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TRIPLE-AXIS COMMON-PIVOT ARM WRIST DEVICE FOR MANIPULATIVE APPLICATIONS

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SUMMARY

A new concept in manipulator development to overcome the "weak wrist syndrome" is presented in this paper and is known as a Triple-Axis Common-Pivot Arm Wrist (TACPAW). It contains the usual torque motors for actuation, tachometers for measuring rate and resolvers for position measurements. Furthermore, it provides three degrees of freedom, i.e. pitch, yaw, and roll, in a single manipulator joint. The advantages of this development are increased strength, compactness and simplification of controls. Designed to be compatible with the protoflight manipulator arm (PFMA), the joints of TACPAW are back-driveable with $\pm$ 90° rotation in pitch, $\pm$ 45° in yaw and continuous roll in either direction while delivering 20.5 N-m (15 ft-lb) torque in each of the three movements.

BACKGROUND

Mechanical manipulator arms terminating in some type of mechanical hand or gripping device (end-effector) are commonly employed on space vehicles for performing planetary explorations, satellite and space shuttle operations, as well as on 'Earth-bound' robotic assembly or manufacturing device.

During the past several years an increased effort in manipulator design has been directed chiefly to the guidance and control systems, with some work in the area of actual hardware design. It should not be forgotten, however, that the degree of joint sophistication directly influences the degree of control sophistication. Because of the high level of control-guidance research in the years 1973-1975, with little or no concern for the joint research and design, a "weak wrist syndrome" appeared on the scene. Past joint design resulted in several configurations of small physical shape with externally applied drives and mechanisms; these nullify the objective of improved visibility around the joint which is crucial for space work, especially in the shadow-side where auxiliary illumination is required. (See Figures 1 and 2.)

In many present-day designs of manipulator arms, the wrist-joint configuration has been simplified to the degree that not three but two motions occur in the wrist joint, with the third motion supplied by the shoulder (see Figure 3), or completely ignored. For those arms that have three degrees of freedom in the wrist joint, the actual configurations produce, in some instances, a very bulky joint with external wire loops and not providing the needed visibility.

The design effort relating to wrist joints, therefore, needs to be directed to conformity of sound kinematic manipulator design, elimination of wiring harnesses as loops outside the joint, and reduction of physical lengths (distances) between axes of rotation; one such effort is the Triple-Axis Common-Pivot Arm Wrist (TACPAW).

DESIGN CONCEPT

The third rule of good kinematic manipulator design states that

> "the last three degrees of freedom of the manipulator shall be as close as possible to the terminus (end-effector) and shall have mutually perpendicular axes."

To comply with this rule and to meet the specific design criteria of a FFTS (Free Flying Teleoperator System) configuration which can be tested in a TOBE (teleoperator experiment on shuttle) program, the concept of TACPAW was born as an application of the three-axis system of a sphere.

In keeping the center as a fixed pivot point (with the X-plane as its platform), the total freedom of motion relative to this pivot point can be observed. (See Figure 4a.) Thus, allowing rotation about the Z-axis produces YAW, about the Y-axis creates PITCH, and about the X-axis ROLL is accomplished; hence, three degrees of freedom, three axes mutually perpendicular and zero physical distance between these axes (this latter item provides for simplification of the mathematical location of a point on the terminus work sphere).

The immediate question now is how to implement this concept into an actual piece of hardware. To create the YAW motion, a disc segment, which is solidly attached to the lower arm and hence considered a fixed body, will allow two hemispheres (coupled together) to rotate about their common (Z) axis which is also the axis of the disc. (See Figure 4b[1].)

Another shell can be made to move around the initial sphere to supply the PITCH motion. A flat surface, provided on each of the hemispheres, allows for linking the two hemispheres together into a single unit and establishes a pivot axis for the pitch motion. (See Figure 4c.) Around this pivot (Y) axis, a body B as shown in Figure 4d, can provide the second degree of freedom pitch motion. Thus the YAW (X-axis) and PITCH (Y-axis) motions are at right angles to each other and the third (X-axis) motion, i.e. ROLL, can now be obtained easily: a body rotating about or within part B.

This concludes the TACPAW concept, which has been fully disclosed and is patented under U.S. Patent Nr 4,068,763, issued to J.C. Fletcher (NASA), invention by Leendert Kersten and James D. Johnston, on January 17, 1978. (See also Reference 1.)

