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HIGH STABILITY DEPLOYABLE BOOM

by

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ABSTRACT

Meaningful magnetic field vector measurements in space require accurate placement of a magnetometer beyond the magnetic fields of a spacecraft. This paper describes the design and development of a deployable boom which ensures accurate deployment of an instrument package and maintains high stability after extension.

INTRODUCTION

Predictability of boom alignment and stability of the boom after deployment were the driving design requirements. Specifically, these requirements were:

1. The alignment of the boom after deployment shall be predictable within 20 minutes of arc in both twist and deflection.

2. Boom twist shall not exceed 5 minutes of arc and boom deflection shall not exceed 15 minutes of arc from all sources, including thermal effects from solar radiation and air drag at altitudes above 200 Km.

These stringent stability requirements, coupled with a 6.8 Kg weight limitation for a 6 meter boom that can be stowed into a volume of 0.057 m^3 (2 ft^3), dictated the following features for the boom design:

- Largest closed cross section possible, consistent with the stowed volume constraints.
- Construction using a framework truss which will receive nearly equal thermal input throughout.
- Minimum play in the boom truss and linkage joints.
- Use of non-magnetic, lightweight materials having very low thermal coefficients.

To meet these requirements, an adaptation of a Fairchild patented folding box beam was designed and is described in the following sections.

DESIGN DESCRIPTION

The basic building block of the high stability deployable boom is a modular bay, and the length of the boom is determined by the number of modules linked together in series. Each module consists of two side truss panels supported and deployed between two synchronized scissor linkages. When the boom is fully deployed, as shown in Figure 1, the side panels, which are hinged along their transverse center lines, lock into position and form two sides of a box beam. Shear capability is inherent in the truss panels whereas the shear continuity in the two opposite sides of the box is furnished by the links themselves. Both the links and the truss panels are of sandwich construction using low density (2-3 lb/ft^3) aluminum honeycomb with Graphite Fiber Reinforced Plastic (GFRP) face sheets. This construction provides for maximum strength, minimum weight, and low thermal distortion.

Flexure hinges are used where each truss folds or is attached to its neighbor. The flexure hinges serve three functions: (1) as a hinge, (2) as a deployment spring, and (3) as a deployment lock. As shown in Figure 2, the flexure hinge has a configuration similar to that of a carpenter's rule, with a radius of 19 mm. The hinges are made from GFRP and a significant test program was conducted to achieve acceptable hinge properties. The results of the test program are discussed under a separate heading.

As stability in the deployed boom is a critical requirement, all bearings at the extremities and centers of the scissors links are close tolerance (0.0002-0.0005 inch radial clearance) ball bearings. For magnetic cleanliness reasons, these bearings are manufactured from beryllium copper.

It can be seen that any play at the base of the boom after it is deployed will adversely affect boom deflection. To prevent this, a system for deployment was designed as shown in Figure 3. A ball screw, one half with a left-hand lead and the other half with a right-hand lead, is located across the center of the housing at the base of the boom. Depending on the direction in which the screw is turned, two carriages, one on each end of the screw, will simultaneously move toward or away from each other. Rotation of the carriages is prevented by parallel rods positioned on either side of the ball screw as shown in Figure 3. The degree of tolerance between the linear bearings and the rods determines to a large extent the amount of boom deflection. The lower extremities of the four scissors links at the base of the boom are pinned to the clevises which are an integral part of the carriages.

The engineering model is deployed using a hand crank; however, the design is flexible enough to accommodate a drive motor. In addition, for flight booms, the drive assembly will be designed for minimum weight.

FLEXURE HINGE DESIGN

The most critical component in the boom design is the flexure hinge. Its primary purpose is to provide a stiff lock between side panels after the boom is fully deployed and a secondary function is to provide a spring force to aid in boom deployment. Important characteristics of the flexure hinge are:

- A high value of EI for stiffness
- Good spring properties
- Flexibility
- Made from non-magnetic material
- Made from material with a low thermal coefficient

It is evident that, because of the flexibility requirement, the hinge must be made from a thin strip of material. Therefore, for stiffness, the strip is configured similar to a carpenter's rule to increase the area moment of inertia of the cross section.

