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DESIGN, DEVELOPMENT and EVALUATION
of STANFORD/AMES EVA PREHENSORS

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(NASA-CR-182688) DESIGN, DEVELOPMENT AND
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SUMMARY

Space Station operations and maintenance are expected to make unprecedented demands on astronaut Extra-Vehicular Activity (EVA). With the Space Station expected to operate with a 8-10 psi atmosphere (versus 4 psi for Shuttle operations), the effectiveness of pressurized gloves is called into doubt at the same time that EVA activity levels must be increased. To address the need for more frequent and more complex EVA missions and also to extend the dexterity, duration and safety of EVA astronauts, NASA-Ames Research Center and Stanford University have an ongoing cooperative agreement to explore and compare alternative solutions.

This document plus the accompanying computer tape constitute the final report of design and development of a series of Stanford/Ames manually-powered EVA Prehensors. Each prehensor consists of a shroud forming a pressure enclosure around the astronaut's hand, and a linkage system to transfer the motions and forces of the hand to mechanical digits connected to the shroud. All prehensors are intended for attachment to a standard wrist coupling, as found on the AX-5 hard suit prototype, so that realistic tests can be performed under normal and reduced gravity as simulated by water flotation. A collateral task is the development and implementation of a "Performance Assessment Work Station" for evaluating the prehensor designs.

Work described herein includes final design modifications to two types of manually powered prehensors for compatibility with existing wrist connections, production of detail part drawings and specifications in CADAM format, preparation of specification and supplier lists for purchased components, and submission of plans for testing and comparison with conventional gloves under realistic conditions.

PROBLEM STATEMENT and GOALS

In its most general form, the intent of this design effort is to determine whether the function of the gloved hand may be adequately replaced or improved upon by a mechanical gripper powered by the muscular movement of the user's hand. The motivation stems from the present and foreseen incapacity of the EVA Suit glove to accommodate the extremes of required function: from low-load, highly intricate tasks exemplified by instrument repair and adjustment, to prolonged heavy-load activities such as truss assembly or satellite retrieval. Results of this study may also apply to interfaces for teleoperators having improved translation of human hand motion into simple linear and rotary movements for transmission to a remote device, and to more capable end effectors for self-powered robots as envisioned for Space Station assembly tasks¹.

Actual wearing and use of an EVA suit equipped with prehensors is the only definitive test of completeness of the design. Impact of a particular design upon visual field, excessive use of certain muscle groups causing accelerated fatigue, possible compression or abrasion of soft tissue or skin at pressure points, inefficient or impossible end-effector paths due to constraints on joint motion², or dimensional incompatibility with certain suit-related tasks such as glare shield operation cannot be completely predicted. Thus, in order to achieve acceptance, the performance of prehensors must be clearly superior to gloves for a given task. One method of comparison is to provide a glove for one hand and a prehensor for the other, which may in fact be the preferred mode of use. The prehensor design must be inherently safe and reliable and its usage self-evident from the outset.

WORK ACCOMPLISHED

Three different prehensors were designed, each representing an increasing degree of complexity³: the "1-DOF" or "Prosthetic Prehensor" having a detachable two- or three-fingered end-effector is intended to establish criteria for mechanical simplicity, compactness, comfort and ease of training by which more capable devices can be measured. The "2-DOF" or "Multi-Grasp Prehensor" has

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a fixed thumb plus two fingers capable of pinching against each other and against the thumb independently; a second thumb can potentially be added to perform specialized tasks. The "6-DOF" or "Direct-Link Prehensor" was completed earlier and was reported on elsewhere⁴.

Since the last progress report (April, 1987), the following tasks have been accomplished:

1. Final design modifications to two types of manually powered prehensors for compatibility with existing wrist connections,
2. Production of detail part drawings and specifications in CADAM format,
3. Preparation of specification and supplier lists for purchased components (also in computer-readable format), and
4. Generating plans for testing and comparison with conventional gloves under realistic conditions.

1. SINGLE DEGREE-OF-FREEDOM PREHENSOR—1DOF

The one degree-of-freedom, two-finger prosthetic prehensor provides a modified pinch grasp. This design is restricted to a single linear hand motion and is intended to use off-the-shelf prosthetic hardware wherever feasible. The constraint on mobility is intended to establish criteria for mechanical simplicity, compactness, comfort and ease of training by which more capable devices can be measured.

