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Generic telescope truss

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ABSTRACT

This paper describes the structural design, analysis, and load/deflection tests of a generic all–beryllium telescope truss (metering structure). The assembly serves to verify the viability of building lightweight precision mirrors and structures for high performance space–based optics and to measure the integrated performance of state–of–the–art CCD focal planes. It demonstrates the feasibility of manufacturing lightweight and stiff structures that can support high performance optical systems and meet their alignment requirements. The goal of building a telescope worthy of space flight was met.

1. INTRODUCTION

The generic telescope is an all–beryllium assembly (structure and mirrors) supported on a pedestal. The telescope is surrounded by a light attenuating enclosure attached to a pedestal that permits ±3 deg rotation in elevation and azimuth. It is mounted to a vibration isolation bench.

The generic telescope truss is the mechanical/structural support for the optical assembly, which consists of three mirrors and a focal plane assembly. One of the mirrors is oscillated by an image motion compensation mechanism (IMC). The truss maintains the proper axial and lateral separation of the optical elements, and transfers all the loads to the support pedestal. It also provides passive thermal control for the spacing of the optical elements. Since the truss and the mirrors are all beryllium, the focus of the system will remain fixed over the expected temperature range of ±55°F.

Beryllium was used for the structure because of several factors. It best meets the requirements for a stiff and lightweight structure and is also most thermally compatible with the beryllium mirrors. Since the all–beryllium telescope is athermalized, no thermal control metering devices or focus control is required. Other materials such as steel, aluminum, and titanium were considered. Using these materials requires a heavier and more complicated telescope to accommodate different coefficients of expansion with the optics. The beryllium structure meets all of the requirements, and is fabricable. One intent of the program was to produce a space flight qualifiable telescope.

2. TECHNICAL DISCUSSION

This telescope was designed to meet the requirements of a spaceborne sensor. The project provided a telescope assembly with high performance image qualities to test various guest focal plane assemblies and demonstrate the feasibility of fabricating an ultra lightweight all–beryllium telescope.

Our goals for the telescope were to:

- Keep assembly weight under 44 lb and truss weight under 21 lb.
- Maintain a minimum telescope/gimbal/enclosure resonant frequency of 75 Hz.
- Maintain optical alignment to the following values through the thermal (70 ±5°F) and g load environments (±40 g's):
  - Despace: 50 μm
  - Decenter: 50 μm
  - Tilt: 20 arcsec.

The configuration of the telescope is shown in Fig. 1. The truss is approximately 22–in. long, 16–in. deep, and 18–in. high. It consists of an aft and a forward bulkhead, each tied together by means of tubular rods and central hubs that interface with the pedestal (Fig. 2). The parts are bolted and pinned together and the mirrors are flexure mounted to subplates which in turn are tied kinematically to the bulkheads to provide fine adjustment capability for the optics. Thicknesses of beryllium parts range from 0.020 to 0.1 in.

Much effort was made to lighten the structure without compromising space flight worthiness. The lightweight design also had to maintain a minimum resonant frequency of the assembly to 75 Hz, and be fabricable. This included a 10% factor to account for joint losses. The pedestal was fabricated out of steel, and the sheet metal enclosure was made of aluminum and the 75–Hz frequency kept the system reasonably stiff, with resonances above the servo critical frequencies. The telescope is rigidly fixed to the pedestal at its two trunnion mounts.

