6. TELESCOPIC BOOMS FOR THE HAWKEYE SPACECRAFT

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INTRODUCTION

Several boom arrangements were proposed for the HAWKEYE spacecraft (formerly called the INJUN series of spacecrafts).

The design chosen to fly consists of one pair of stem roll-out booms and a set of telescopic booms. Some of the advantages of choosing this boom configuration were that the booms could be stored in the belt line area, which is near the center of gravity of the spacecraft, and also with the approach the telescopic booms could be extended at the spacecraft's initial spin rate (180 rpm). By being able to extend these booms at the initial spin rate of the spacecraft the need for a despin system was eliminated, thus weight saving to the spacecraft. With the method of storage and extension employed by the telescopic design, the desirable sensor distance from the spacecraft could also be attained.

FIRST DESIGN

The first telescoping booms to be constructed were operated by hand, and from the first model a number of redesignings were made; a second redesigned unit was constructed with special Delrin brushings, weight-reduction methods, and a small DC motor. With this redesigned unit a number of successful deployment tests were conducted.

FINAL DESIGN

The final design employs three telescoping aluminum tubing sections which slide inside one another on special Delrin brushings. The outer section is made from 3/4" x 3/4" square cornered tubing in which the outside dimensions are milled down to attain a wall thickness of .025". The middle section is made from 1" x 1" square cornered tubing and milled to a wall thickness of .025, and the largest section is 1-1/2 x 1-1/2 square tubing, which will have a final milled wall thickness of .030. So the final dimensions of these sections will be .675 x .675, .925 x .925, and 1.31 x 1.31, respectively.

These aluminum boom sections ride on brushings made from a Teflon-impregnated Delrin material, which encompasses the low frictional qualities of Teflon and the structural rigidity of Delrin. Figure 1. The aluminum sections are extended and retracted by reeling stainless steel cables in or out from aluminum storage drums.

This steel cabling is 3/128" in diameter and is strain hardened by pre-stretching. Figure 2. It has been found through tests that this cable will stay in the elastic portion of the stress-strain curve up to about 39 lb and has a breaking strength of $\approx$ 60 lb. The maximum tensile load the cabling is expected to experience is about 13 lb , thus nearly a 5:1 safety factor.

Housed inside the telescoping boom sections are the sensor cabling harness for the search coil and magnetometer sensors. The cabling is stored inside the telescoping boom sections and, as the telescoping sections extend, the sensor harness also extends. Figure 1. The cables are fabricated by the "Cicoil Corp." and consist of 5 shielded and 1 twisted pair of #30 wires encased in silicon rubber, thus providing a flexible ribbon. The cables are then accordioned and surgical elastic rubber is attached to either side with lacing cord by personnel at the University of Iowa. This method of construction provides an essential 3.5 to 1 cabling elongation.

The boom's drive motor is fabricated by "MPC Products" and has mounted on the end a gearhead which gives an 84:1 gear reduction. The AC 2-phase motor has a rated torque of 7.6 in-oz @ 212 rpm and a no-load speed of 23,700 rpm. Curves of motor-gearhead characteristics of the two motors received are shown in Figure 3.

TESTING AND PROBLEMS

In order to do bench testing of these booms a centrifugal force simulator was constructed (fig. 4).

Since the building of this simulator many tests have been performed on the DVU (Design Variation Unit) and the protoflight booms.

When the DVU motor was received, it was mounted on the DVU boom. This boom was complete with the exception of not having the sensor harness installed (no cables were available at that time). Several boom extensions and retractions were performed on the simulator and on the spin table. It became apparent that some additional loading was occurring on the simulator. After some modifications were performed, the simulator provided loads necessary. A sketch of the simulator is provided in Figure 4. The simulator force vs. boom extension curve is shown in Figure 5. Also on this same figure a plot of the calculated curve is provided.