[1]The two hemispheres were (later in the development stage) changed to a 'marriage' of two cylinder halves (Figure 5).

DESIGN AND DEVELOPMENT OF TACPAW

To demonstrate the feasibility of the concept, a wooden, full-size, mock-up was made and is shown in Figure 6.

Issuance of Contract NAS8-31897 required the analysis and design of the prototype TACPAW.

Task Description

To produce and manufacture a new manipulator wrist required the establishment of design criteria, specifications and preparations of all necessary detail and assembly drawings, with the added stipulation that this wrist shall be made compatible with existing manipulators ESAM and PFMA at the Marshall Space Flight Center.

This resulted in the necessity for the following steps to be taken to complete the task:

1. design of a new drive system, other than shown in the patent, but within the framework of the conceptual configuration
2. inclusion of tack-generators, resolvers, and brakes within the established configuration
3. design of the wiring harnesses such that all wiring will be internal whenever and wherever possible; this required utilization of the reliable "polytwist" slipring assemblies to avoid looping for the reduction of noise-levels and elimination of line-breakage
4. establishment of a simulated mathematical model for reference in thermal behavior

Performance Characteristics and Requirements

The unique design of TACPAW shall allow for the following characteristics in motion:

a: YAW _____ approx. $\pm 45^0$ (90^0 total = 1.6 rad)
b: PITCH _____ approx. $\pm 90^0$ (180^0 total = 3.2 rad)
c: ROLL _____ continuous either direction

The drive system employs a back-driveable gear train (Figure 7), allowing for a 20.5 N-m (15 ft-lb) torque delivery in each of the joint movements. Within the limits of the gear tooth strength, the anticipated maximum torque is designed for 35 N-m (25 ft-lb).

Thermal analysis shows that for full solar exposure the unit may exceed the functional parameters of the internal components. Therefore, full exposure in a fixed position should be avoided through shielding or rotation in space. The cold environment in shadow positions require the addition of heaters to stabilize the working range of component temperatures. These conditions prevail for the entire arm and are therefore not unique to the wrist design or its configuration. The hardware design and interfacing of parts and components were detailed in Phase I of the investigation.

BUILDING THE PROTOTYPE TACPAW

A continuation of contract NAS8-31897 required the actual manufacturing of the previously established parts and the complete assembly of all components in a prototype of the manipulator wrist TACPAW. Aside from the stock items, such as the DC torque motors, resolvers, brakes, tack generators, wiring connectors, etc., all machined parts were produced locally (Lincoln, Nebraska) by a tool and die firm. The assembly of the various components and the fabrication of the wiring harnesses were performed by students in the department of engineering mechanics at the University of Nebraska. (See Figures 8, 9, 10 and 11.)

The addition of a full rotational slipring in the roll mode allows for a total of 21 terminal leads; 10 of which are for signal transmission, 9 for power transmission and 2 for the control of the end-effector; see Figure 12 where it is to be noted that these 21 leads are terminated in the adapter ring by means of a polarized MDB1-21 Cannon connector.

A full description of parts and components can be found in NAS8-31897 (August 1977) report as well as the November 1978 report (Phase II).

With the unique capability of producing a torque of (at least) 20.5 N-m (15 ft-lb) in each of the joints, yet weighing only 9 kg (20 lbs) and measuring some 355 mm (14 inches), the TACPAW wrist configuration is recommended for all sizes of remote controlled manipulation.

The Earth-bound capabilities are also extremely interesting. It should be recognized however that the gravitational environment reduces the torque capabilities in the "outward" motions by a factor equivalent to lift the joint-weight. With the over design of a maximum 35 N-m (25 ft-lb) torque capabilities in the "outward" motions by a factor equivalent to lifting the prostetics, medical equipment (scanner positioning), industrial robotic applications, high-risk or high-danger environmental task performances, delicate and precise placement of assembly components, etc. Some streamlining of the outside cosmetics, due to different selection of poly-twist modules in the yaw-axis, is easily accomplishable and will greatly enhance the looks of the new wrist TACPAW.