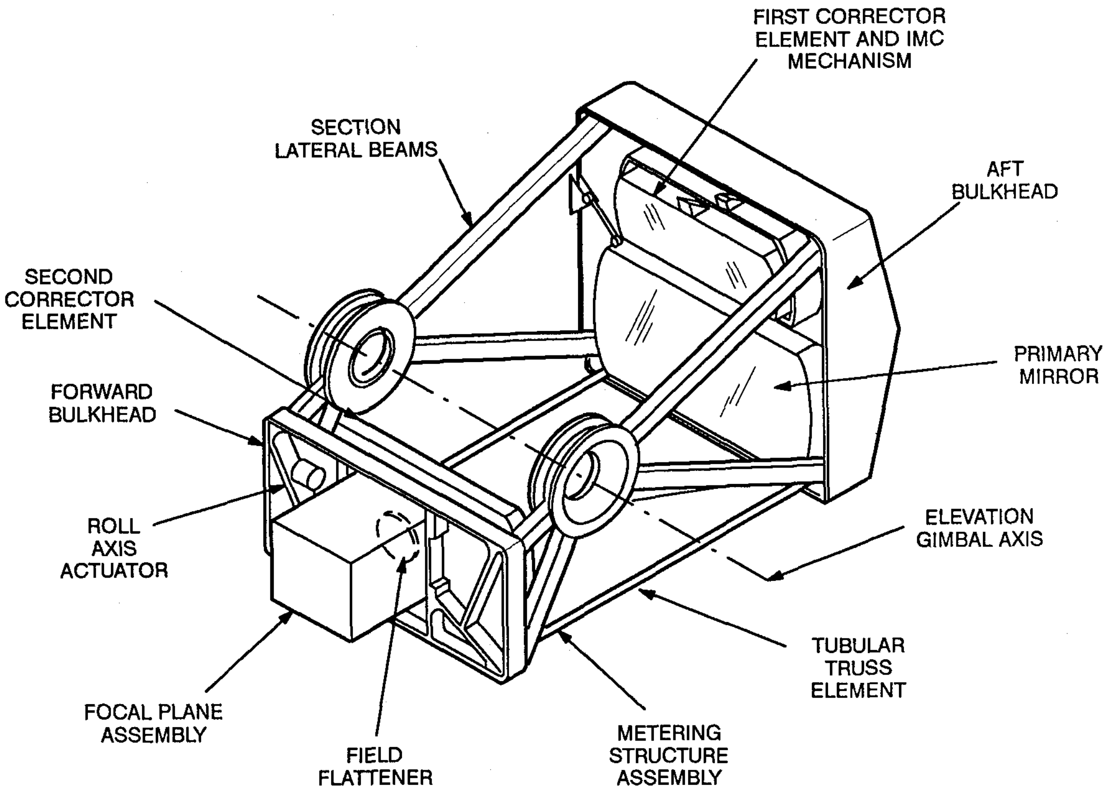
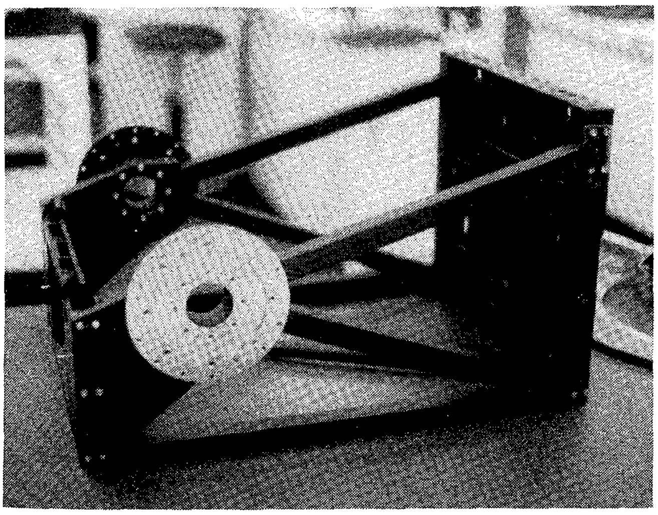


Fig. 1. Telescope assembly configuration.



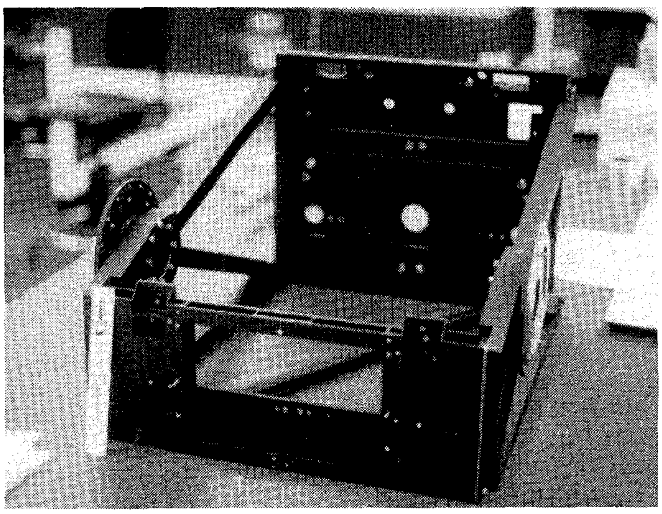


Fig. 2. Beryllium truss.

The stress and dynamic analyses were initially done by hand, then repeated using NASTRAN. For telescopes of this nature the governing structural design criteria is usually stiffness or rigidity, not stress. Stresses were calculated for the 40 g load factor in all directions and were well within the allowable level for beryllium.

3. RESULTS OF ANALYSES

The initial sizing of the major structural components was done using hand stress analyses and subsequently, that geometry was used for the NASTRAN modelling. The analytical results for deflections and resonant frequency are reported here, and the deflections (or equivalent frequencies), are compared to actual measured deflections on the metering truss.

The telescope was fixed at its elevation axis trunnion mounts. For each actual measurement (in all three axes) dial indicators were located directly under the load and at the fixed trunnion. The latter measurement (the tare) was subtracted from the deflection under the load. This eliminated any free play or joint looseness from the final measured deflections.