Because it was felt that the antenna may be subjected to high coriolis forces during extension (from the combination of spin deceleration and extension speed) and, furthermore, that these forces may tend to bind the brushings during erection, the unit was installed on a spin table, which had inertias comparable to the proposed spacecraft. In this configuration, the antenna was extended and retracted successfully under various spin rates, while the power consumption of the motor was monitored. The booms were deployed at 40, 60, 100 and at 180 rpm. The approximate spin rate of the spacecraft before telescoping boom deployment is 180 rpm.

From calculations the bending loads on the boom sections were obtained, with the maximum bending occurring when a 1-G load is on the boom, during erection. This will occur only in ground testing and occurs in the largest section and is $\approx$ 33 ft-lb (Fig. 6). The maximum stress in the booms takes place in the smallest section and is 1140 psi, which is a factor of $\approx$ 35 below the yield point of the aluminum (Fig. 6). The other bending loads that occur on the boom are forces occurring from coriolis. The stress levels produced from these forces are very small, a factor of 50 below the G loading factors, so they are disregarded.

Because of some extension-retraction problems encountered during testing on the simulator, an investigation into the friction between worm and worm gear was undertaken. It was found that the friction changes considerably with environmental changes. The coefficient of friction of the dry stainless worm against the bronze worm gear could change from .25 to .55.

A lubrication expert was contacted on this problem and it was recommended to coat the gears with molybdenum disulfide. With this lubricant a coefficient of friction of .1 to .15 could be expected. From actual tests performed on the lubed gear, it was found that indeed the friction was a satisfactory .15. Calculations are shown in the appendix and in Figure 5.

To insure that no tooth shearing damage would take place in the gears of the aluminum storage drums, the loads in the gears were studied. With the maximum load of 28 lb , it was found that the maximum stress was $\approx$ 356 psi. The shear strength of the 7075 aluminum used is 40,000 psi, resulting in a high safety factor. Calculations are shown in the appendix.

CONCLUSION

At the time of this writing, the DVU and protoflight boom units have gone through extensive testing. The flight telescopic boom is now in fabrication with additional testing planned for it.

APPENDIX

ALUMINUM GEAR DRUM CALCULATIONS

Aluminum Gears

The maximum centrifugal is $\approx 13 \times 2$ sides. With frictional losses, we assume a load of ≈ 28 lb.

CAL OF STRENGTH IN TOOTH

From Lewis formula (Ref. 1, p. 396):

$$W_E = \alpha_\rho Fy$$

$$\alpha = \frac{W_t}{\rho Fy} = \frac{28 \text{ lb}}{1.125 \times .2 \times .35}$$

$$\alpha = 355.5 \text{ psi}$$

Where
W_t = transmitted load = 28 lb
α = normal stress = ?
ρ = circular pitch dia. = 1.125
F = face width = .2
y = form factor $\approx$ .35

From Barth equation (Ref. 1, p. 396):

$$\alpha_d = \alpha \frac{1200}{1200+V}$$

$$\alpha_d = 355.5 \frac{1200}{1200+2.45}$$

$$\alpha_d = 354 \text{ psi}$$

Where
V = Velocity at pitch line = 2.45 ft /min
α_d = stress due to dynamic load = ?

The 7075 aluminum material used has a shear stress of 40,000 psi, so: The safety factor is very high.

Worm and Worm Gear Efficiency

(Ref. 1, p. 455):

$$\text{eff} = \frac{\cos \phi_n - \mu \tan \lambda}{\cos \phi_n - \mu \cot \lambda}$$

ϕ_n = pressure angle
λ = lead angle

From measurements 7.6 in-oz at motor gearhead is 64 in-oz on pinion.

so: $$\text{eff} = \frac{64 \text{ in-oz}}{7.6 \text{ in-oz} \times 30:1 \text{ ratio}} = .28$$

$$\text{eff} = .28 = \frac{\cos \phi_n - \mu \tan \lambda}{\cos \phi_n - \mu \cot \lambda} = \frac{.9681 - \mu(.0627)}{.9681 - \mu(16.00)}$$

$\mu = .15$, so coefficient of friction = .15.

