USE OF EXTENDIBLE BOOM DEVICES FOR SPACE SHUTTLE AND EVA OPERATIONS

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1.0 INTRODUCTION

The purpose of this paper is to give a "state-of-the-art" review on a particular device that could have wide application in orbital maintenance and safety activities on the space shuttle. This is the extendible boom device for which we use the general term of STEM (Storable Tubular Extendible Member).

The STEM principal was first invented in the National Research Council just after World War II and in 1959 was adapted by Spar (at that time the SPAR Division of The de Havilland Aircraft of Canada) for the 150ft. sounding antennas on the Alouette I ionospheric research satellite.

Since then over 350 of the units have flown successfully on rockets and satellites for a variety of applications, some of which will be described in this paper. By showing the varied uses to which the basic principle has been put, it is hoped to illustrate the specialized design techniques that have been developed and the extent of flight experience gained to date.

The principle of operation for the STEM is shown in Figure 1. During launch the material, in the form of a flat strip, is wound on a storage drum. In orbit, the drum is rotated so that the resilient spring material forms into a tubular shape of high strength. To increase the strength and reduce packaging size, the BI-STEM principle in Figures 2 and 3 has also been developed. With either type, the drive arrangement can be motorized, if partial extension or retraction is required, or, using the spring energy of the element material, extension can be achieved by simply releasing the tip of the unit.

In Section 2.0 illustrations are given of STEM units that have already been developed and have either flown, or been qualified for flight. Section 3.0 reviews current and future developments which have more direct relevance to the space shuttle program.

Section 4.0 provides a brief summary of design characteristics that are available to the designer for future space shuttle applications.

2.0 STEM UNITS DEVELOPED PAST PROGRAMS

The boom units described here illustrate the state-of-the-art in the time period 1960-1969.

The figures are grouped according to function. Figures 4 to 10 are actuators. Figures 11 & 12 show an antenna. Figure 13 illustrates a docking application and Figures 14 and 15 are astronaut aids.

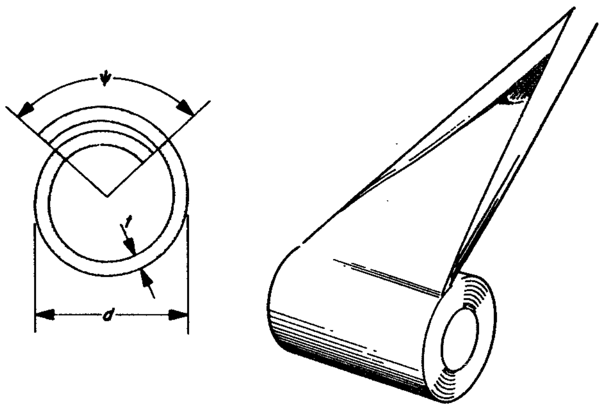

Fig. 1. The STEM principle

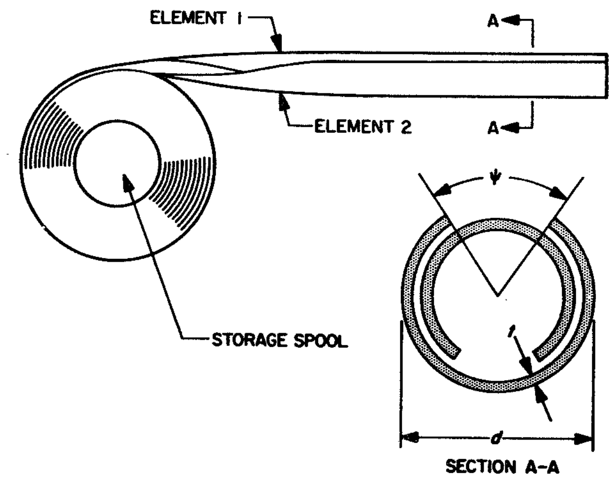

Fig. 2 The BI-STEM principle

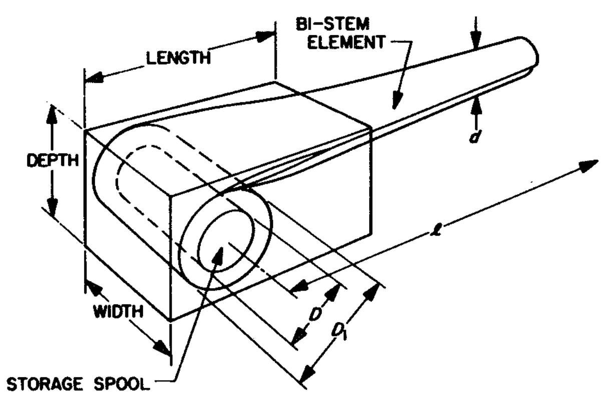

Fig. 3. BI-STEM dimensions

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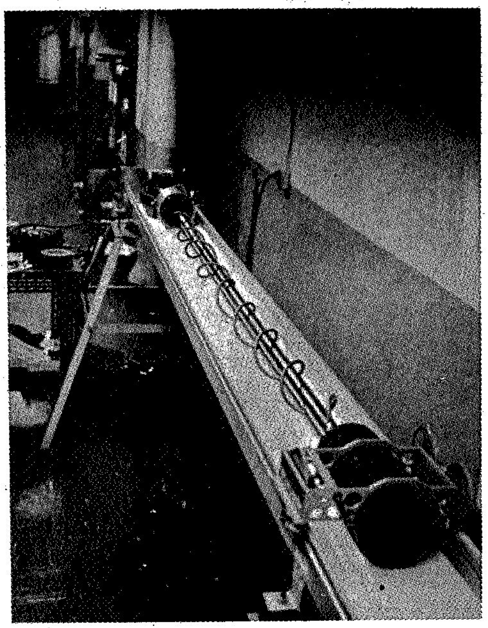
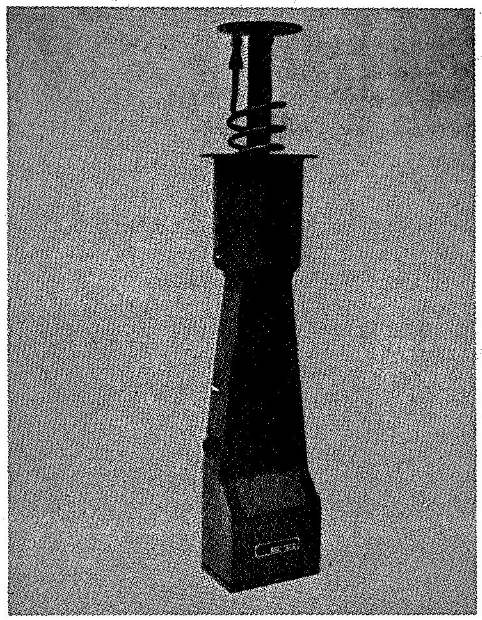
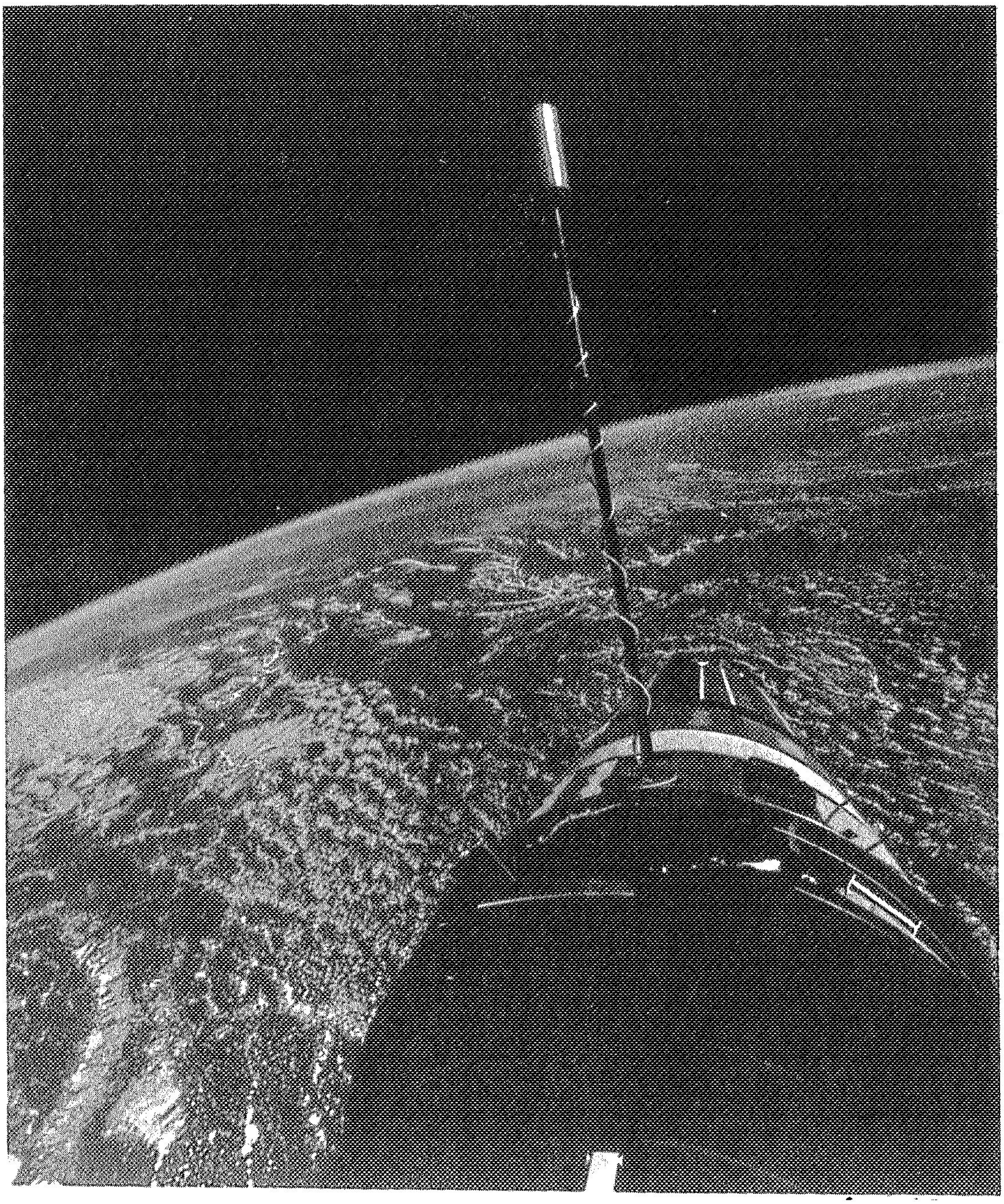
This unit, termed a TELE-STEM, was used to extend the radar transponder on the Agena Target Docking Vehicle.