3.1. Hand calculation

The vertical 1 g deflection of the aft bulkhead as mounted to the truss was calculated by hand to be 0.0028". The resulting predicted first resonant frequency was 59 Hz.

3.2. NASTRAN model

The finite element model (FEM) included a beryllium telescope truss with optics, an enclosure, and a support pedestal (Figs. 3 and 4). The NASTRAN model consisted of 870 grids and 856 elements and a Q of 40 was chosen to represent a realistic transmissibility for the structure. All beryllium structures and mirrors are modelled as plates with equivalent stiffnesses with the local truss end fittings modelled as rigid connections.

The first resonance of the telescope (aft bulkhead on truss) was calculated to be 79 Hz in the elevation direction. The 77 Hz is a local mirror IMC resonance.

3.3. Actual measured deflections on truss (as mounted to pedestal)

Load deflection measurements were taken on the truss in three directions (Figs. 5, 6, 7 and 8). The data in Fig. 6 corresponds to the vertical or elevation directions calculated above. The measured vertical deflection of the aft bulkhead for a load of 8 lb (corresponds to the 1 g load used in the hand analysis) is 0.0019–in. By calculation, this is equivalent to a resonance of 72 Hz. Table 1 summarizes these results.

Table 1. Vertical Deflections for the Aft Bulkhead/Truss

	Deflection (inch)	Frequency[a] (Hz)
Hand analysis	0.0028	59
NASTRAN model	0.0016[b]	79
Actual measured	0.0019	72[b]

[a] Goal 75 Hz.
[b] Equivalent.

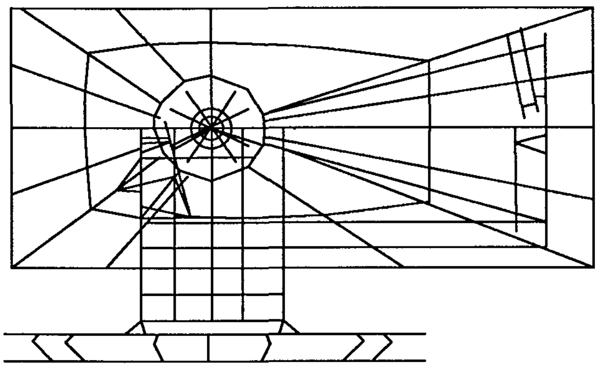
The measured weight of the truss is 18 lb, and the telescope weighs 42 lb.

The measured results come close to the NASTRAN values, while the hand analysis predicts larger deformations. The hand analysis is conservative because it assumes hinged joints with little degrees of fixity, and does not account for the stiffening effects of the truss framework (lower diagonal stabilizer strut). The actual measured deflections include possible joint "looseness," and have a measurement accuracy of $\pm$10%. If we compare the measured versus calculated deflections for axial loading on the aft bulkhead itself, we get:

Calculated axial central deflection of aft bulkhead = 0.000021 in.

Measured axial central deflection of aft bulkhead on truss = 0.000024 in.

The close comparison is undoubtedly due to the inherently stiffer truss properties in the axial direction.



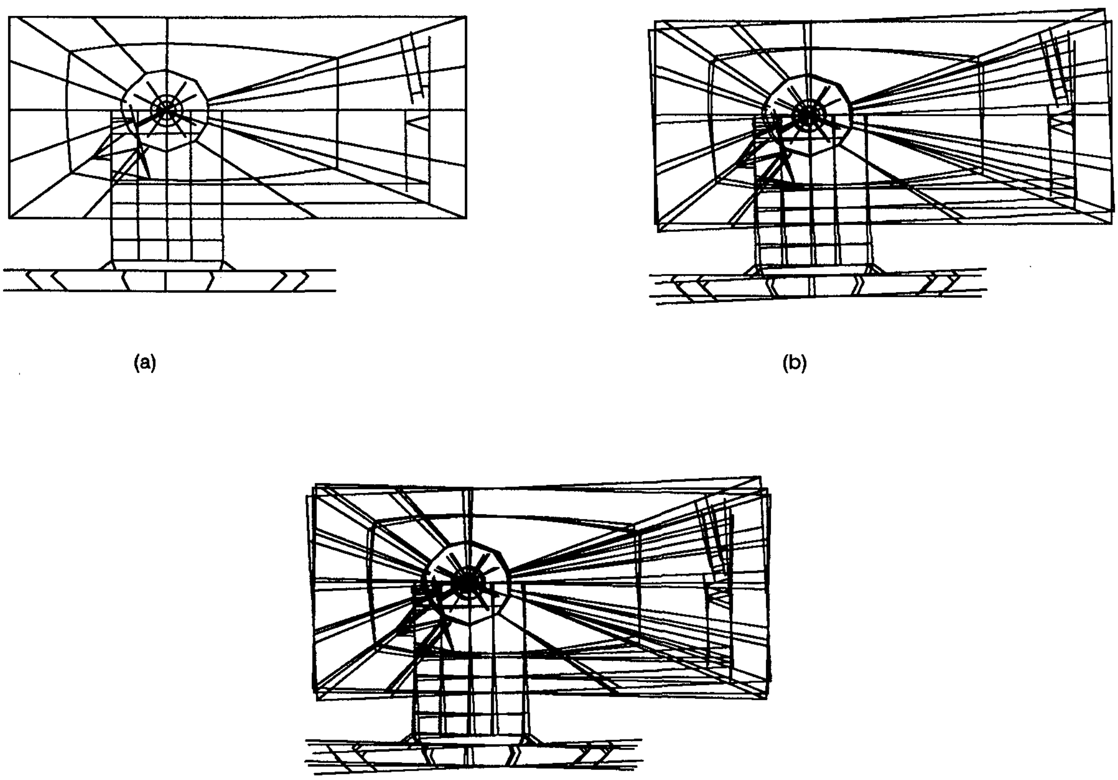
WEIGHT	(lb.)
TELESCOPE	42
ENCLOSURE	20
SUPPORT STAND	305
	367