REFERENCE

1. Shigley, J.: Series in Mechanical Engineering. McGraw-Hill Book Co., Inc., 1963.

CABLE OPERATION OF ANTENNA BOOM

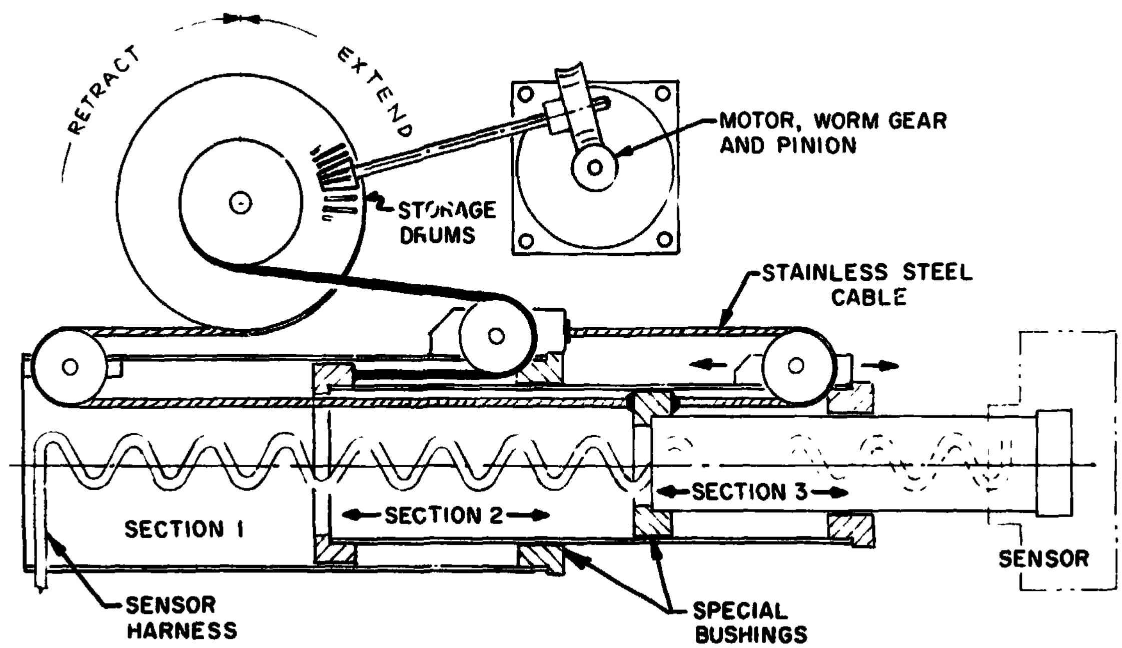

Figure 1.