A preliminary review of available material for the hinge indicated beryllium copper as the most likely candidate. However, a thermal analysis showed that there would be an unacceptable distortion of the boom unless the maximum temperature difference between a sunlit portion of the boom and a shaded hinge is held to 69.5°C. It must be realized that the flexure hinges comprise about 20% of the length of the deployed boom.

Various schemes to limit the temperature differential across the boom were then evaluated including the use of beryllium copper conductor straps placed along the inside of the panel diagonals. An alternative solution, and the one that was implemented, was the use of GFRP as the hinge material. It can be seen from Table 1 that the tensile modulus, E, is very close to that of beryllium copper, but the big advantage of GFRP is its thermal coefficient, a minimum of 20 times less than that of beryllium copper.

Before the feasibility of using GFRP for the flexure hinge could be established, an experimental test program was performed to evaluate the following:

- Optimum lay-up configuration
- Best bonding agent
- Degree of flexibility
- Minimum bend radius (for minimum stowed volume)

Table 1. Physical Properties of GFRP

Property	Lay-Up		
	*90° Cross-Ply	Isotropic	Unidirectional
E	17×10^6 psi	10.6×10^6 psi	20×10^6 psi
G	$.65 \times 10^6$ psi	4.0×10^6 psi	$.65 \times 10^6$ psi
75°F to + 300°F	$.42 \times 10^{-6}$ in/in/°F	$.80 \times 10^{-6}$ in/in/°F	$-.49 \times 10^{-6}$ in/in/°F
75°F to -225°F	$.06 \times 10^{-6}$ in/in/°F	$.35 \times 10^{-6}$ in/in/°F	$-.16 \times 10^{-6}$ in/in/°F

*Two longitudinal plies and one transverse

For test purposes, flat strips of GFRP were laid up in widths of 0.5, 0.75 and 1.0 inches for each configuration of A through J as shown in Table 2. Two plies were considered optimum, each ply being approximately 0.005 inches thick and made from AS3501-5 GFRP. Kapton was included in some samples because it was thought that this would inhibit the tendency of the strips to delaminate.

Each sample was tested to determine the shortest practical length and the minimum bend radius for each configuration. The results are given in Table 2, and it can be seen that for one ply oriented 30° to a longitudinal ply, a bend radius of 4.3 mm can be achieved with a strip 70 mm long. It was found that neither strip width nor Kapton had any significant effect on the bend properties.

Another grade of GFRP material (HMS3501-5) was tested and found to be much more brittle. However, it can be seen that the possible variations in material and configuration are considerable and it is not claimed that the 0°/30° lay-up of two plies of AS3501-5 provides the best hinge material. Further testing is required to determine the optimum parameters.

Using the 0°/30° two-ply lay-up, flexure hinges were heat treated, five at a time, in the tool illustrated in Figure 4. The force versus deflection characteristics of the resulting hinges are shown in Figures 5 and 6. As expected, the spring force is much greater when the flexure hinge is bent round with its normal concave surface as the outer bend radius.

CONCLUDING REMARKS

The purpose of this paper is to present a unique boom design for deploying instruments from spacecraft and maintaining the instruments in a stable configuration under all combinations of space environments. Of prime importance to the stability of the boom is the flexure hinge design. The need for a material with an extremely

CONFIGURATION	OUTER PLY[a]	MID PLY	INNER PLY[b]	RESULTS
A	GFRP	None	GFRP at 0°	MIN. RAD. = 10 mm FOR A 120 mm LG ELEMENT
B	GFRP	None	GFRP at 15°	MIN. RAD = 6.4 mm FOR A 102 mm LG ELEMENT
C[c]	GFRP	None	GFRP at 30°	MIN. RAD. = 4.3 mm FOR A 70 mm LG ELEMENT
D	GFRP	None	GFRP at 45°	MIN. RAD. = 7.9 mm FOR A 102 mm LG ELEMENT
E	GFRP	None	GFRP at 90°	MIN. RAD. = 10.2 mm FOR A 120 mm LG ELEMENT
F	GFRP	None	KAPTON 3 MIL	THE USE OF KAPTON HAD NO APPRECIABLE EFFECT ON THE COMPOSITE
G	GFRP	None	KAPTON 5 MIL	F & G COMPARED TO A, H & J COMPARED TO E
H	GFRP	GFRP at 90°[b]	KAPTON 3 MIL	
J	GFRP	GFRP at 90°[b]	KAPTON 5 MIL	