REFERENCE

1. 1975 NASA/ASEE Summer Faculty Fellowship Research Program - Final Administrative Report. BER. Rep. No. 199-94, Univ. of Alabama, Sept. 1975. (Available as NASA TM X-72500.)

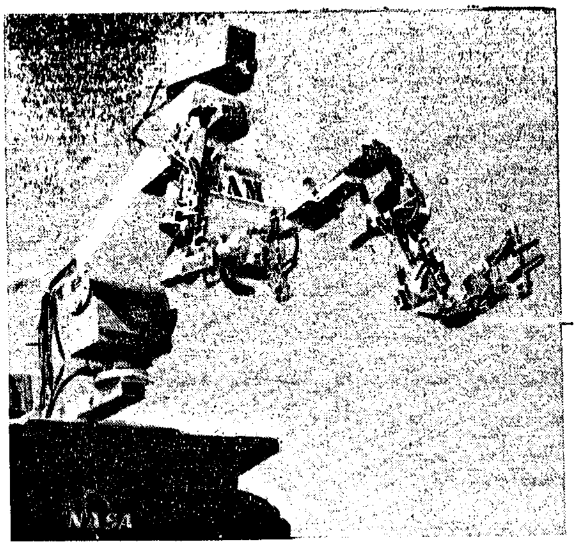


Figure 1.- NASA's application of the Rancho Antropomorphic Manipulator (RAM-M12) for test purposes as a Space Arm Manipulator (SAM).