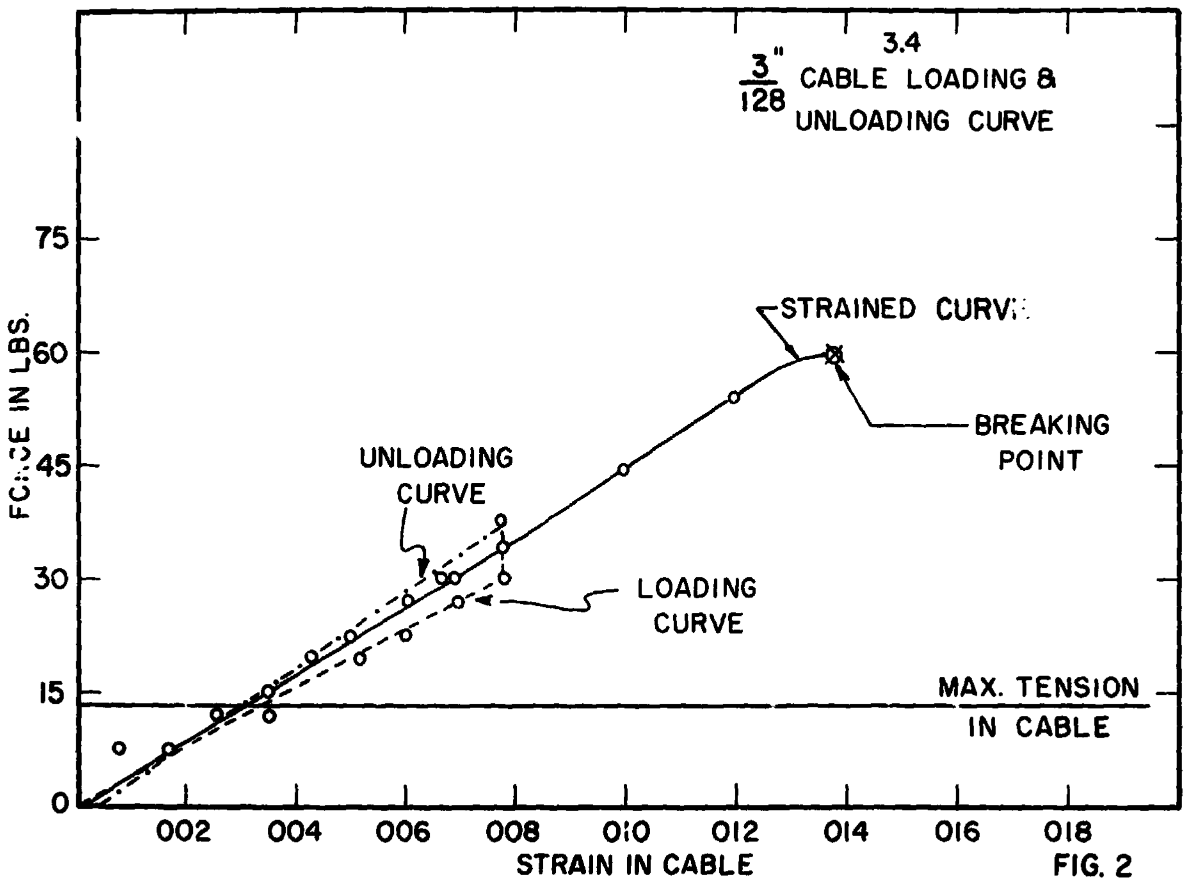

FIG. 2

Figure 2.