a FIBERS RUNNING LONGITUDINALLY

b WITH RESPECT TO OUTER PLY

c .75 mm WIDE ELEMENT TESTED

TABLE 2. Flexure Hinge Experimental Results

low coefficient of thermal expansion influenced the choice of GFRP and therefore instigated a hinge development program. As stated earlier, the hinge configuration used in the engineering model meets all requirements for its intended use but there is obviously room for further development.

Fabrication of an engineering model of the boom is currently underway at the time of writing. Deployment and solar simulation test results may be available at the 10th Aerospace Mechanisms Symposium.

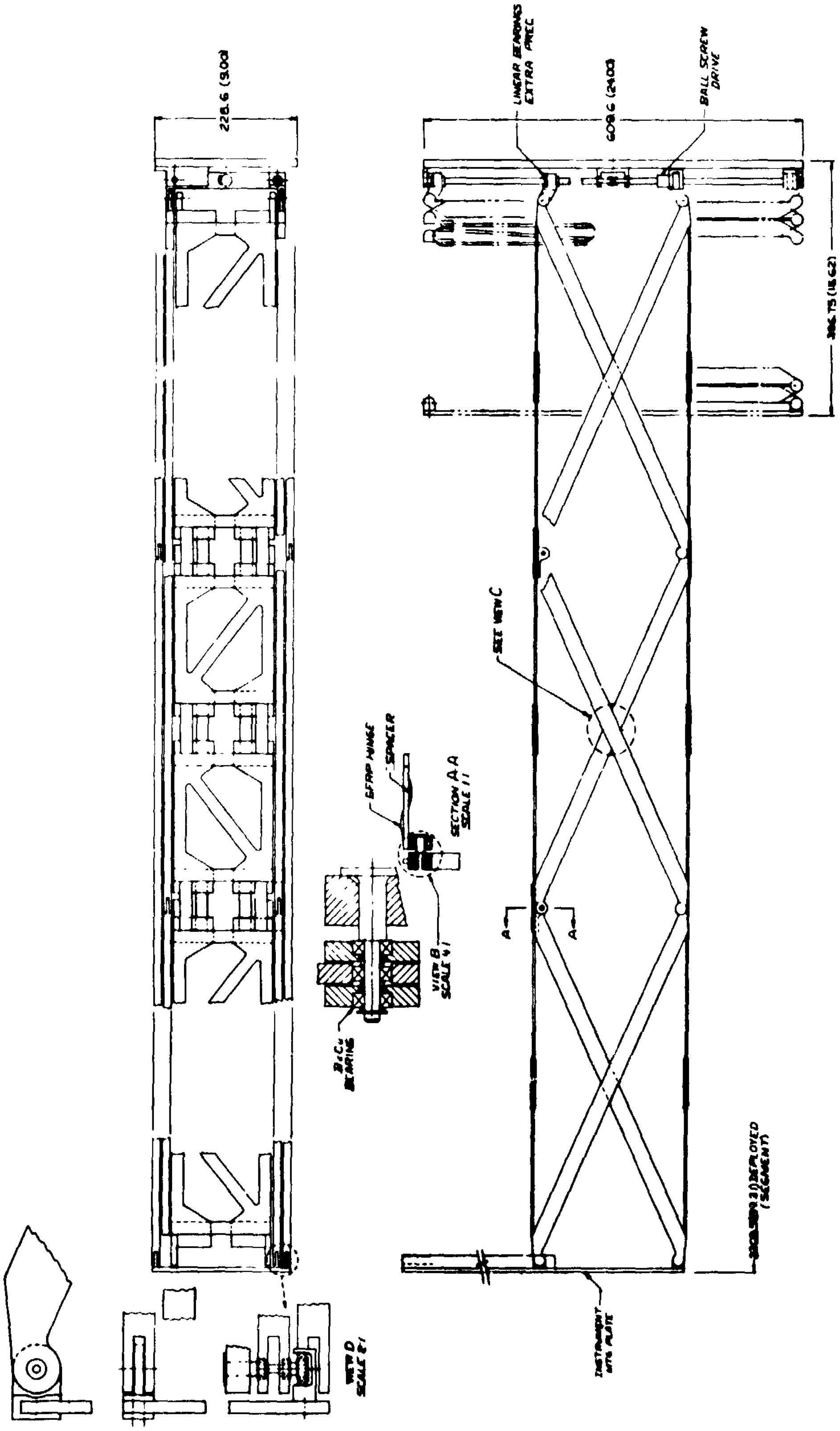
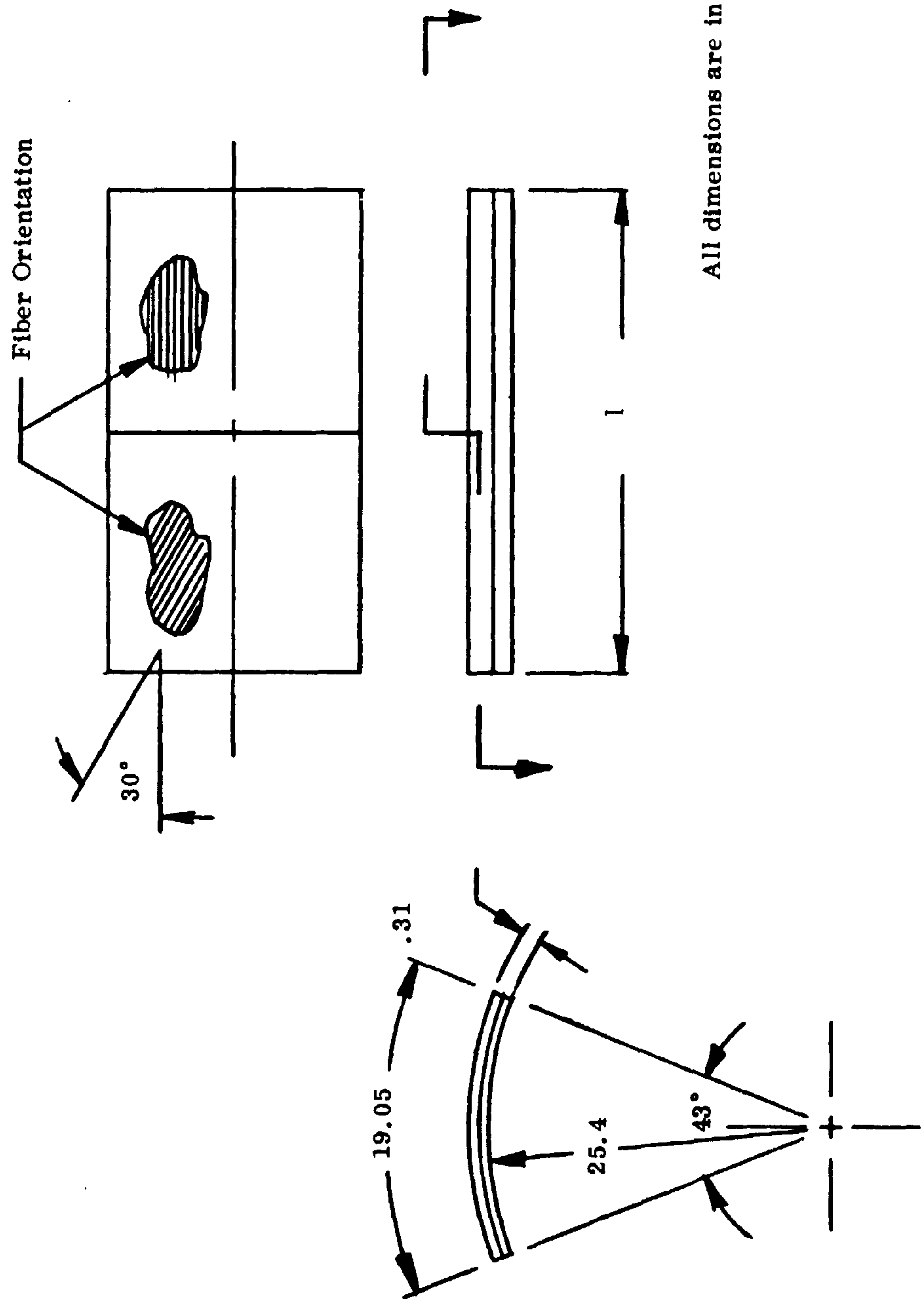


Figure 1. High Stability Boom



All dimensions are in mm.