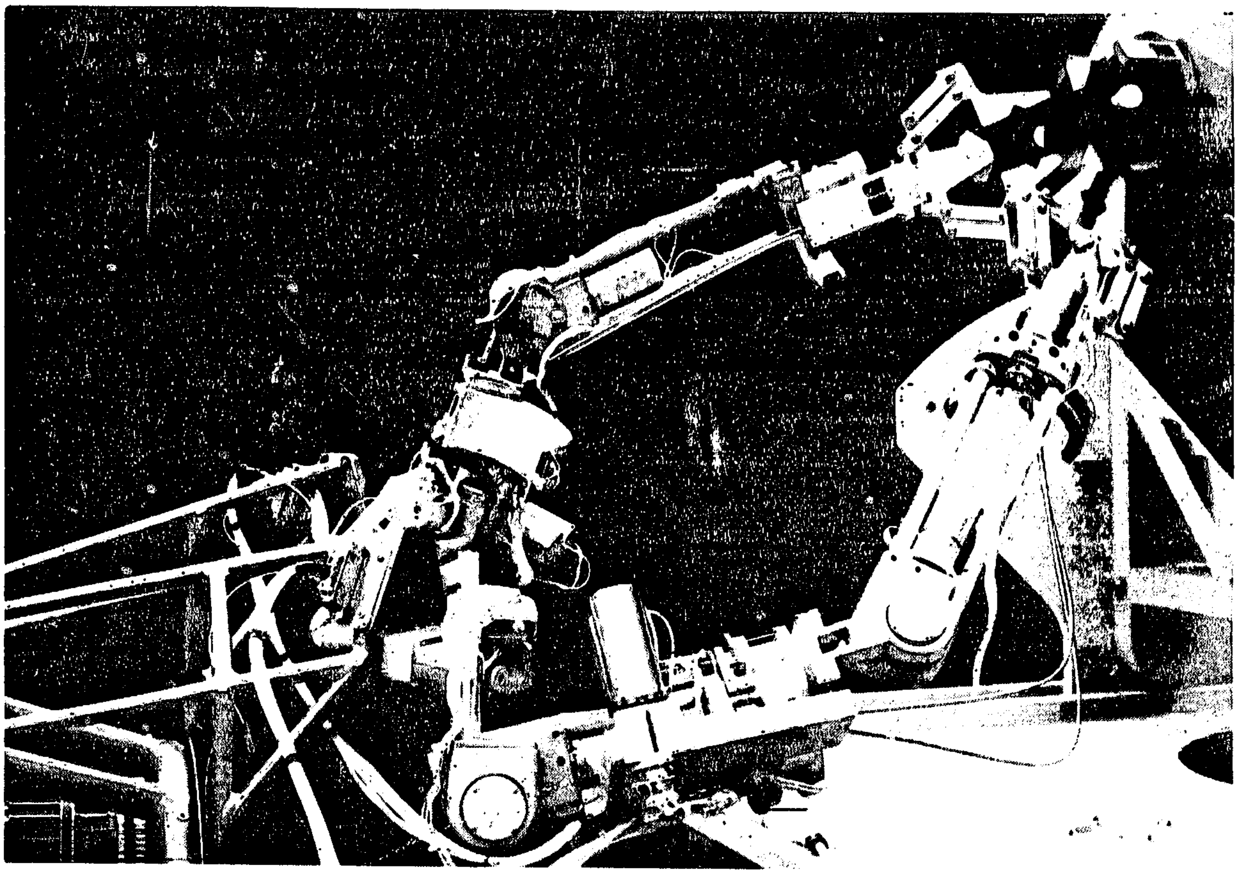


Figure 2.- The Rancho Antropomorphic Manipulator (RAM-M12) being evaluated for space applications. The primary objectives of such tests are for guidance and control studies, not work-load evaluations.

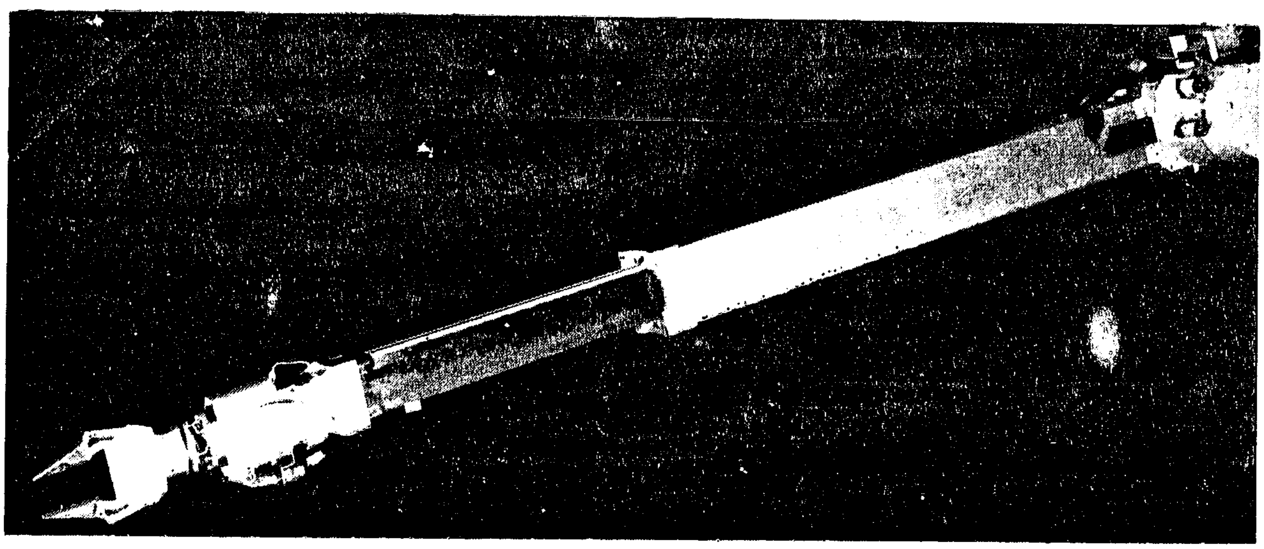
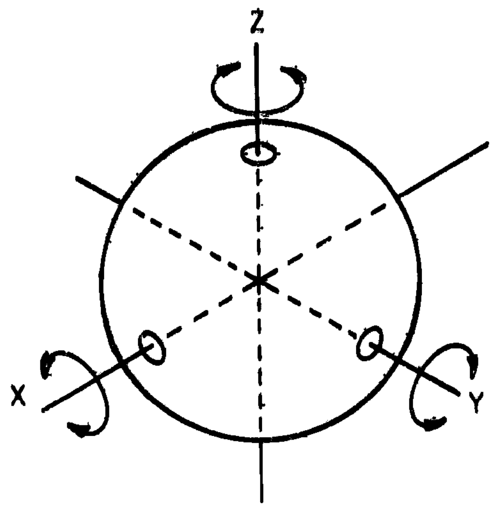
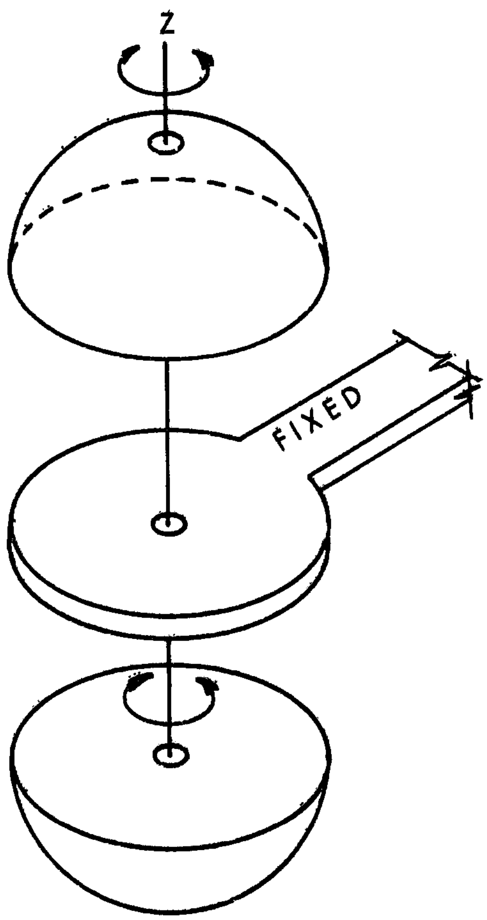