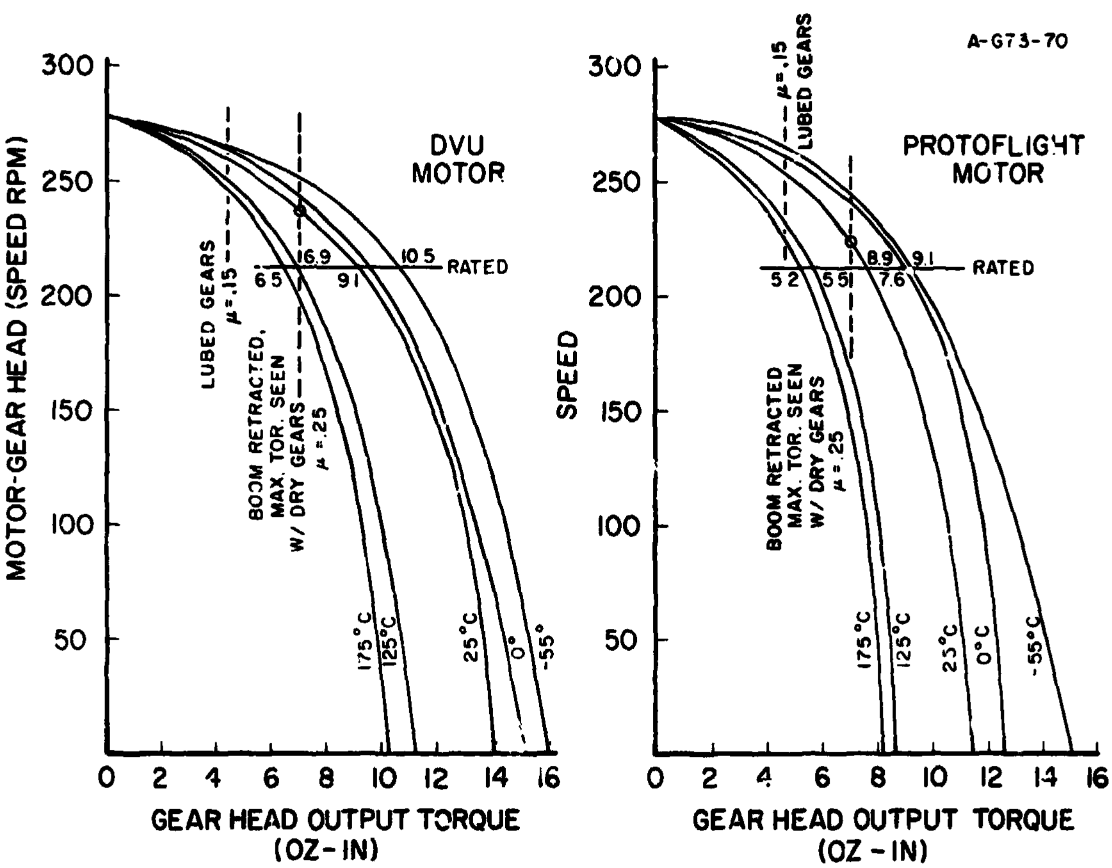
A-G73-70
DVU MOTOR
PROTOFLIGHT MOTOR
MOTOR-GEAR HEAD (SPEED RPM)
SPEED
GEAR HEAD OUTPUT TORQUE (OZ-IN)
GEAR HEAD OUTPUT TORQUE (OZ - IN)
RATED
LUBED GEARS μ=.15
BOOM RETRACTED MAX. TOR. SEEN W/ DRY GEARS μ=.25
175°C
125°C
25°C
0°C
-55°C
16.9
10.5
6.5
9.1
8.9
5.2
5.51
7.6

Figure 3.