Cable deployment was arranged by an external coil similar to a telephone cord. As the boom was required to withstand the bending loads resulting from restart of the Agena engine, it was designed with a system of close-fitting telescoping tubes which resisted the bending moment while the STEM provided the actuation force.



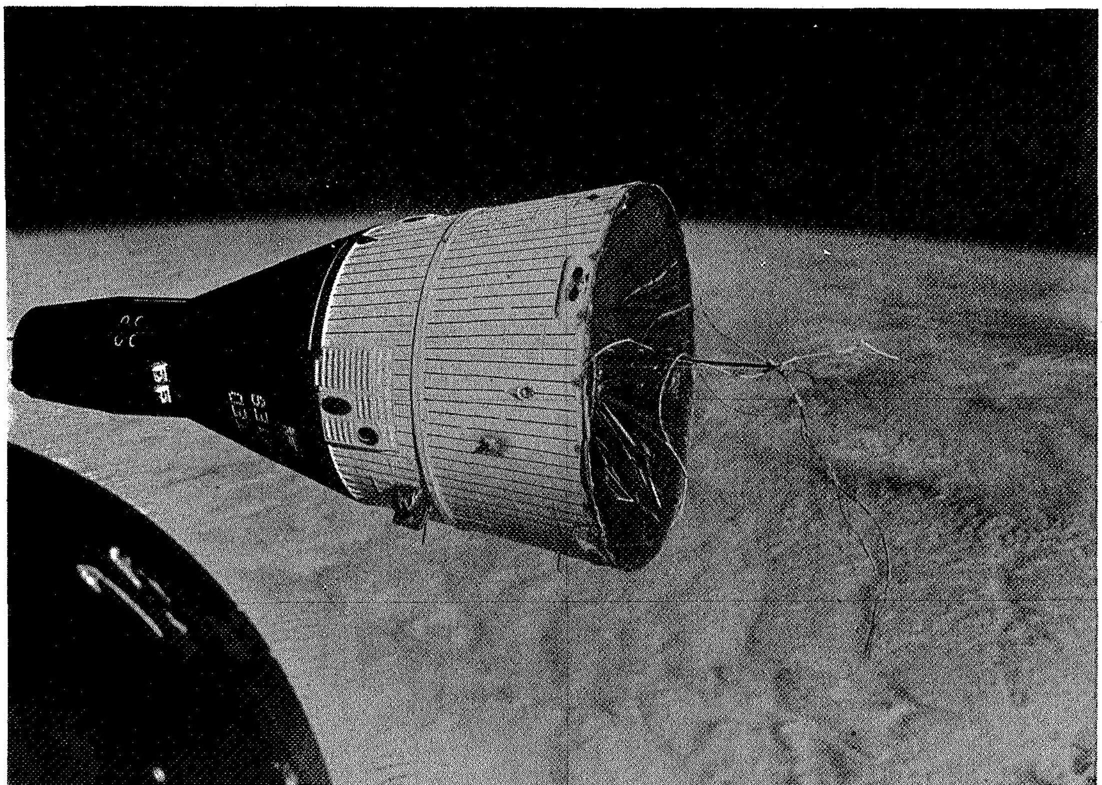




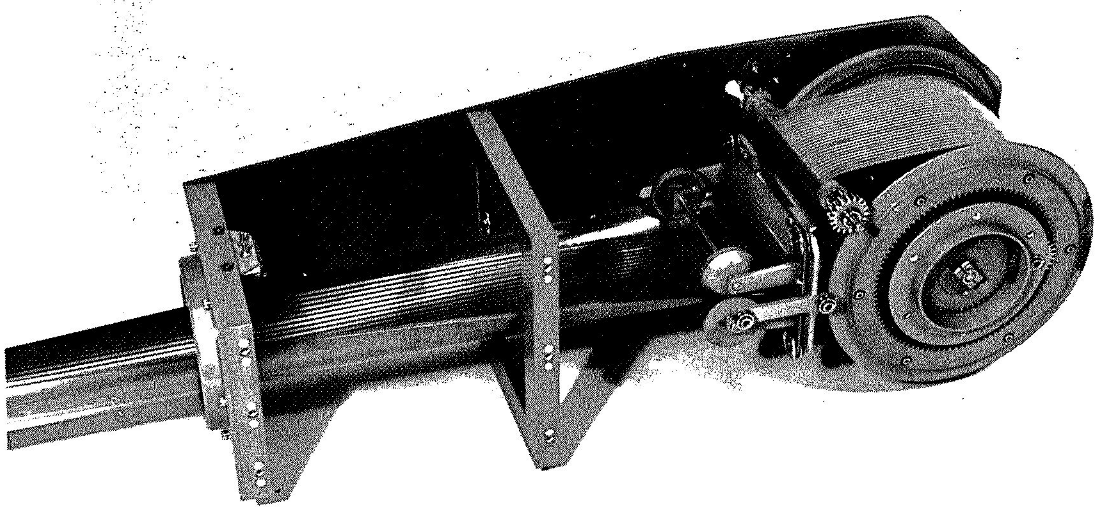
Gemini 6 is shown in orbit in this figure, with a STEM boom at the base extending a three-axis magnetometer.