Figure 3.- The Extendable Stiff Arm Manipulator (ESAM) being tested at Marshall Space Flight Center. The wrist joint provides only Pitch and Roll where the shoulder must provide the Yaw motion.

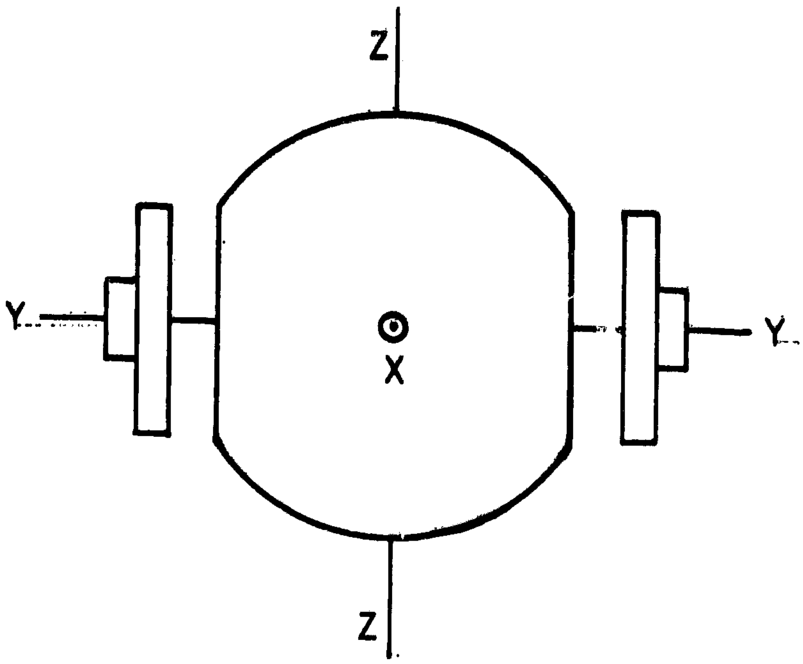


a.- The triple axis concept.