As described in the progress report of April, 1987, a full-scale functional mock-up including shroud but omitting the wrist coupling was constructed of acrylic plastic; fitted with a single-moving-finger hook-shaped end-effector, it proved capable of reasonably precise pinch grasp, such as holding a pencil, but was not intended for high-load situations.

This design was originally produced as a right-handed version using CADAM. Supplementary work consisted of:

- a. Part and assembly CADAM drawings for both left- and right-hand versions on the assumption that tests are to be performed with the left-hand 1-DOF unit being simultaneously compared to right-hand versions of other prehensors or gloves.
- b. CADAM files copied to machine-readable tape.
- c. Designs for alternate end-effectors interchangeable with the baseline two-fingered Roberts-linkage unit, including three-fingered and ratchet-wrench devices (Figure 1).

2. TWO DEGREE-OF-FREEDOM PREHENSOR—2DOF

The two degree-of-freedom, three-finger prehensor with one finger ("thumb") fixed, is intended to provide experimental data regarding the cost and benefit of incremental degrees of freedom. An acrylic mock-up, excluding the shroud, was fabricated and demonstrated, as described in the progress report of April, 1987. Hand-made drawings of the 2-DOF pressure-suit compatible prototype were submitted for fabrication in a right-hand version only.

The 2-DOF prototype was originally described in hand-made drawings in a right-hand version only. Supplementary work consisted of:

- a. Part and assembly CADAM drawings of the right-hand version, checked for dimensional consistency and compatibility.
- b. A CADAM design for an adaptor section to couple the prehensor shroud to the standard AX-5 wrist.
- c. CADAM files transferred to machine-readable tape.

3. DIRECT-LINK PREHENSOR—6DOF

The six degree-of-freedom, semi-anthropomorphic prehensor with two degrees-of-freedom for each of three fingers, demonstrates some ability to manipulate objects as well as grasp them, and represents the current extreme of level of complexity, cost and performance. No additional work was performed on this concept under this agreement.

4. PERFORMANCE ASSESSMENT WORK STATION—PAW

The PAW consists of hardware to enable the suited subject to perform a series of activities closely resembling actual usage in EVA situations. The test series may be combined with precise biomechanical descriptions of the functional requirements, so that prehensors can be compared to gloved and unencumbered human hand performance, and with standard and specially-devised performance tests such as are used in rehabilitation assessment following injury to the hand.

In addition to analytical tools developed at Stanford for robotic end-effectors⁵ and existing standardized human hand assessment tests and NASA in-house and contracted tests that may be used as is or modified for evaluating prehensor *vs.* gloved and un-encumbered hand performance, the following performance measurement protocols were identified in the progress report of April, 1987, as applicable to prehensor tasks:

1. *Stanford Instrumented Grasp Strength Assessment.*
2. *Stanford Functional Hand Task Assessment.*
3. *University of Minnesota Tracking System.*

A JR3 6-degree-of-freedom force-moment sensor was obtained for a temporary trial, and was found to be suitable for purposes of the PAW either as a stand-alone device or attached to another structure such as a rotary crank.

Supplementary work consisted of continued progress toward the goal of objective measurement of the relative performance of each prehensor against the performance standards of (1) the high-pressure space suit gloved hand, (2) developmental glove designs, and (3) the un-encumbered human hand, in particular:

- a. *Identify additional standardized human hand assessment tests that may be used as is or modified for prehensor evaluation.*

One such assessment protocol is the Jebsen Hand Function Test⁶, intended to assay function as it relates to capability to perform well-defined activities of everyday living, evaluated by a "time-motion measurement" method. It consists of seven subtests:

1. Writing,
 2. Card turning (simulated page turning),
 3. Manipulation of small common objects (bottle caps, coins, *etc.*),
 4. Simulated feeding (pick up beans with a teaspoon),
 5. Stacking checkers,
 6. Handle large light objects (move and manipulate empty cans), and
 7. Handle heavy objects (move and manipulate full cans).
- b. *Develop additional quantitative and qualitative performance test strategies, methodologies and equipment.* (see item e., below).
 - c. *Investigate specific measurement instrumentation, for example:*
 - Handles with quick-release capability on a six degree-of-freedom force/moment transducer to simulate various types of grasp (Figure 2).

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- Accelerometers, load cells, or other force/motion analysis sensors to monitor performance during specific tasks.

While it is possible to place accelerometers on a body so as to record segmental motion (Figure 3), it would be necessary to telemeter outputs to a stationary receiver to avoid restriction of motion due to cable interconnections; also, because the AX-5 suit joints permit unrestricted rotation as well as bending, tracking of accelerometer axis vector is complicated.