In this case, cable deployment for the instrument leads is achieved by a flat conductor cable which feeds up the centre of the STEM element.

A design feature which has been developed for instrument applications such as this is an interlocked element which provided greatly increased torsional rigidity. This is often required if the instrument must be oriented in a particular direction.



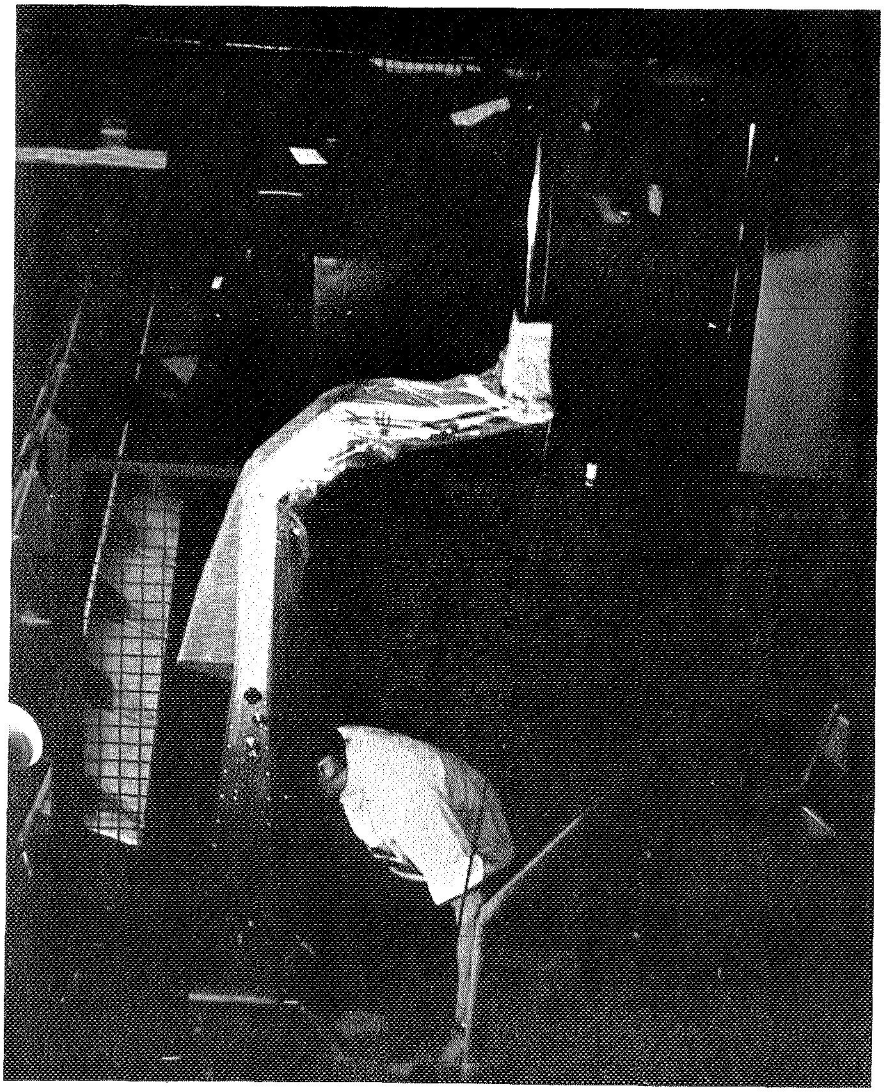
A view of the A-26 magnetometer boom with the cover removed shows the system used to feed the 26 element flat conductor cable into the center of the STEM. A special interchange chamber is used to enable the cable to be rewound as the element is retracted without recourse to slip rings.



A ground application shown here is a unit designed to enable a camera and light unit to be fed into the cavity of a large solid fuel rocket to inspect for cracks in the grain.

The STEM element is maintained in a flat form as it passes through a series of articulated links which enable the unit to be fed up past several corners before entering the propellant chamber.

Such a device, possibly combined with a fibre optics inspection head, could be useful to inspect inaccessible areas in the wings or fuselage of the space shuttle.



An example of the extension of a large diameter STEM boom is shown here with a 3.12 inch ground mast supporting a large tip mass.

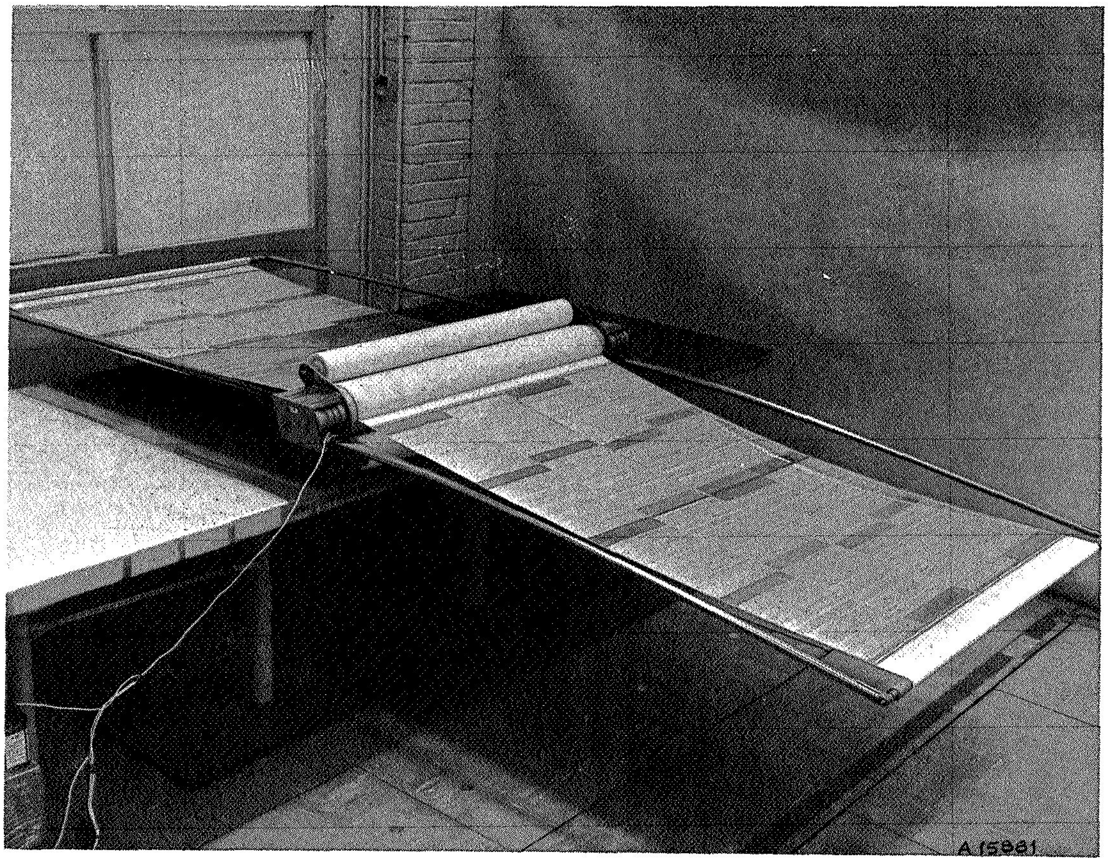
The bending moment and compressive loads generated in such a ground environment are similar to those which could arise in a space shuttle cargo transfer operation.

An important current application is the use of booms to extend flexible solar cell panels.

Here four BI-STEMs, 0.86 in. in diameter, are extended in synchronism to deploy a pair of Hughes roller type solar cell panels.