Figure 2. Flexure Hinge Configuration

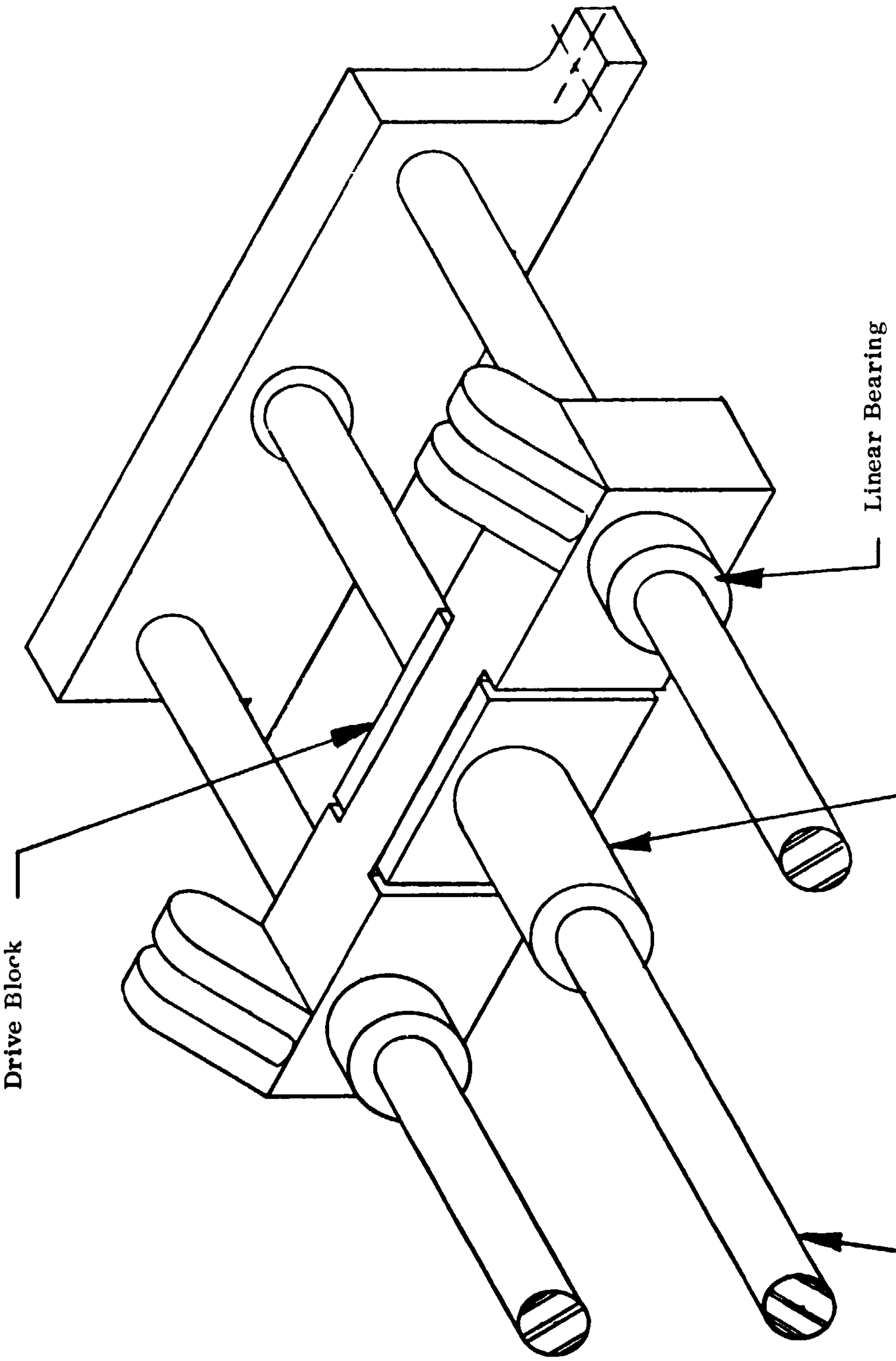


Figure 3. Deployment System