In general, the application of force-measurement sensors should be to the structure or object being manipulated, rather than to the EVA suit or prehensor, for the same reasons given above.

d. *Investigate requirements for data acquisition, analysis and display hardware/software.*

Commercially available telemetry and data-logging hardware is adequate for performance assessment needs. Processing of the data so obtained can be begun using commercial software, but will ultimately require custom programming, for example, to relate EVA suit position to simultaneous measurement of force applied to an object being manipulated.

e. *Recommend possible methods to apply assessment tests in simulated microgravity (flotation tank) and zero-g/vacuum environments, such as:*

- Orthogonal video image analysis,
- Measurement of grasp and manipulation ability at extremes of reach,
- Time-to-completion of tasks such as coupling and uncoupling bayonet-type connectors or screwing together pipe sections.

The environment of the flotation tank ("wet facility") is an extremely difficult one in which to obtain precise positional information by optical means, due to restricted fields of view and to multiple light reflections. Electromagnetic transponders placed on each suit or hand segment to be tracked may be a better option, but still are subject to operation in an electrically conductive medium within a steel tank. A better approach for position determination in the flotation tank may be self-contained acoustic transponders which are time-gated and/or frequency encoded so as to give unambiguous distance from an array of fixed ultrasonic sources based on time-of-flight measurement. However, both optical and electromagnetic methods are applicable to use in space, whereas acoustic transponders are not.

Our recommendation is to omit (for the time being) obtaining position of suit segments, and concentrate on measuring performance by completion of specific tasks. Simulated tasks could consist of push-and-turn fixtures (Figure 4, inset) which optionally have digital position and force encoders and variable resistance to motion. These would be located on a rack at the extremes of reach (Figure 4); the rack could also hold less abstract task apparatus, such as couplings to be connected or bolts to be turned.

f. *Explore the potential of real-time dynamic display of prehensor performance using animated graphic solid modeling analysis and demonstration of prehensor design and control.* If implemented, this concept would complement development of the PAW by generating a computer model of each prehensor and its properties, with the potential for predicting performance rather than relying on *post facto* testing to refine a design. To the extent that objects in the user's environment are included in the model, it could also be valuable as a training tool to facilitate the transfer from glove to prehensor.

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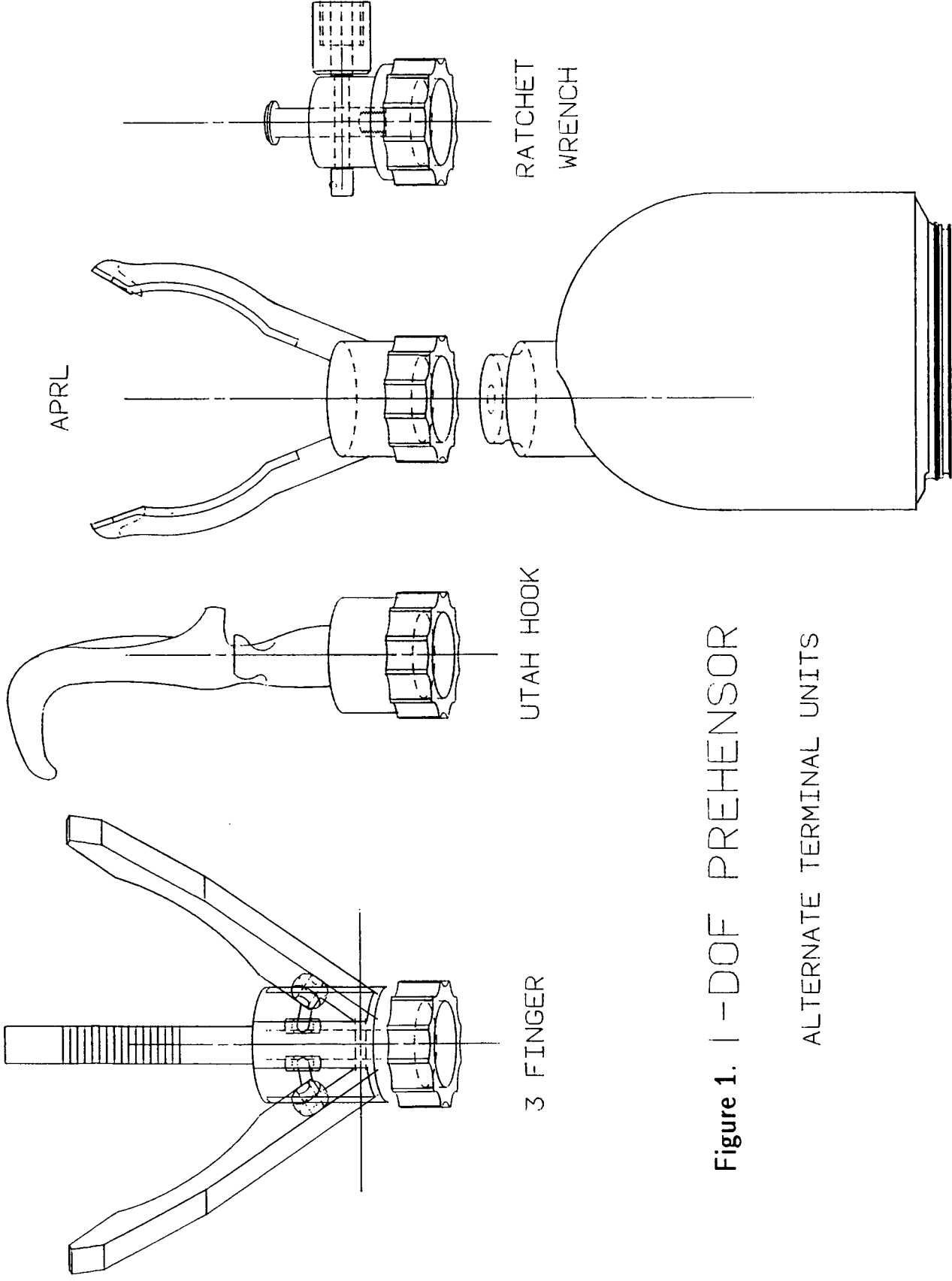