An alternative arrangement is with a single central boom flanked by two panels which are attached to a tip mounted tee-bar.

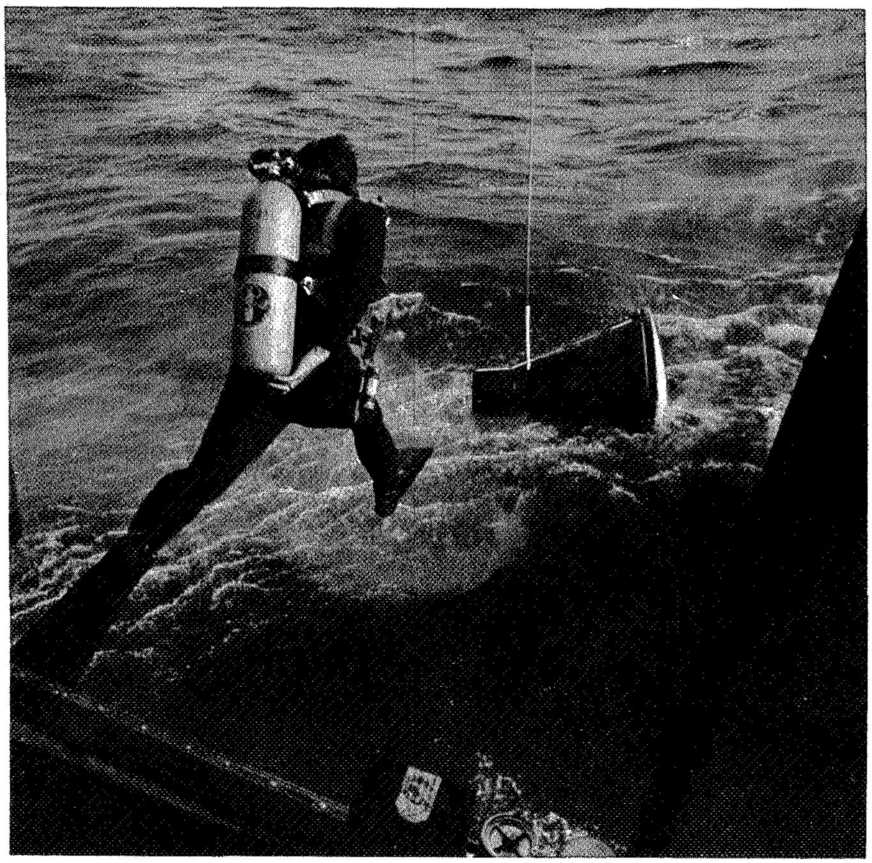
Such designs require the boom to withstand compressive loads both during and after the extension so that the panel is kept in tension.



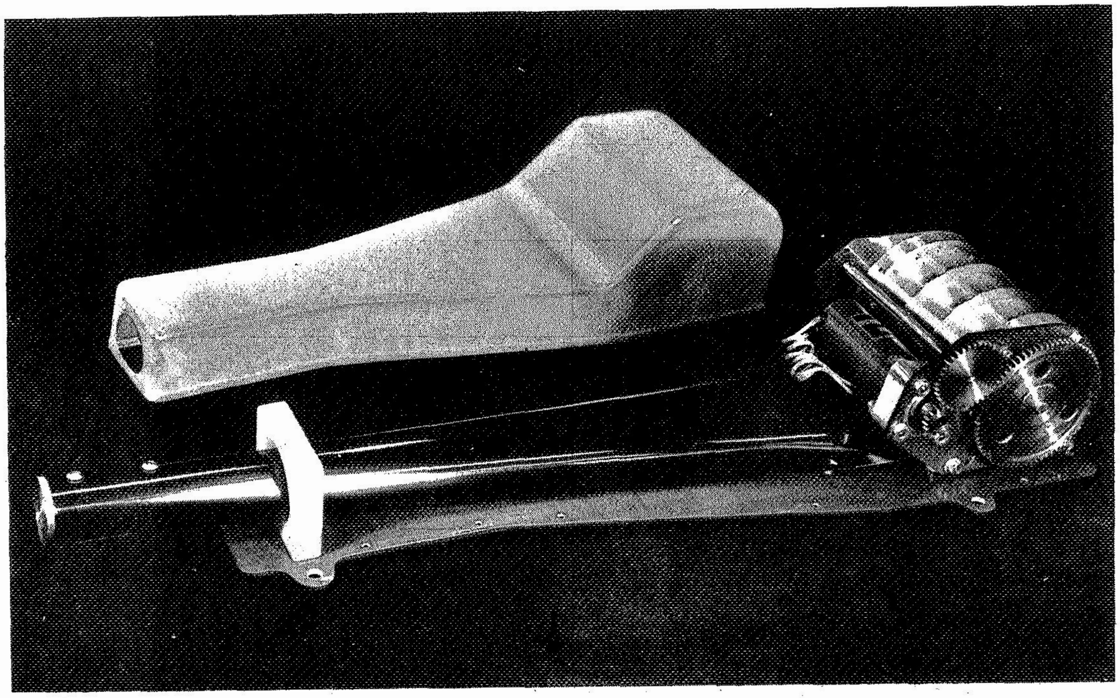
In this view of the recovery operation of one of the Gemini capsules, the HF recovery antenna can be seen extended from the spacecraft. A similar unit was used for orbital HF communications.

The whipping action caused by heavy sea state conditions required the use of a nesting technique with 8 separate elements inside one another at the root of the antenna.

At the base of the antenna the white silicone guard sleeve can be seen. This prevented the ingress of sea water to the inside of the unit.

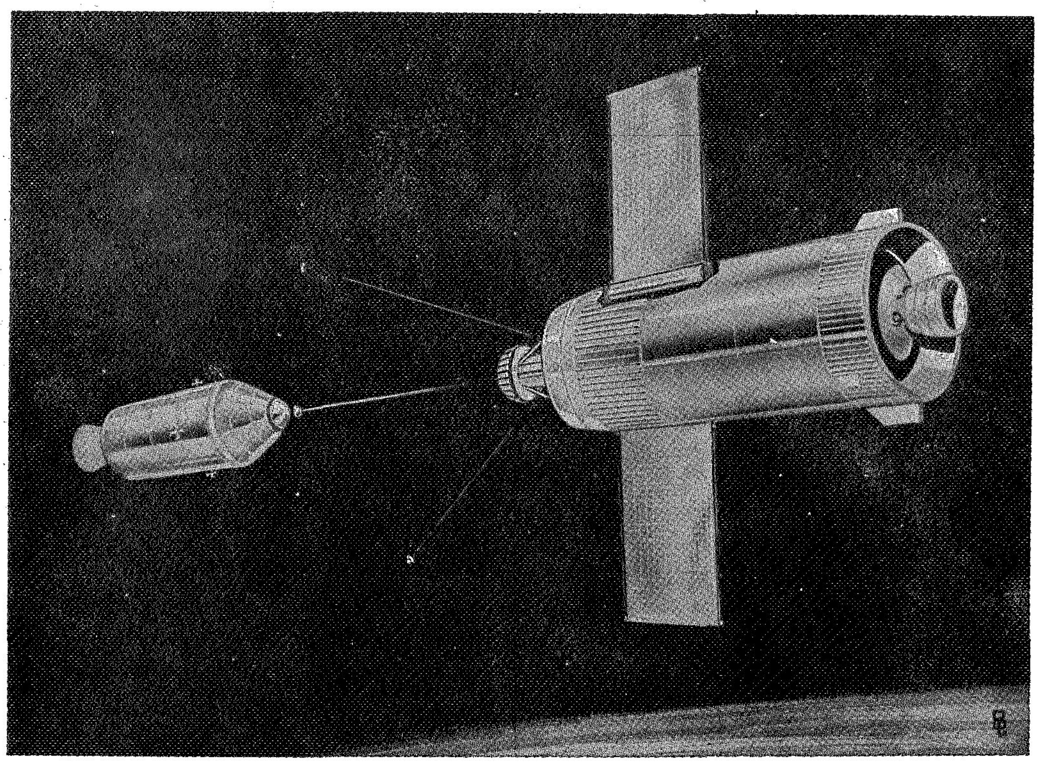


The HF antenna used for Gemini recovery operation is shown in this view.