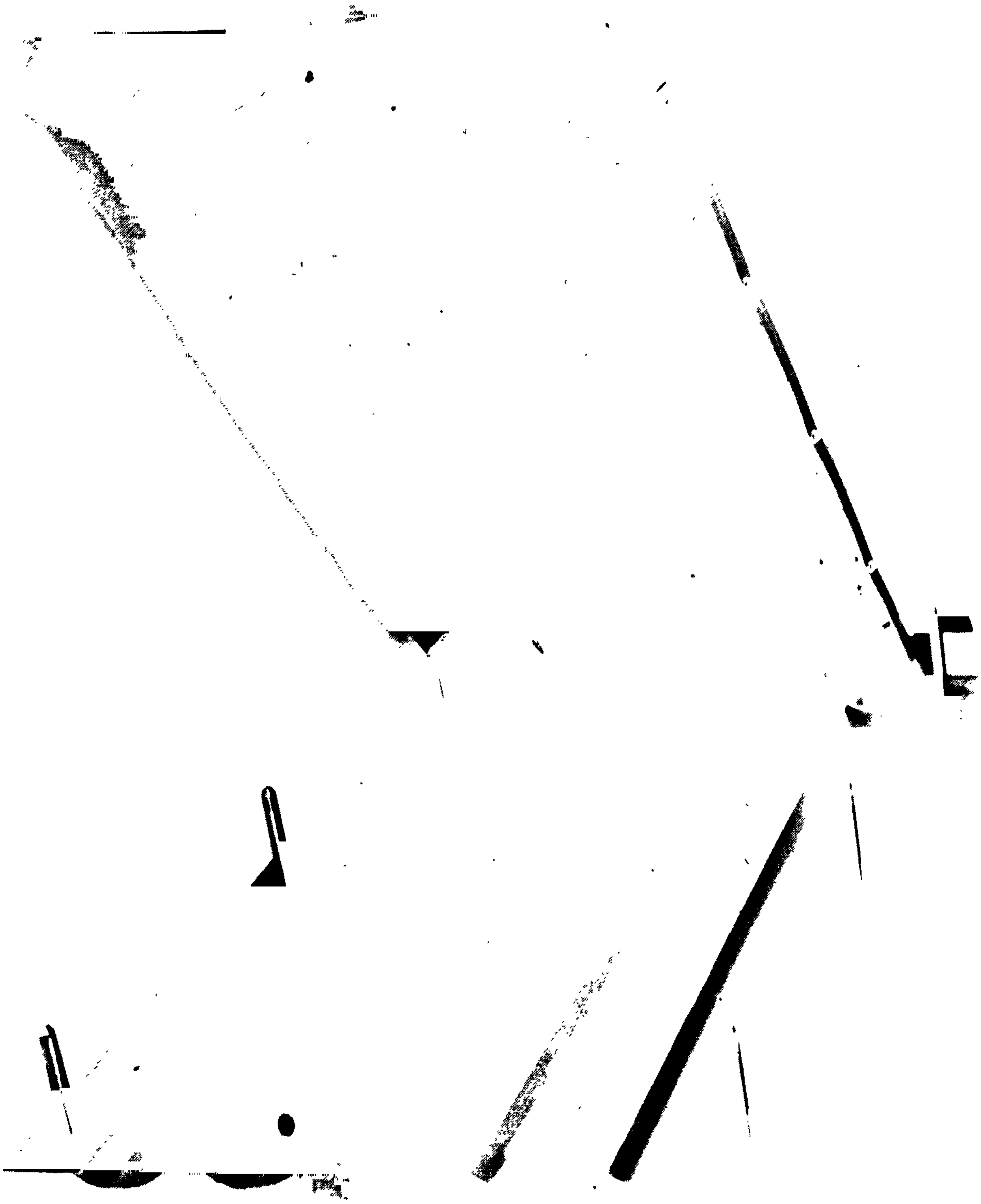


Figure 4. Flexure Hinge Heat Treat Tool

