system, in addition to its obvious positive effects on the skeletal muscle system.

In conclusion, the authors wish to acknowledge several individuals without whose inputs and efforts this program would never have existed or been accomplished. Earl V. LaFevers, Ph.D., recently with JSC's Bioengineering Systems Division and now a human factors consultant, was Principal Investigator and prime mover on all of the muscle stress studies conducted at JSC over the past 4 years. It was at his behest that the BRMSA was devised, and without his constant encouragement (and in some cases, harassment) it would never have been built. Mr. James S. Arthur of JSC's Equipment Engineering Branch handled the myriad administrative details involved with the contract under which Mr. Hooper and Mr. Setzer accomplished the detailed design of the system, and in conjunction with Mr. Dave Mullins of the Planning and Scheduling Office, administered the fabrication contract for the BRMSA. Mr. Eugene K. Wendler of JSC's Crew Systems Division is to be commended for his tireless hours spent in designing, redesigning, and repairing the subject restraint harness. Mr. Joe Baker, Mr. William N. Crozier, and Mr. John Donaldson of Technology, Incorporated's Cardiovascular Laboratory support group at JSC are also to be given a large amount of thanks for their diligent work in the design, fabrication, maintenance, and operation of the BRMSA instrumentation system.

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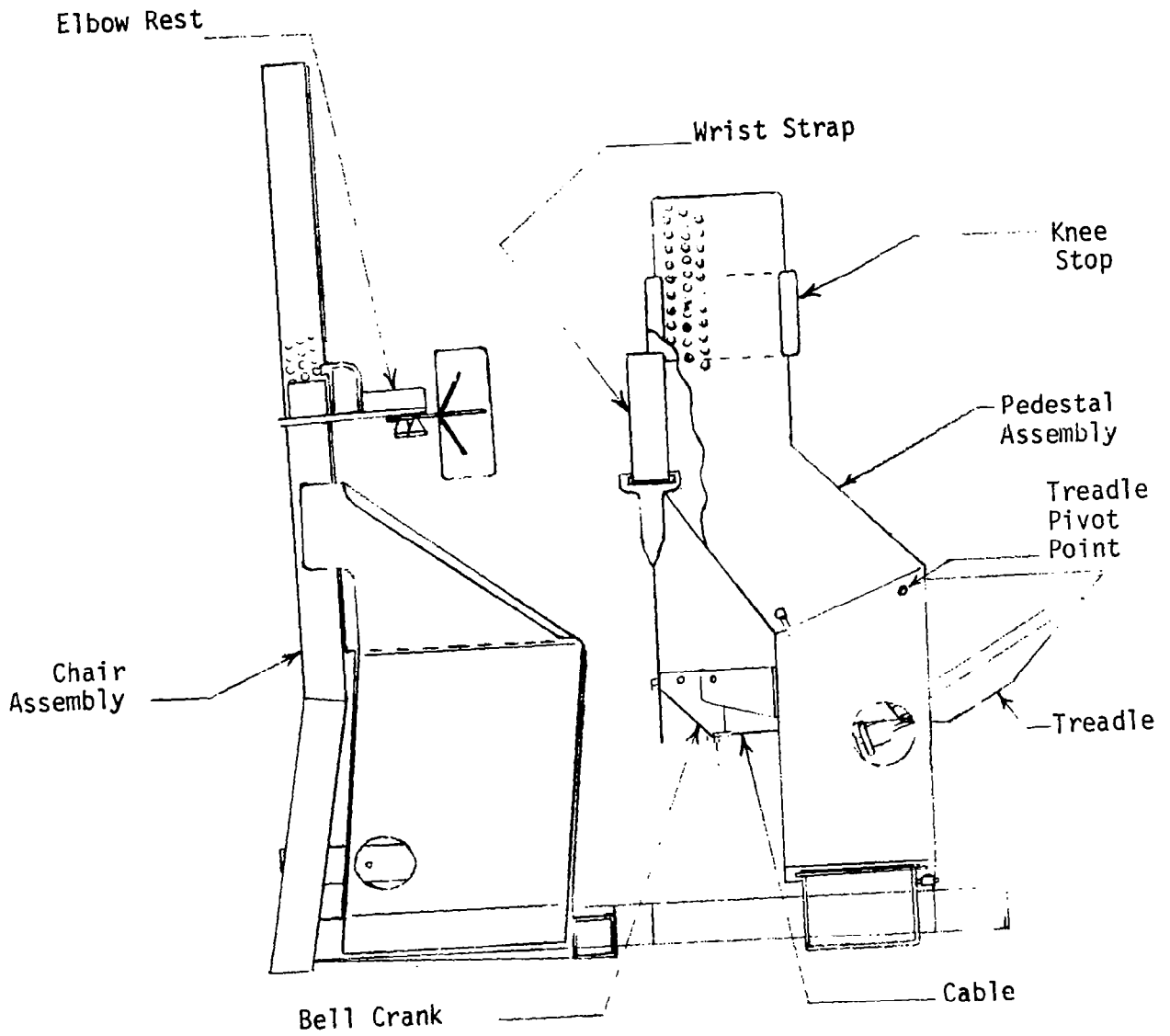