Early in the Gemini program, a soft docking procedure was evaluated. For this, the two spacecraft maintain formation while a grappling boom extends into a receiving cone. After the tip of the boom is secured in the cone, the boom is retracted, thus bringing the two vehicles together.

Although this approach was abandoned for Gemini in favour of a hard docking procedure, its feasibility was demonstrated with dynamic tests conducted at NASA/MSC using space frames on a large air bearing table to simulate the full scale vehicles.

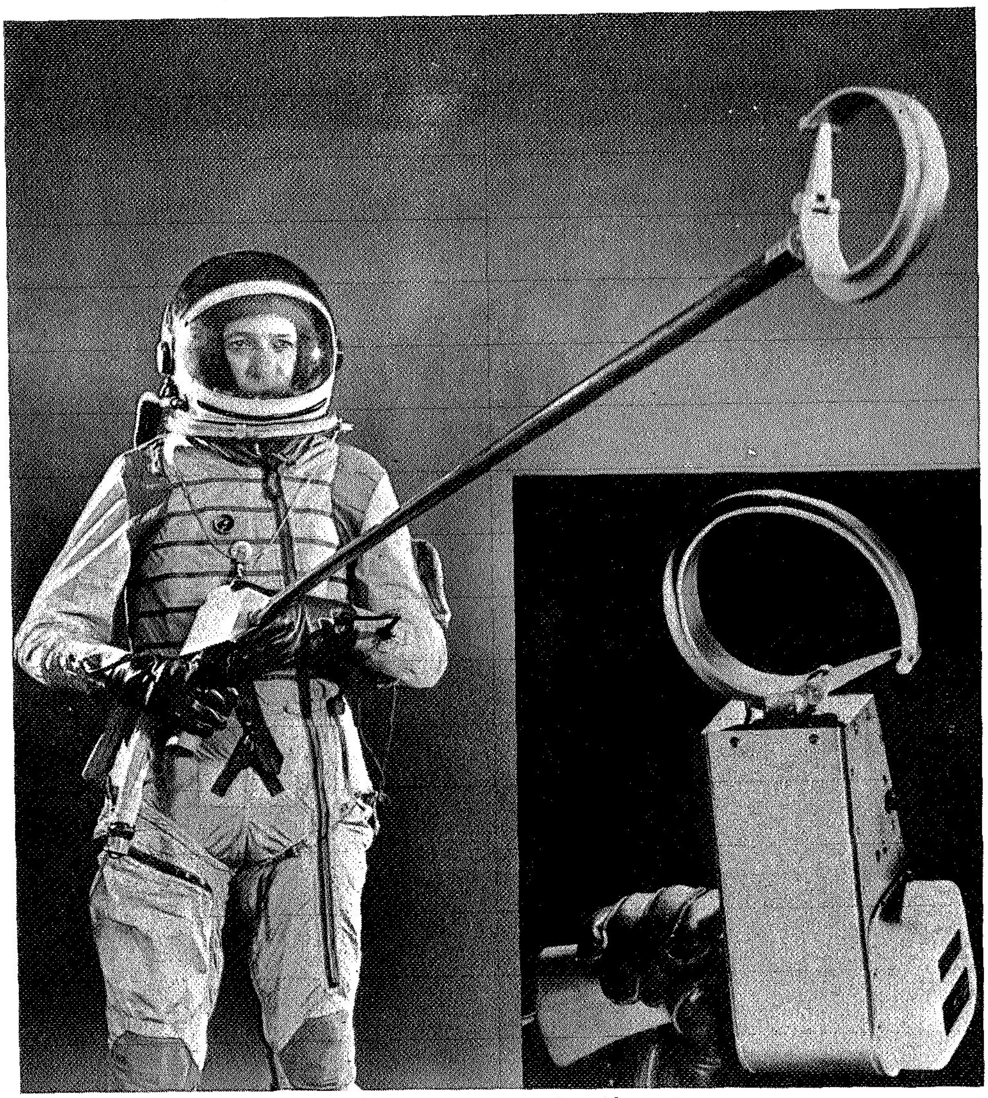


An example of an astronaut aid is the back pack unit developed for the U.S. Air Force. Three STEM units with special end fittings are used to enable an astronaut to secure himself at an external location on a spacecraft. In this way, torque reactions from a maintenance task can be transferred to the spacecraft.

The control pack enables the three booms to be actuated either in unison or individually.

A second astronaut tool is the Extra Vehicular Crew Transfer (EVCT) device shown here. Used with a pistol grip, it enables the astronaut to extend the boom up to 25 feet and grapple onto a bar on an adjacent spacecraft.

In this way, he has an emergency procedure to permit personnel transfer between two vehicles even if there is a failure in the docking system.



3.0 STEM UNITS FOR CURRENT AND FUTURE PROGRAMS

The next series of figures shows the present status of boom technology and touches on future applications envisaged.

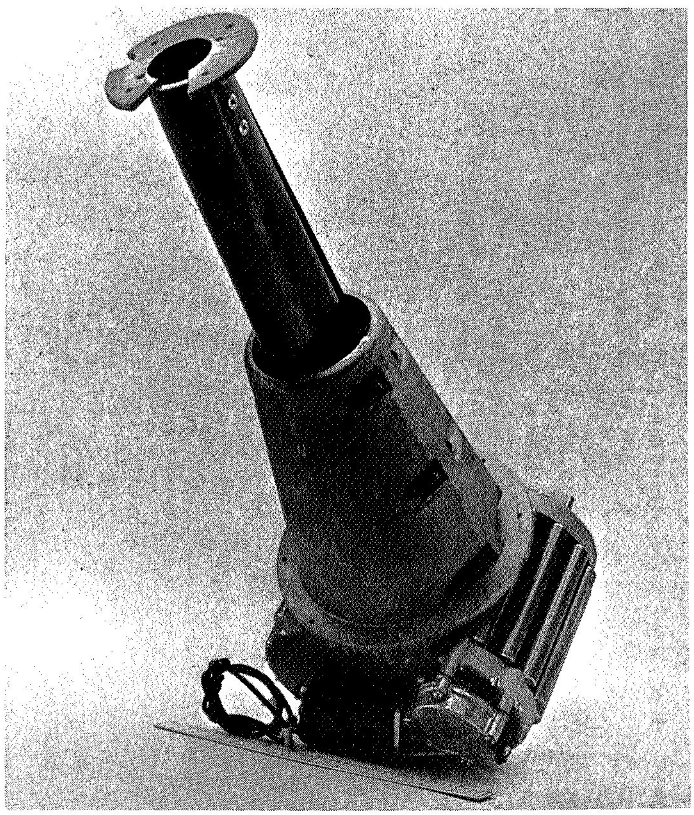
Figures 16 to 19 show actuation applications, Figures 20 to 23 described a novel approach to in-orbit manufacture of a space structure, and Figure 24 is a space shuttle application.

The unit shown here is a 2 inch steel BI-STEM originally designed for a ground application but converted to serve as a 25 foot instrument boom on the Apollo J missions.

Using two such units, it is planned to extend a mass spectrometer and a gamma ray spectrometer laterally from the service module while the Apollo is in orbit around the moon.