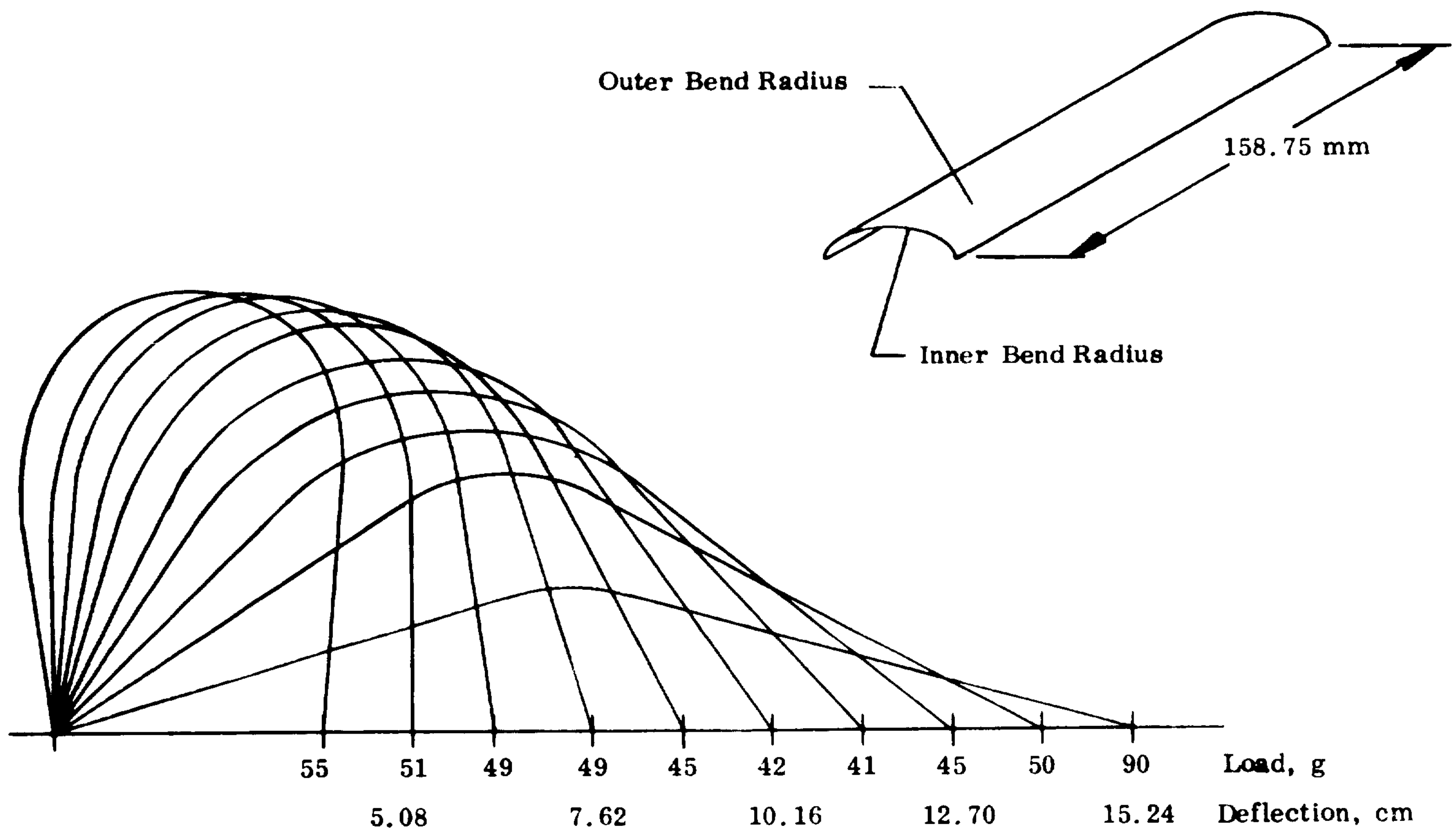


Figure 5. Flexure Hinge Force vs Deflection Characteristics

