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A HIGH STRENGTH, TORSIONALLY RIGID, DEPLOYABLE AND RETRACTABLE MAST FOR SPACE APPLICATIONS

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ABSTRACT

The era of retrieving and/or servicing satellites in orbit has mandated that extendable elements, such as those used to deploy solar arrays, thermal radiators, communications antennas, instruments and numerous other appendages have inherent in their design a highly reliable retraction capability. Throughout the past year a structural mast has been developed which during and after full deployment produces a supporting structure with the characteristics of a high bending moment capability, high stiffness and, particularly important for instrument deployment, a high degree of position repeatability and torsional rigidity. These features have been accomplished while providing an easily retractable mast with a high life cycle capability. Since these properties are consistent throughout the full range of deployed lengths, partial deployments or retractions can be utilized for check-out, balance, fine tuning or whatever other reason may be deemed necessary for operation modes or spacecraft stability.

INTRODUCTION

The mast, shown in Figures 1 & 2 to be discussed, is of a triangular cross-section and is formed by the interlocking of three identical strips of material along their common edges. The interlocking of the edges is achieved by a meshing of a series of socket-type inserts permanently attached to rolled tabs alternately spaced along the length of each strip of material. In the stowed configuration, the material is unlocked and is therefore very flexible. This allows great packaging freedom since the three separate storage spools of material can be located remote and in any orientation with respect to the locking station within the mechanism. The packages for a given mast can therefore range from a long cylindrical configuration to a flat rectangular one. Because the strips of material are locked together inside the deployment mechanism, a fully formed mast exits the mechanism and takes all external loading regardless of deployed length. This paper will cover the design requirements, design philosophy, fabrication methods and test methods and results for a specific model mast.

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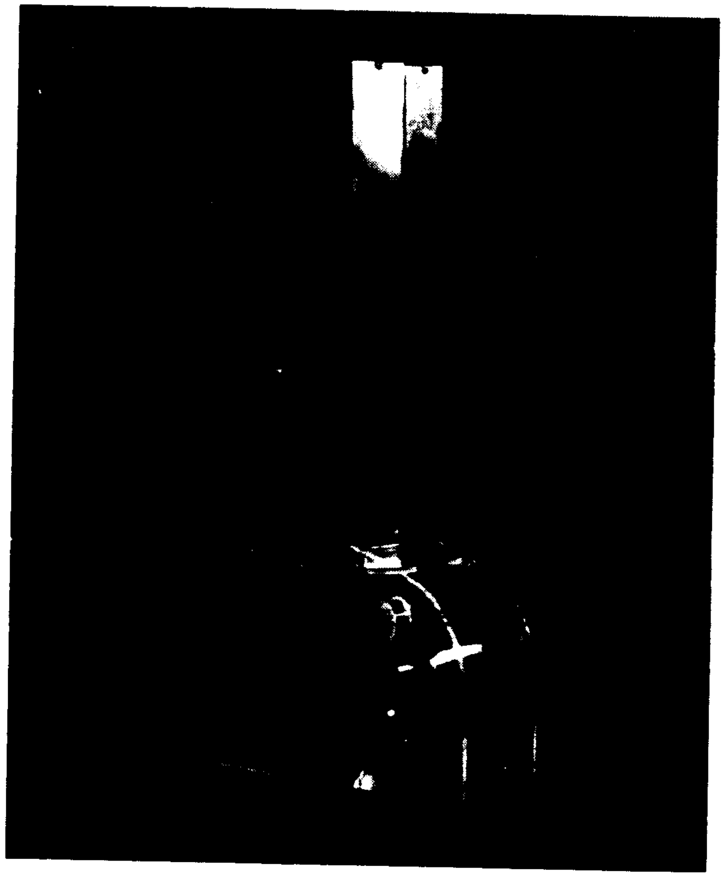