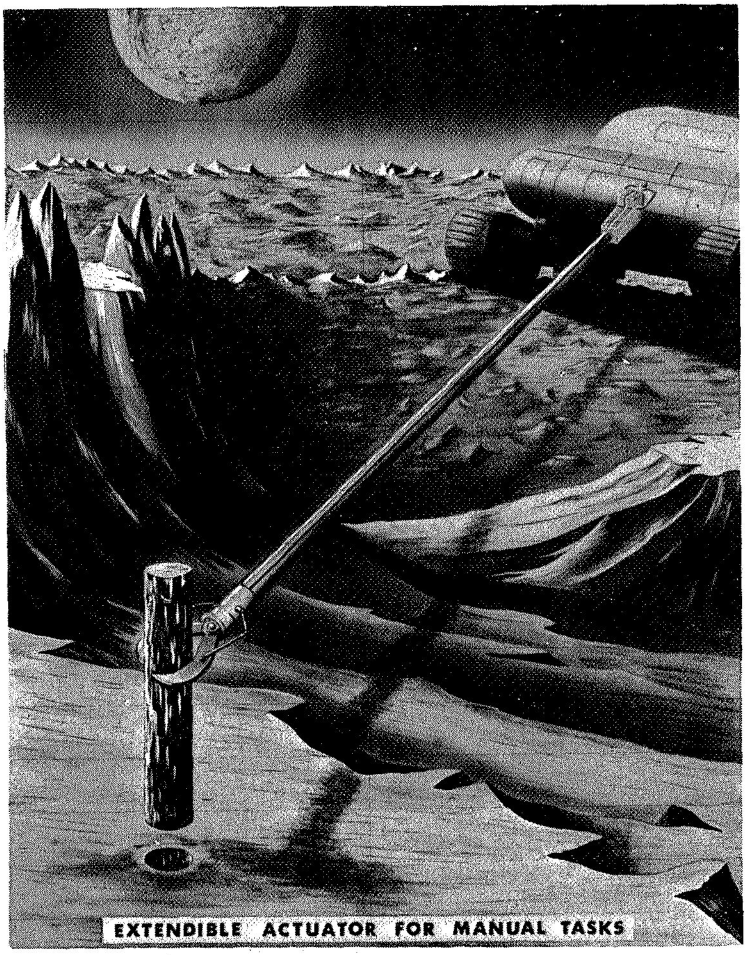
The elements are silver plated to minimize thermal bending and made of extra-thickness maraging steel to withstand manoeuvering loads as the spacecraft maintains its attitude.

The dynamics of the combined boom and spacecraft must be carefully studied in such cases to assess the binding loads in the boom and the probable tip deflection.



An artist's impression of an actuating boom performing grappling functions on the lunar surface is shown here.

Such a device is now being developed for the Viking Soil Sampler experiment where unusual environmental conditions of wind, and blowing sand are combined with digging loads from the sampler's operation. Prior to this, the unit must also survive pre-launch sterilization and the hard vacuum of the long interplanetary voyage.

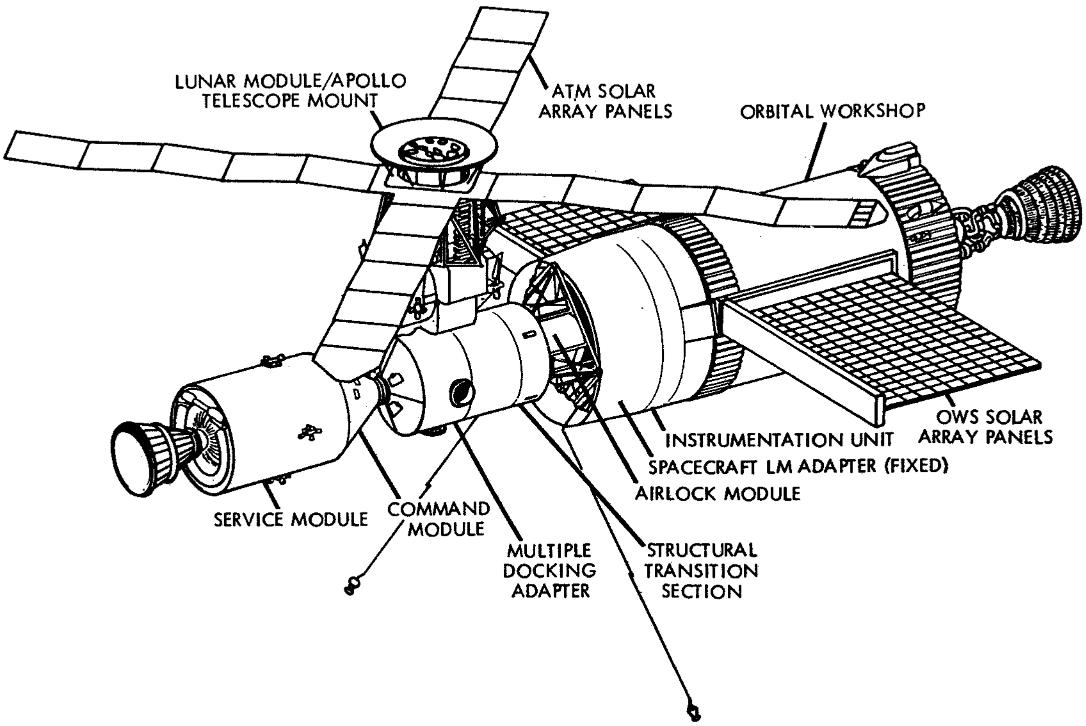


EXTENDIBLE ACTUATOR FOR MANUAL TASKS

One of the major tasks for the astronauts on the AAP or Skylab project is to transfer film packs and cameras from the airlock out to the work stations on the Apollo Telescope Mount (ATM).

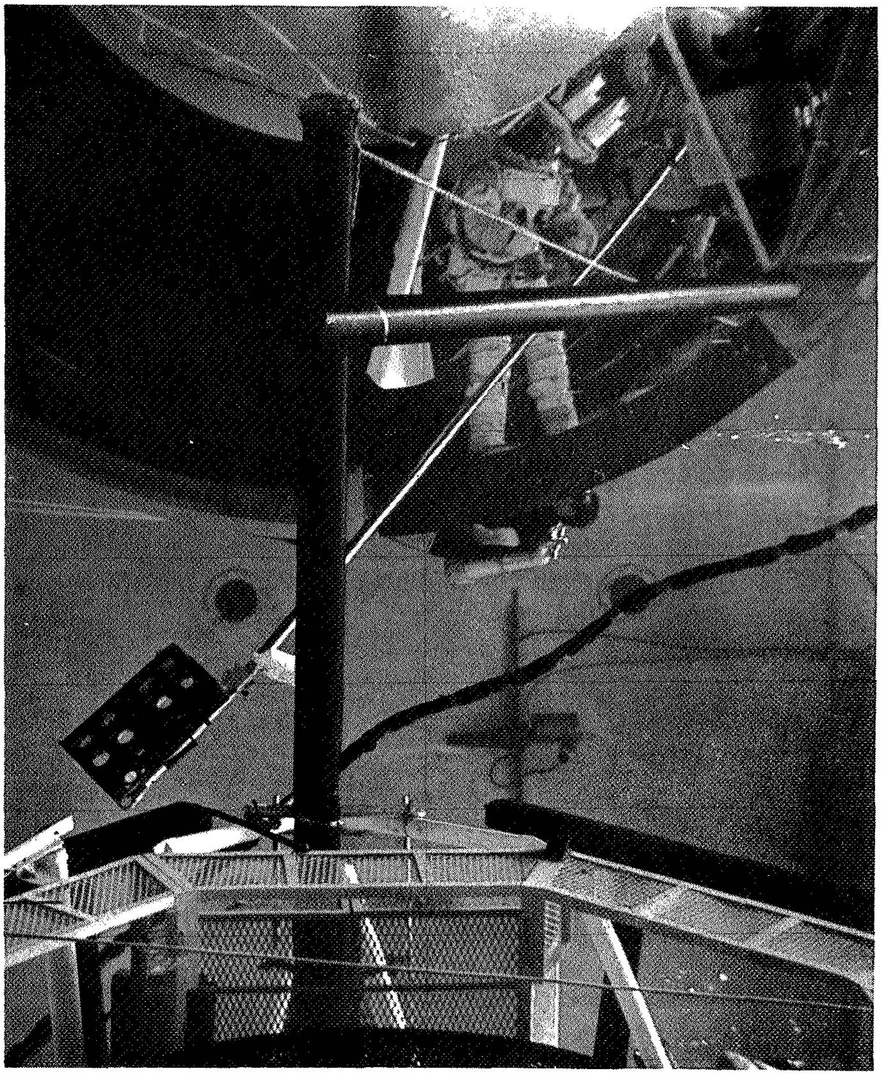
A preferred approach for this is the use of a 2.0 inch BI-STEM hard mounted near the hatch of the airlock. With one astronaut in this location to load the film packs on the end of the boom and a second astronaut at the ATM work station, the unexposed film can be passed out and the exposed film returned to the workshop.