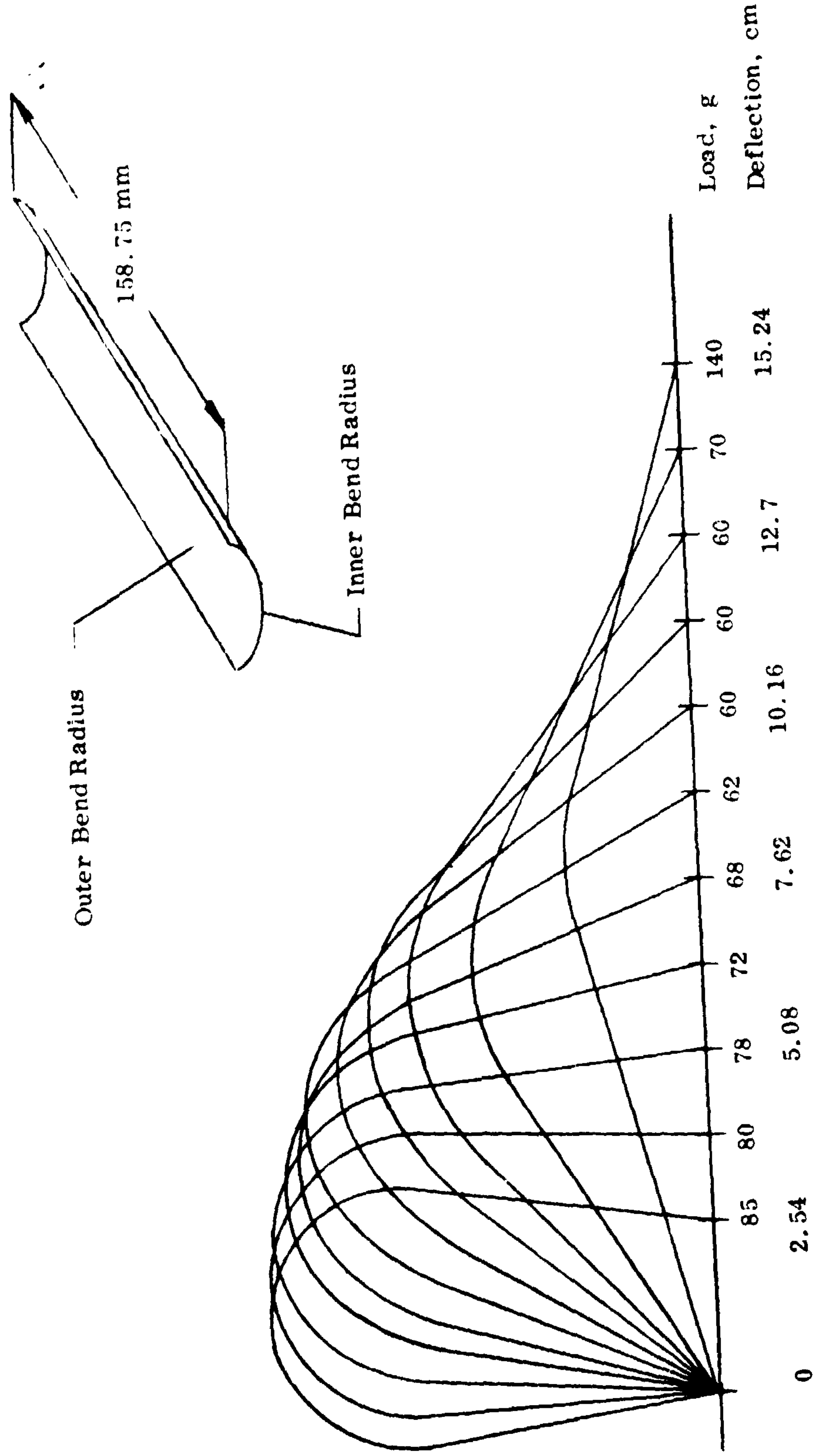


Figure 6. Flexure Hinge Force vs Deflection Characteristics