Figure 1

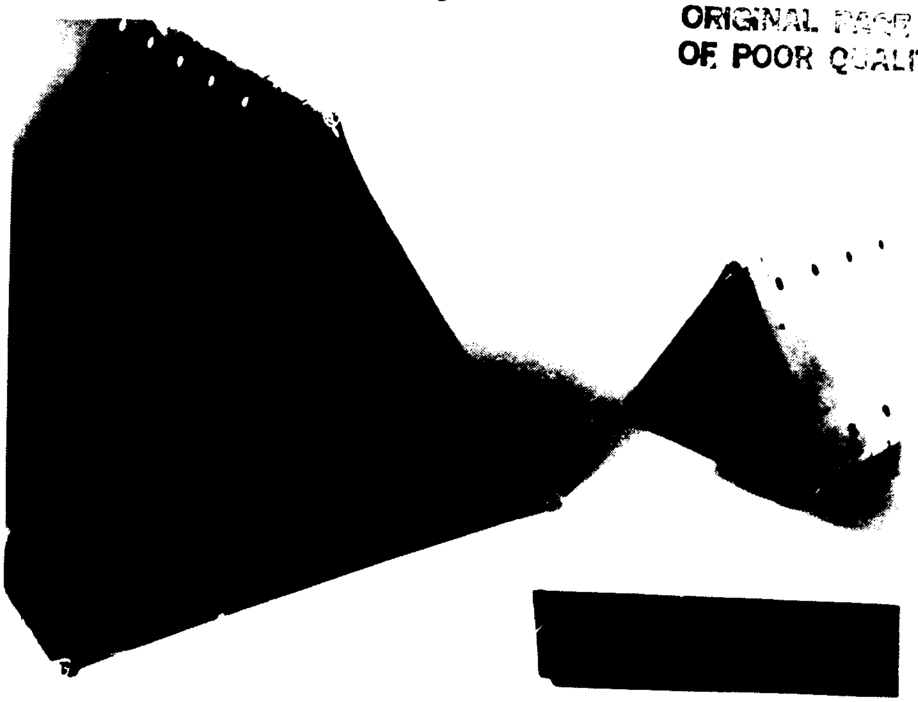

Figure 2

REQUIREMENTS

The design philosophy behind the development of the mast was to select a number of desirable features, establish many as hard criteria and maintain the others as goals which would be studied and traded-off as the program progressed through the design, build and test stages.

Those features considered as hard criteria were:

- Highly reliable
- Extendable and retractable
- Long life cycle capability
- High strength and torsionally rigid
- Provide strength and stiffness throughout the entire deployment/ retraction operation
- Provide accurate and repeatable tip position alignment at any extended length
- Thermally controllable
- Packaging flexibility with a minimum boom ploy length

Those features considered preferable but as a goal were:

- Elimination of sharp edges
- Ease of manufacture for cost purposes
- Adaptable to use with various materials, i.e., non-magnetic, low outgassing, etc.
- Adaptability for positive boom drive (not friction drive)
- Lightweight boom
- Adapt to a wide temp range
- Unlimited extended length selection
- Eliminate expensive heat treat operations
- Easily expand boom size without increasing deployment mechanism complexity

DESIGN APPROACH

After reviewing numerous concepts, it was determined that to satisfy most of the criteria the mast should fit the following description:

- Equilateral triangle mast configuration
- Elements stored in an unlocked configuration
- Locking method along edges and internal to the formed mast
- Close tolerance locking pin
- Identical configuration for each element of the mast

The first choice of material for development and proof of concept was beryllium-copper. This was chosen for a number of reasons including familiarity with material from previous programs, non-magnetic for instrument applications, relatively inexpensive for development work and availability.

The next step was to develop a method for interlocking the individual strips of material. The locking devices had to have the capability of being flexible enough to wrap around the storage spool when in the stowed configuration and yet be stiff and strong enough to take bending and torsional loads when the mast was deployed. The selected design was to utilize a series of tapered cone type of fittings attached within rolled tabs located along the length of each strip of material. These nested fittings along the full length of the deployed mast become the load carrying path of the mast. The rolled tabs were located so that they would be internal to the formed mast, thus creating a smooth external surface which would pose no major deterrent to potential EVA activity in the vicinity of a deployed structure.

A conscientious effort was made throughout the interlocking edge development to keep each element identical to the others. This was done mainly to maintain the commonality of parts and therefore keep the manufacturing costs as inexpensive as possible. As a result of this effort, we were able to meet that objective.

Because results on previous programs with coatings and other methods for controlling thermal distortions have proven our understanding of the problems and our ability to cope with them, it was decided to forego any demonstration of these technologies on this program at this time.