AAP CLUSTER



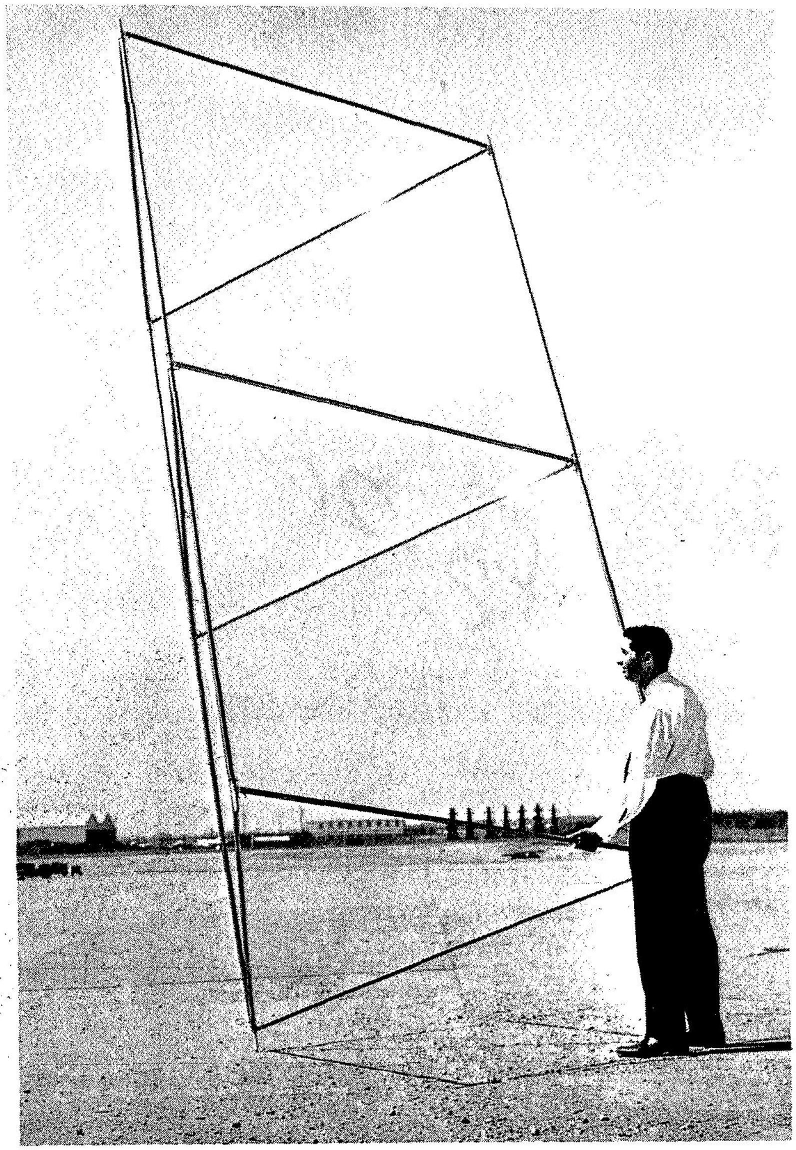
Feasibility of the Skylab film transfer activity has been demonstrated by rehearsals on the full scale mock-up in the large neutral buoyancy water tank at NASA/MSFC.

In this photograph the first astronaut is shown at the airlock location guiding the boom down to the ATM lower work station.

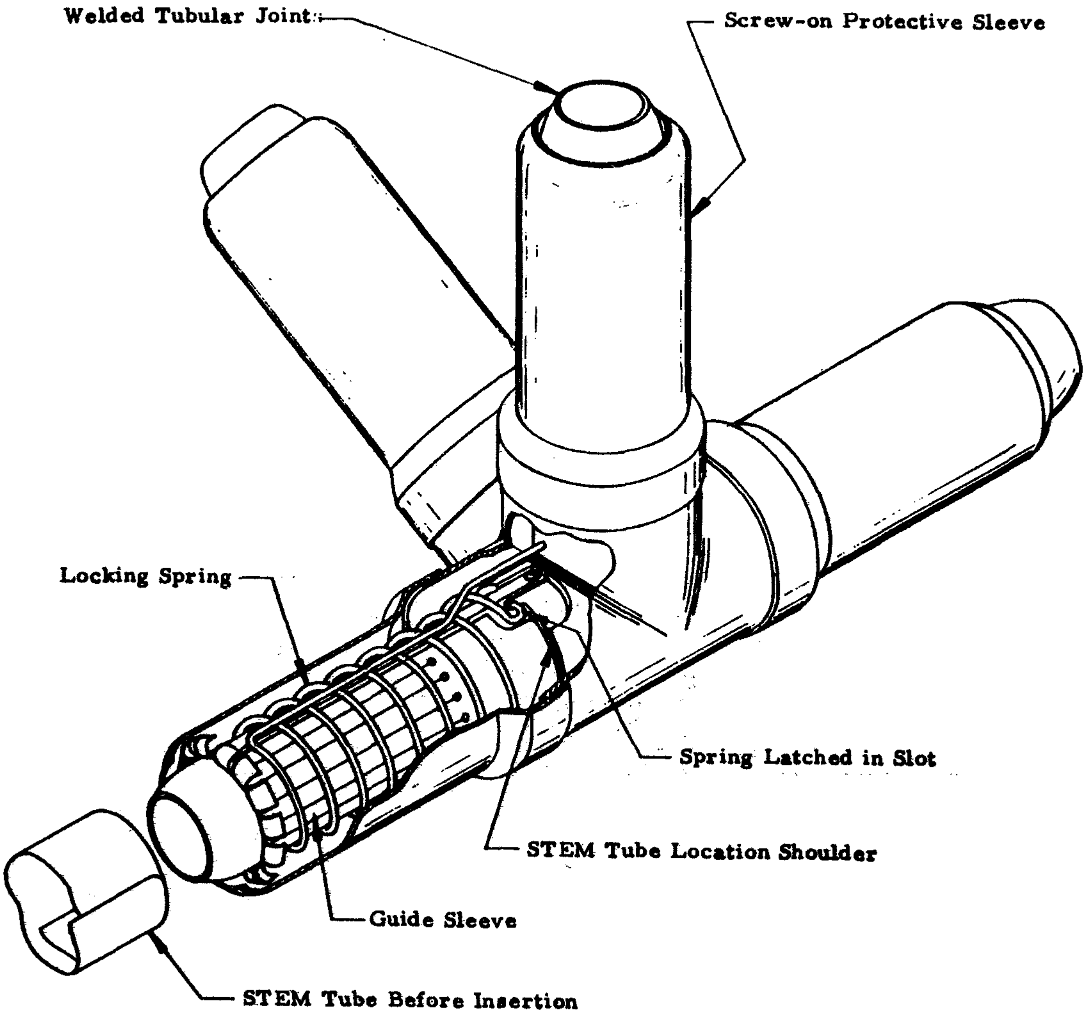


The STEM FAB tool shown here embodies a 105ft. element in a replaceable cassette with a guillotine fitting to cutt off predetermined lengths of element. These can then be assembled into spaceframes of various configurations as required.