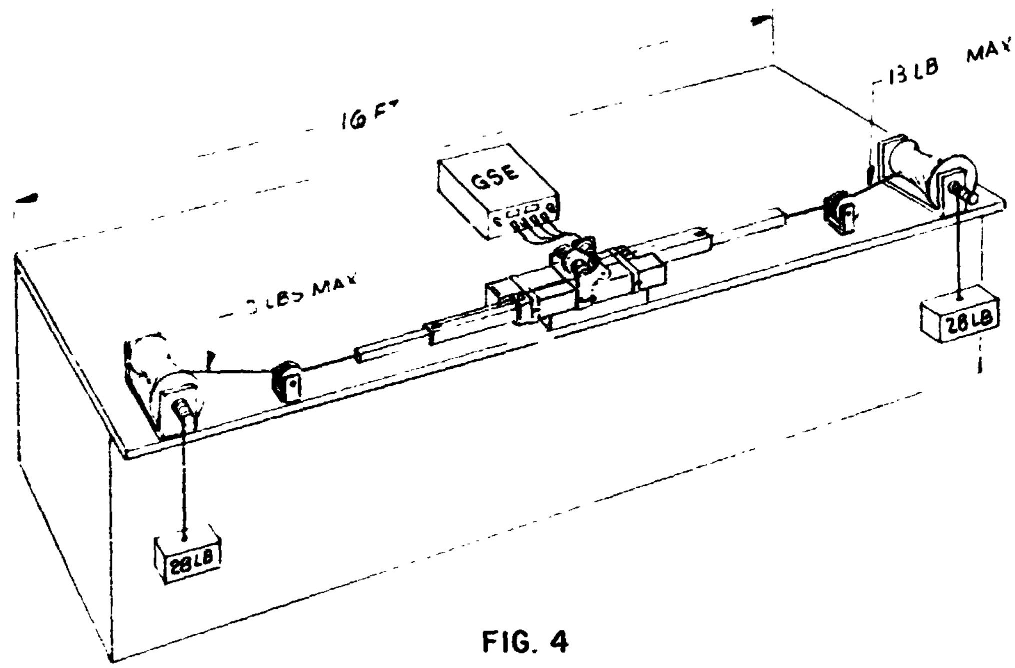

Figure 4.

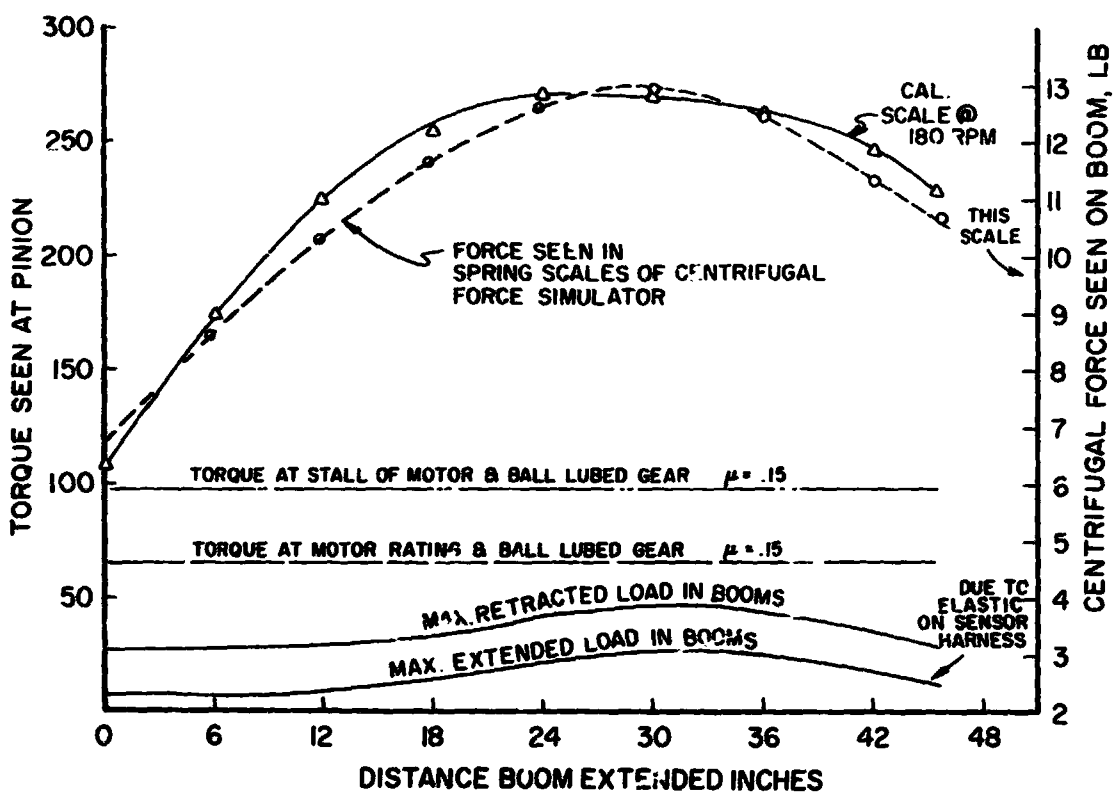

Figure 5.