ELEMENT FABRICATION

The following manufacturing method has been formulated for producing 60 inch lengths of elements which are sufficient for proof of concept and properties testing purposes. This method is fairly simple, relatively inexpensive, and very similar to a projected production type operation. To date, test samples have been fabricated in both 2 inch and 4 inch sizes (measured length of each leg of triangle). The following materials are utilized for the various components of the mast:

- Element sides - 7 mil. beryllium copper
- Fittings - 3/16 inch diameter stainless steel
- Bond - Tin lead alloy solder

The mast wall segments have been fabricated from flat, ribbon type, Be Cu material. They have an identical alternating edge tab design that is punched with controlled high tolerance spacing and alignment. After preshaping the tabs into a full round tube form, the entire wall segment length is heat treated to a final full strength condition. Interlocking fittings, fabricated from stainless steel, are then inserted into each of the rolled tabs. These patented fittings form the primary interlock between the mast wall segments. They are held into position within the rolled tab by flanges located at each end and, in addition, each of the tabs is secured along the open seam with a resistance solder joint. At this point, the three wall segments are ready for interlocking into a triangular mast.

The measured weight of a 4 inch wide triangular mast is .54 lb/ft. No attempt was made to make the initial mast configuration weight efficent. However, it was realized that significant lightening could be effected, without significantly reducing mechanical properties, through a pattern of circular, triangular or other cutouts between the triangular apexes.

MECHANICAL TESTS

Mechanical test performed on the mast specimens consist of applications of torsional and lateral loadings. A fixed-free condition was simulated by embedding one end of the mast in Cerrobend as shown in Figure 3.