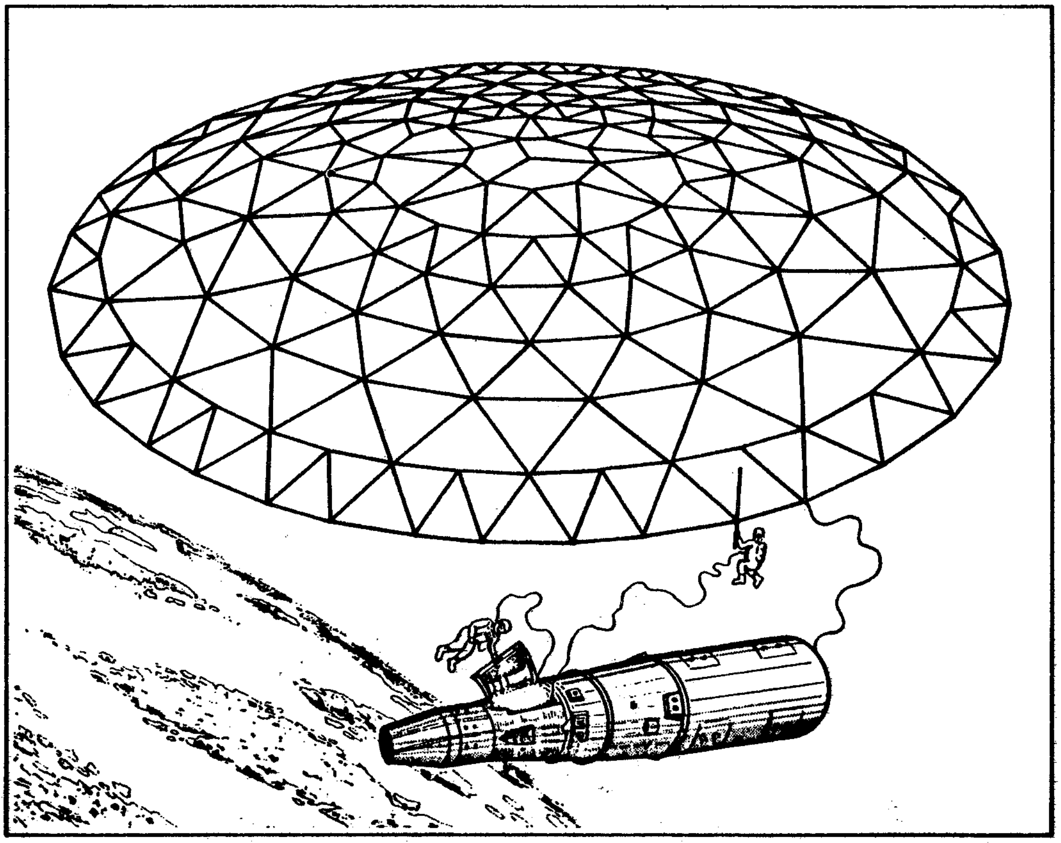
An example of spaceframe formed with the STEM FAB approach is shown in this photograph. In this case, the frame was strong enough to be scaled by a 200 lb. man.



A unique form of self-locking corner joint suitable for triangulated structures is shown here. The astronaut needs only to insert the end of the STEM element and a preloaded locking spring is tripped clamping the element onto a central core.



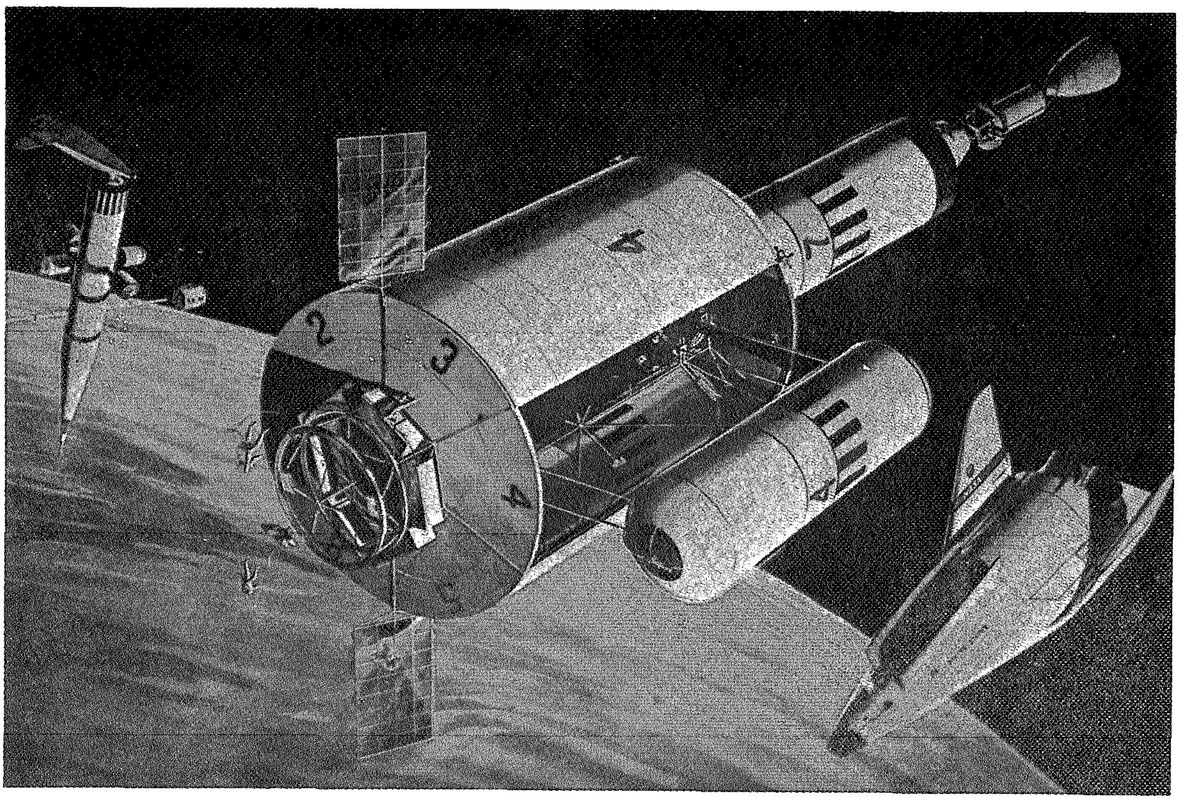
An artist's impression of a large dish antenna structure formed from such triangulated components is shown here.



Perhaps the most obvious application for actuator booms on the space shuttle is the cargo transfer function.

This view shows such an arrangement with a system of booms being used to transfer a fuel tank into the nuclear shuttle as conceived by Lockheed Missiles and Space Corporation.

Synchronization of the boom extension rates is a design requirement here and consideration must also be given to techniques for resisting bending loads in the event of lateral motion of the cargo.



4.0 CONCLUSIONS

With the need for equipment in the space shuttle to be reliable, of light weight and basically simple, STEM units can be used for a number of orbital applications and offer the benefit of extensive flight experience.

The designer has a wide range of characteristics to choose from in meeting particular requirements. Some of these are as follows:

Bending strength and stiffness
Torsional strength and stiffness
Compressive strength
Thermal curvature
Natural element curvature
Synchronization of multiple units
Element length and diameter
Package size
Extension rate
Extension power

The STEM device is a good example of the benefits that can derive from a joint Canadian-NASA program such as Alouette - ISIS. It is hoped that with the space shuttle program, a similar international co-operation can be achieved.