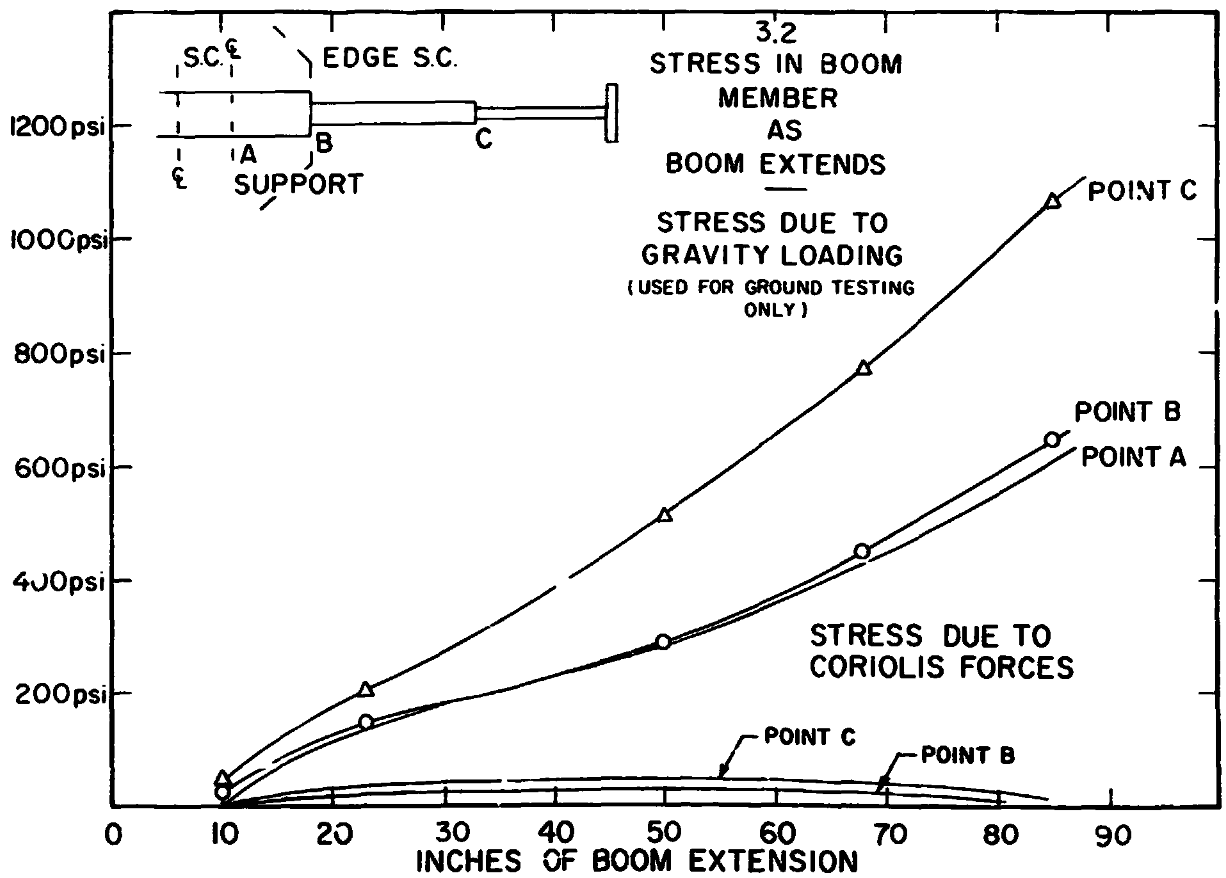
S.C. ℄
EDGE S.C.
A
B
C
℄
SUPPORT
3.2
STRESS IN BOOM
MEMBER
AS
BOOM EXTENDS
STRESS DUE TO
GRAVITY LOADING
(USED FOR GROUND TESTING
ONLY)
POINT C
POINT B
POINT A
STRESS DUE TO
CORIOLIS FORCES
POINT C
POINT B
1200psi
1000psi
800psi
600psi
400psi
200psi
0
10
20
30
40
50
60
70
80
90
INCHES OF BOOM EXTENSION

Figure 6.