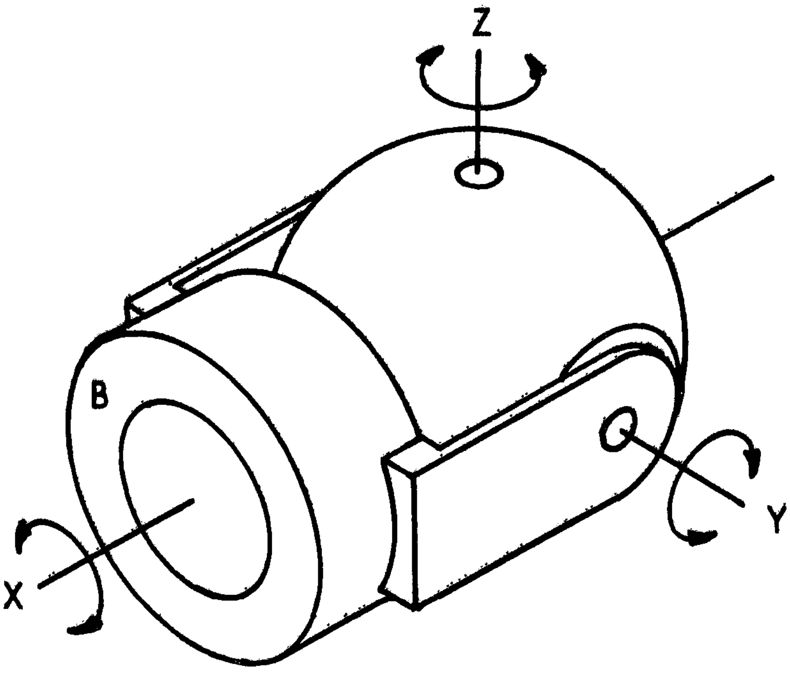


b. Implementing the concept to establish yaw motion
about the Z-axis.

Figure 4.- The triple axis concept and its implementation.



c. Providing the pitch motion about the Y-axis.



d. Completing the concept by creating a continuous roll motion about the X-axis.

Figure 4.- Concluded.

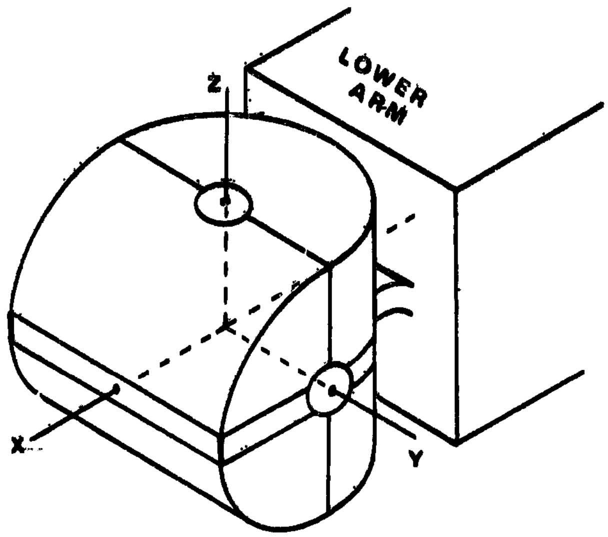


Figure 5.- The evolution from spherical shape to the more volumous double cylindrical configuration.

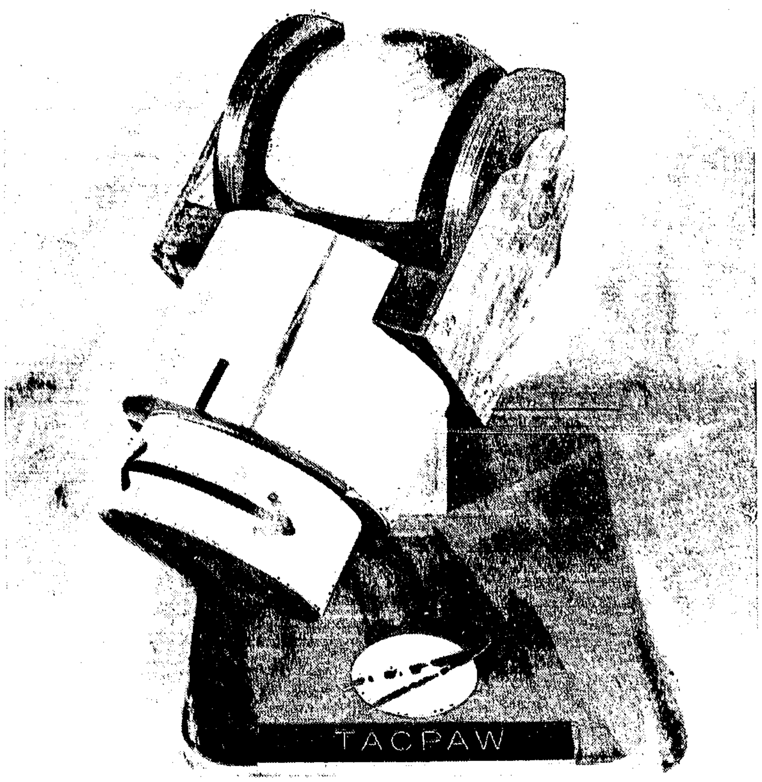


Figure 6.- A concept mock-up of TACPAW to illustrate feasibility.