Figure 3

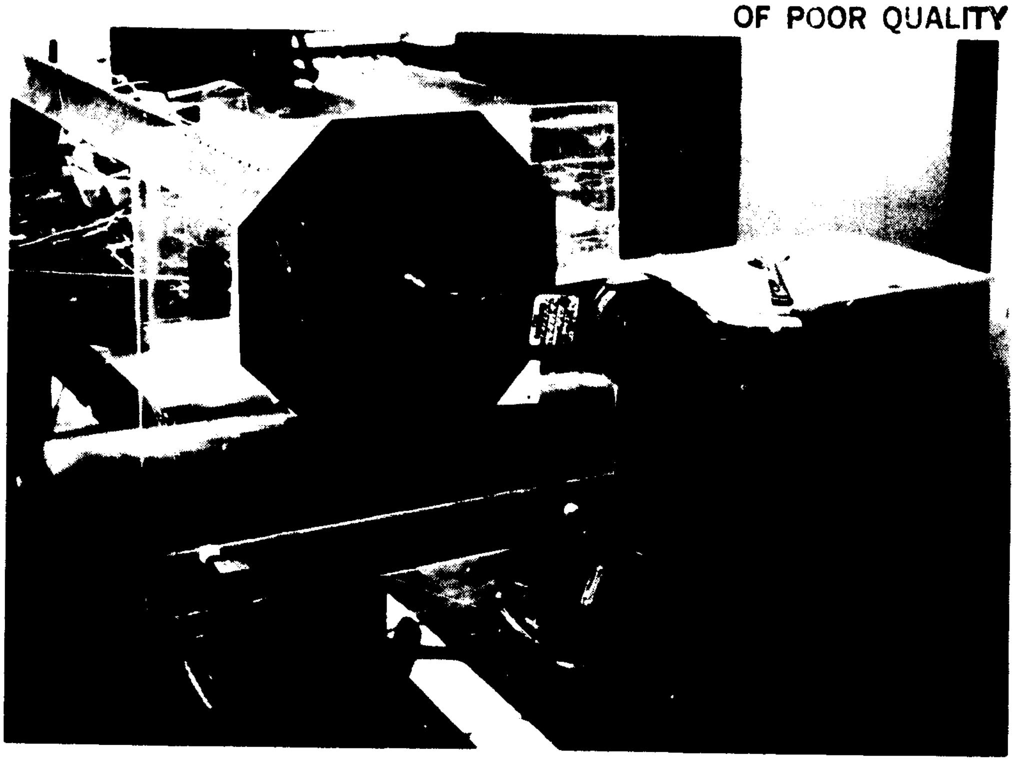

Figure 4

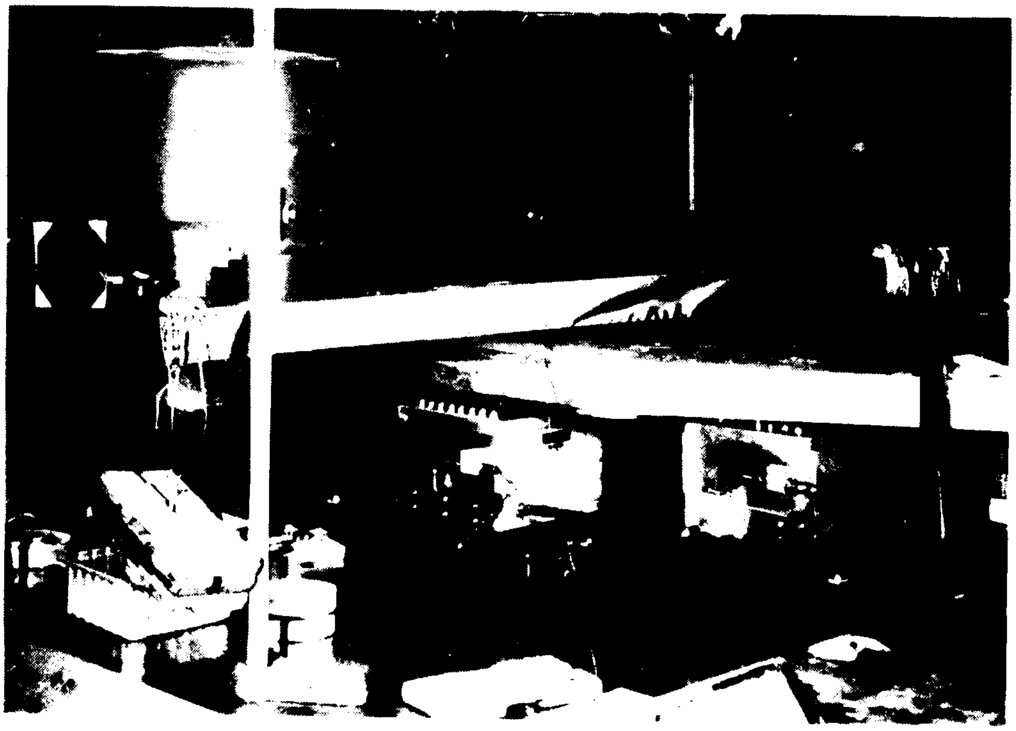

Figure 5

TORQUE TEST

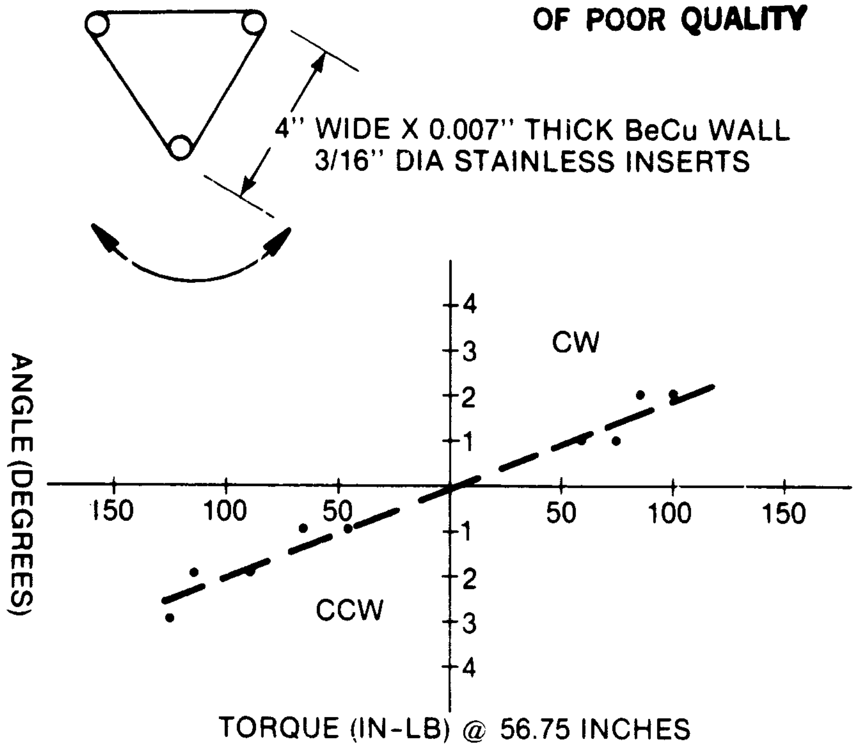

Figure 6

BEND TEST

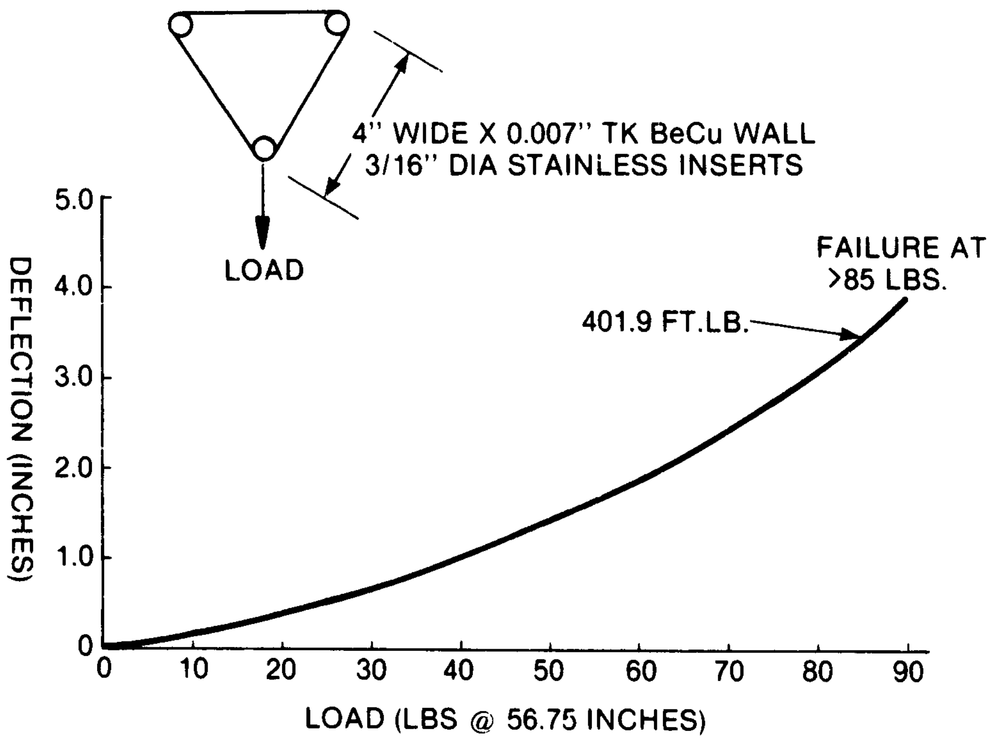

Figure 7

Testing of the mast under torsional and lateral loading conditions was conducted as shown in Figures 4 and 5 respectively. The test results clearly show that the 4 inch wide by 36 inch long mast specimen is capable of torsional forces greater than 100 in. lbs. and lateral forces of greater than 400 ft. lbs. Figures 6 and 7 present recorded load-deflection data.

CYCLE ALIGNMENT TEST

A preliminary deployment alignment/cycle test has been performed with a 2 inch wide triangular mast sample. The mast sample was cycled from a motorized deployment unit. This unit, although designed for demonstration purposes and fabricated from plexiglass, produced sufficient control of the sample mast for optical measurements of the tip position at several extended lengths. The mast was extended vertically under no load conditions and measurements taken between extend/retract cycles numbering 65 through 75.

Measurements of .005 inch maximum variance in both x and y axis were recorded at the full extended tip position of 36 inches. This equates to a repeatable static alignment of .008 degree. The test set up is shown in Figure 8.

Figure 8

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DESIGN EVOLUTION

Finally, after all the concepts have been evaluated and thought out, the real proof is in the fabrication and testing of the hardware. Tolerances that are too tight result in a mast that is difficult to lock and would probably cause jamming of a mechanism. If the tolerances are too loose, the torsional rigidity and bending movement capability is compromised. Some of the problems encountered during the development are hereby presented.

These problems were identified during destructive testing or as a result of test failure mode analysis. The interlocking fittings originally had a stackable straight tubular form and were secured into the curled tabs along the edges of the Be Cu wall by a series of spot welds. These fittings were, at that time, fabricated from brass alloy because of the desirability to utilize as little magnetic materials as possible and because brass is easy to machine and easy to spot weld. Test results of these mast samples showed that the spot welds had failed under test loads. As a result, a structural adhesive, 3M2216A/B, was then selected to replace the spot welds. Test results of these mast samples showed that the failure occurred as a result of compression yielding of the brass fittings and yielding of the fitting bonding agent. The fittings were then redesigned. Flanges were added at each end to provide primary sheer support and positioning within the tab. Also, the fitting material was changed from brass to stainless steel and a solder alloy was selected to secure the curled tabs. To date, testing has demonstrated that this is a successful design combination.

CONCLUSIONS

The mast development has met all the major criteria established at program initiation. The results presented verify that a high bending moment, high stiffness, torsional rigidity and a high degree of positioning/repeatability can be incorporated into a deployable/retractable unit.