FIGURE 1 - SKELETAL MUSCLE STRESS APPARATUS

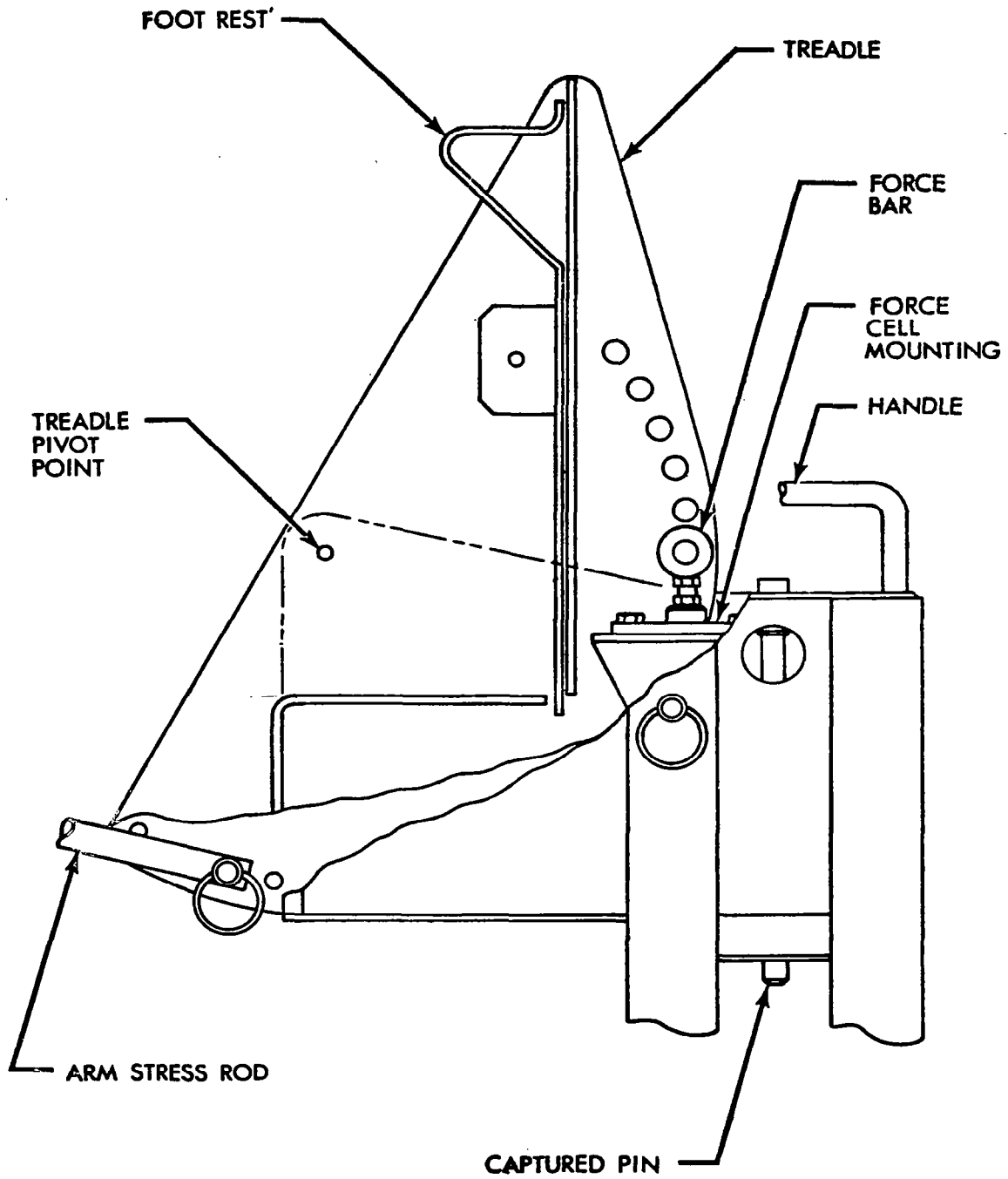


FIGURE 2 - BED REST MUSCLE STRESS APPARATUS