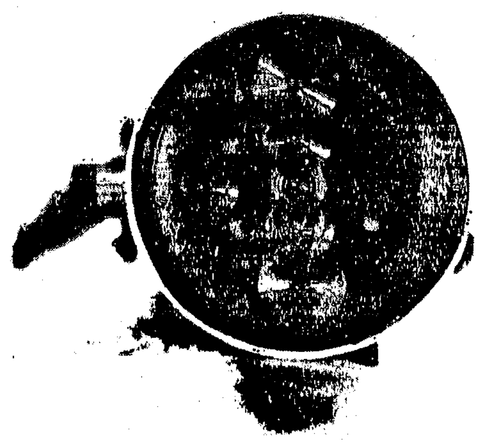


Figure 7.- The back-driveable gear train (100:1 reduction) produces a 20.5 N-m torque, while preloading in both rotational directions enables a near zero backlash.

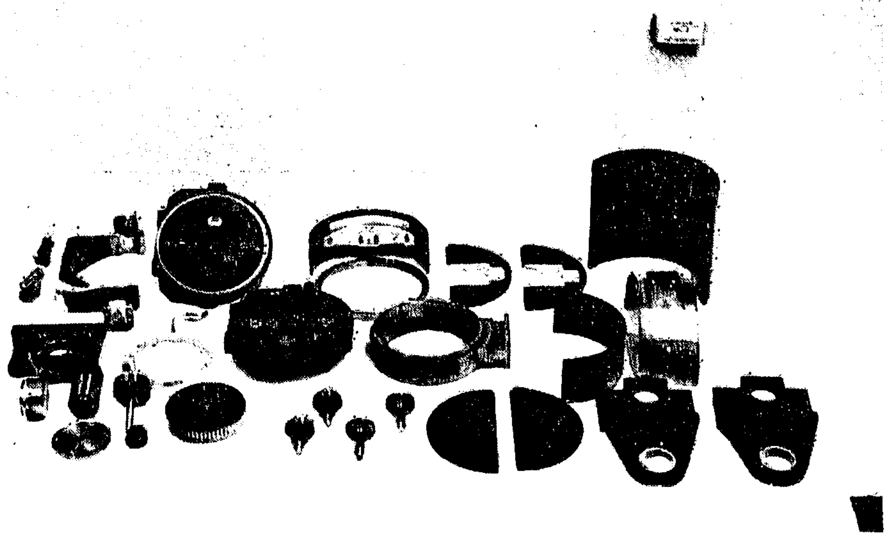


Figure 8.- Major components of the primary embodiment for complete yaw and partial pitch motion.

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Figure 9.- The assembled primary embodiment complete with wiring harnesses. (The sliprings on left and right and coinciding with pitch axis are longer than required as a result of an "off-the-shelf" purchase.)

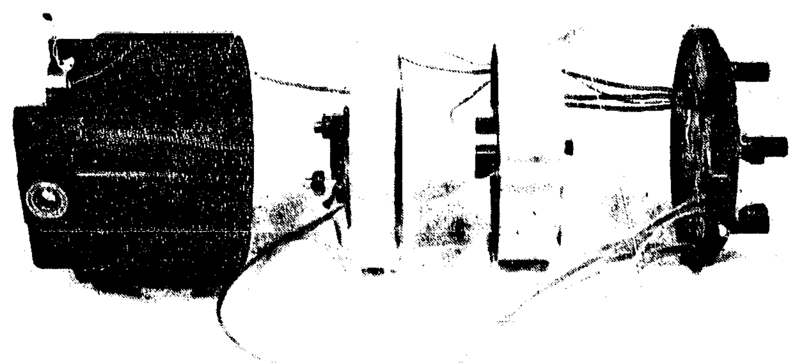

Figure 10.- Various components for the provision of pitch motion prior to complete assembly. The drive for the roll is also in this secondary embodiment.