Figure 1. 1 - DOF PREHENSOR

ALTERNATE TERMINAL UNITS

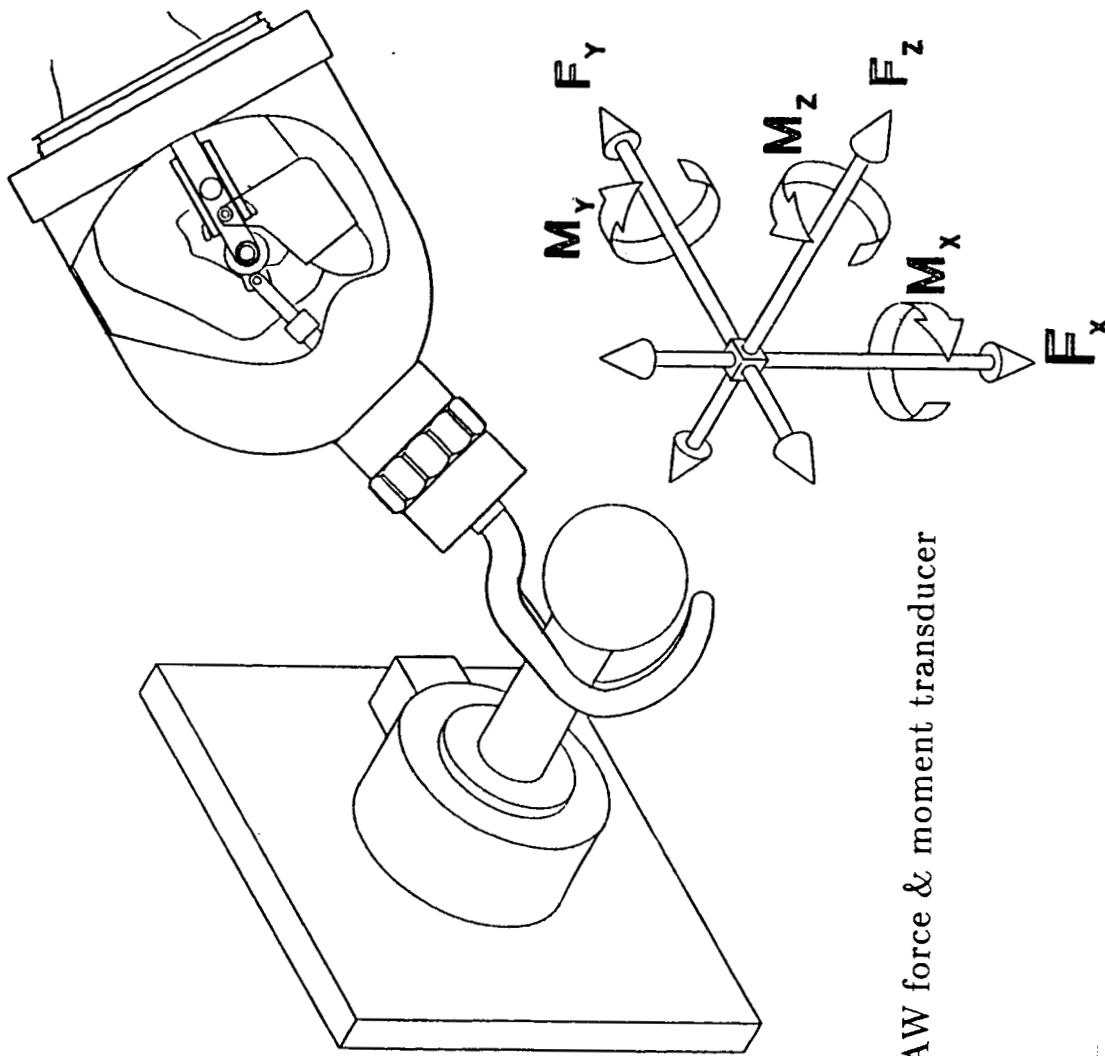
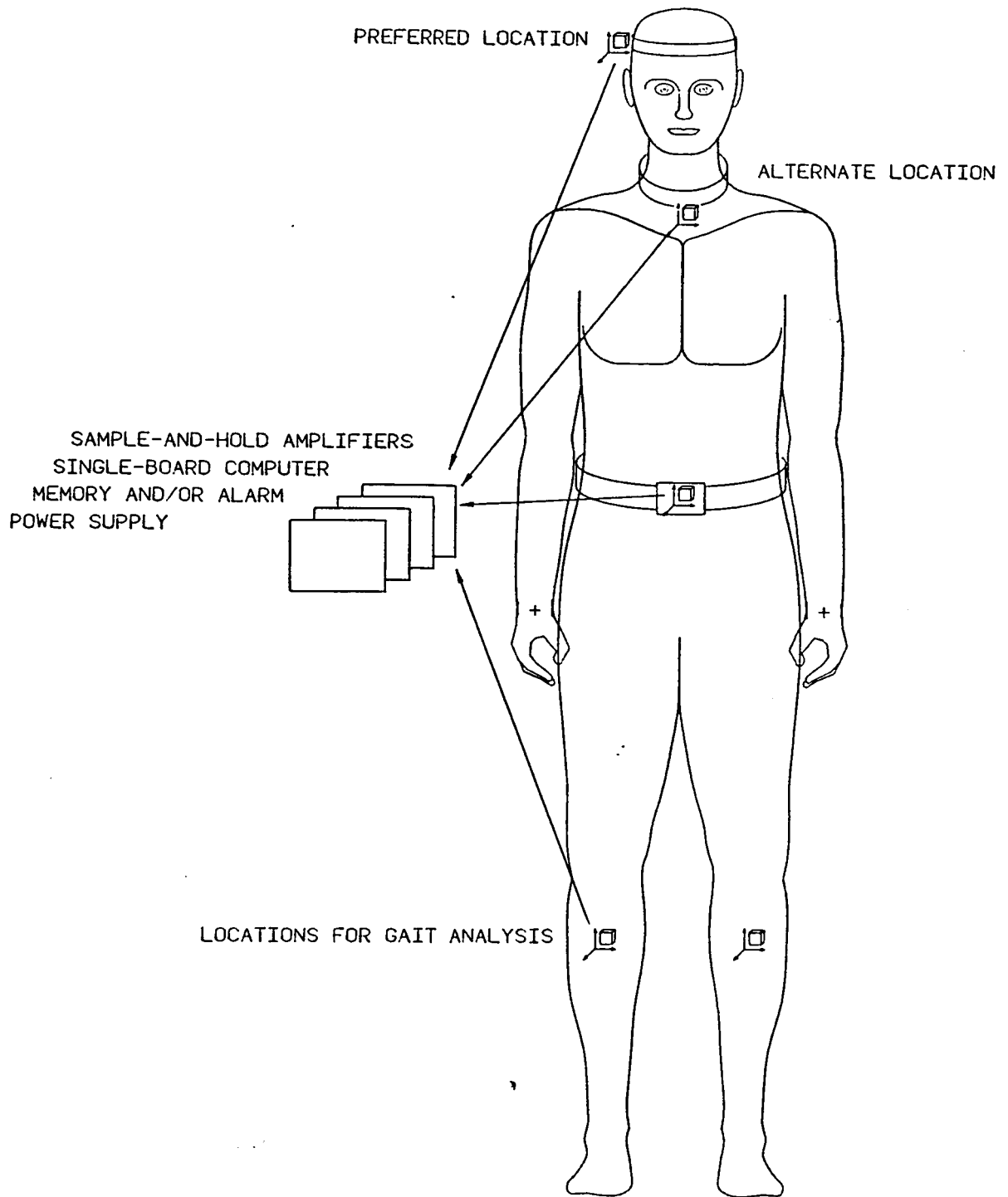