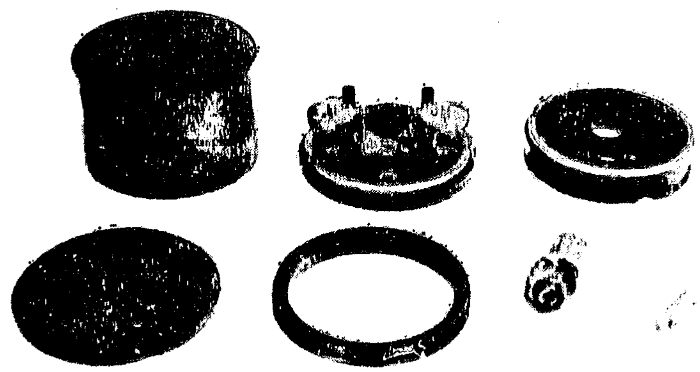

Figure 11.- Preassembly parts of the final embodiment to create continuous roll. The lower right corner shows the 21 lead slipring.

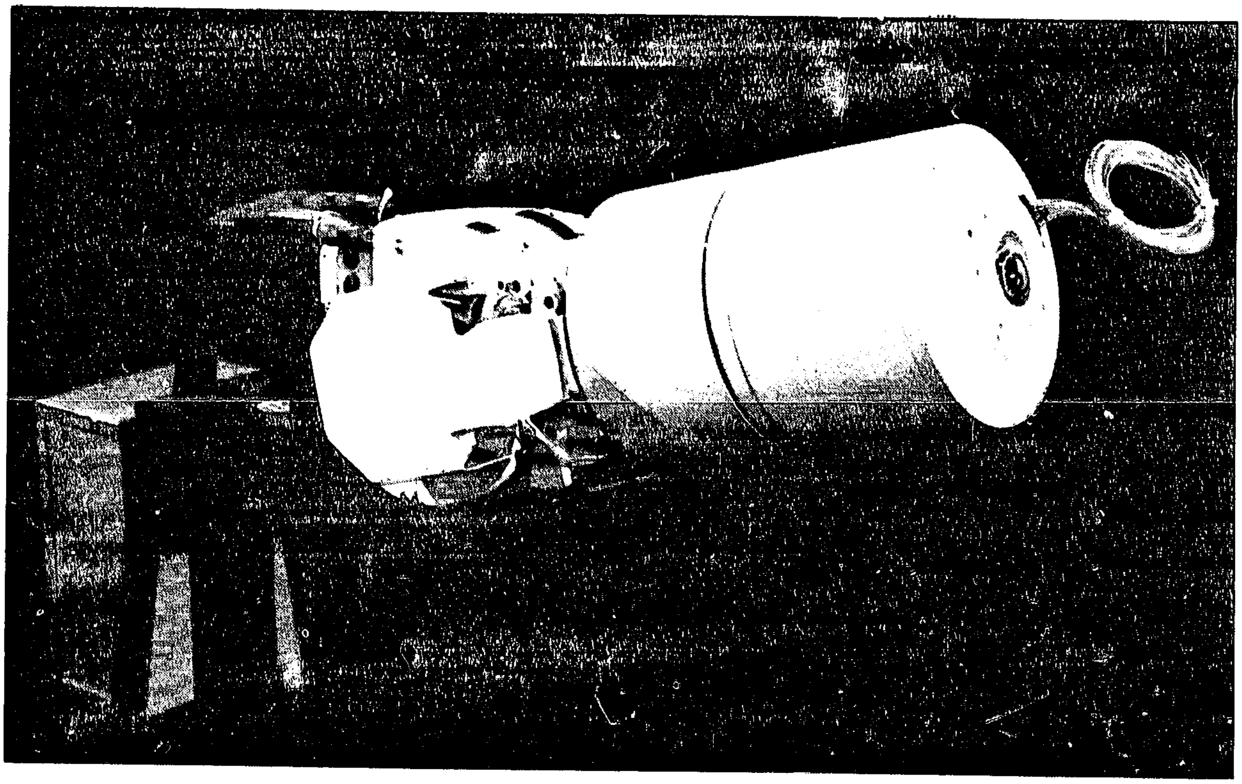

Figure 12.- The completed TACPAW (on test stand) as delivered to NASA NSFC. Note the 21 lead termination on the adapter ring.