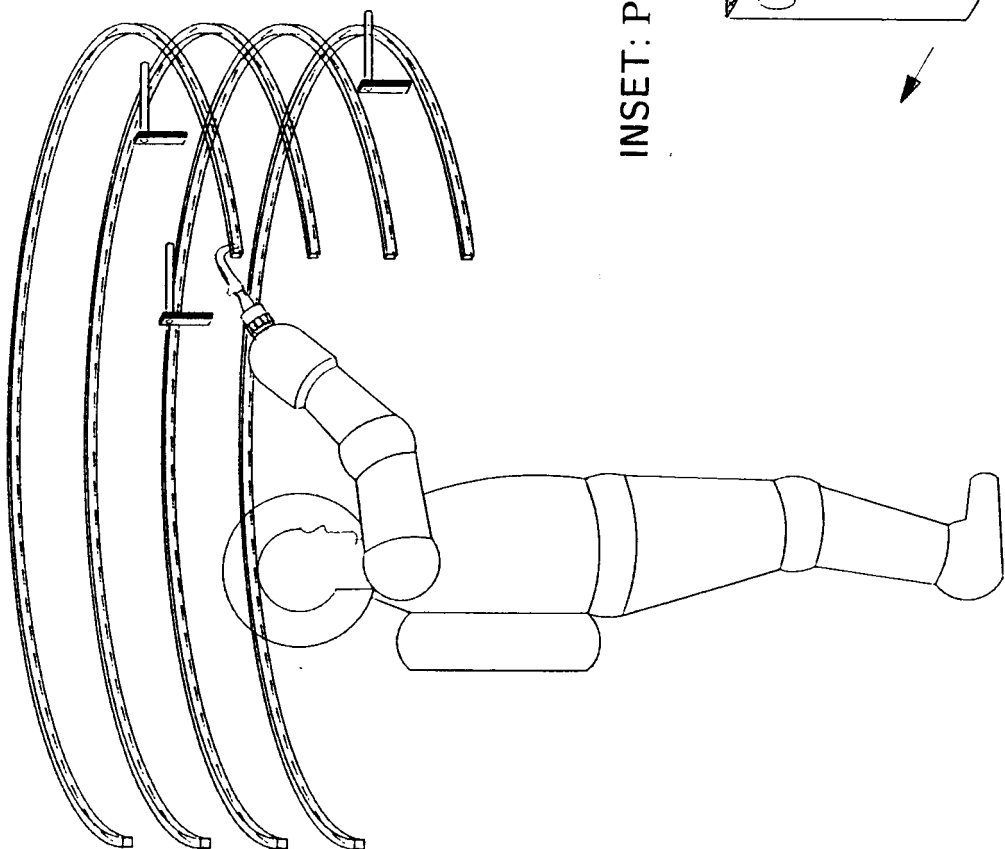


Figure 2. PAW force & moment transducer

Figure 3: Ambulatory Accelerometer Locations





INSET: Push-pull & Rotary Task Simulator

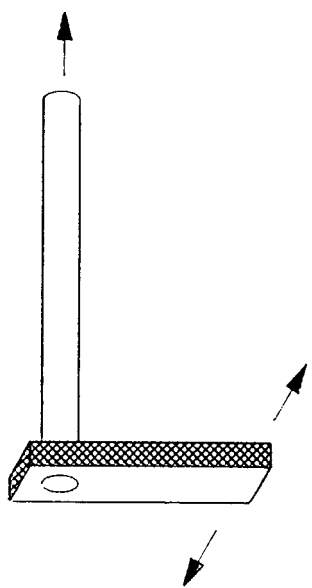


Figure 4. Range of Motion/Effort Test Grid