(a)

FREQUENCY	(Hz)
IMC	1.1, 2.1, 77.0
TELESCOPE (ELEVATION)	79
TELESCOPE (AZIMUTH)	98

(b)

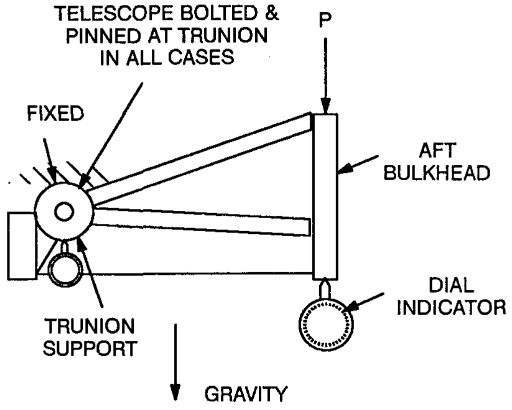
Fig. 3. Results of FEM (a) Summary of weights (lb) and (b) resonant frequencies (Hz).



(a) (b) (c)

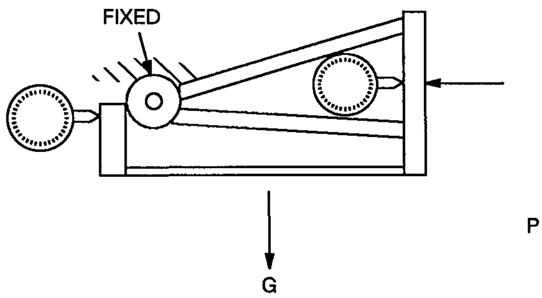
Fig. 4. Results of FEM. The first three mode shapes that occur above the servo bandwidth. (a) 77, (b) 79, and (c) 98 Hz.

LOAD (lb)	DEFLECTION (in)
1	0.0002
2	0.0004
4	0.0008
6	0.0013
8	0.0019
10	0.0021
12	0.0026
14	0.0029
16	0.0034
18	0.0044
20	0.0049
22	0.0054
24	0.0054
26	0.0059
28	0.0062
30	0.0068



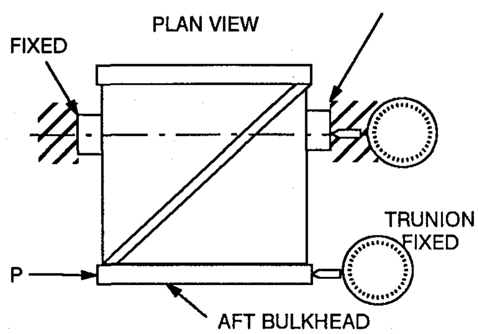
(a)

LOAD (lb)	DEFLECTION (in)
3	0.00000
6	0.00000
8	0.00000
10	0.00003
12	0.00005
15	0.00013
20	0.00018
25	0.00020



(b)

LOAD (lb)	DEFLECTION (in)
3	0.0007
6	0.0014
8	0.0022
10	0.0025
12	0.0030
15	0.0043
16	0.0049
18	0.0056
20	0.0064
22	0.0072
24	0.0079
26	0.0086
28	0.0094
30	0.0099



(c)

Fig. 5. Load deflection measurements. (a) Test 1, (b) Test 2, and (c) Test 3.

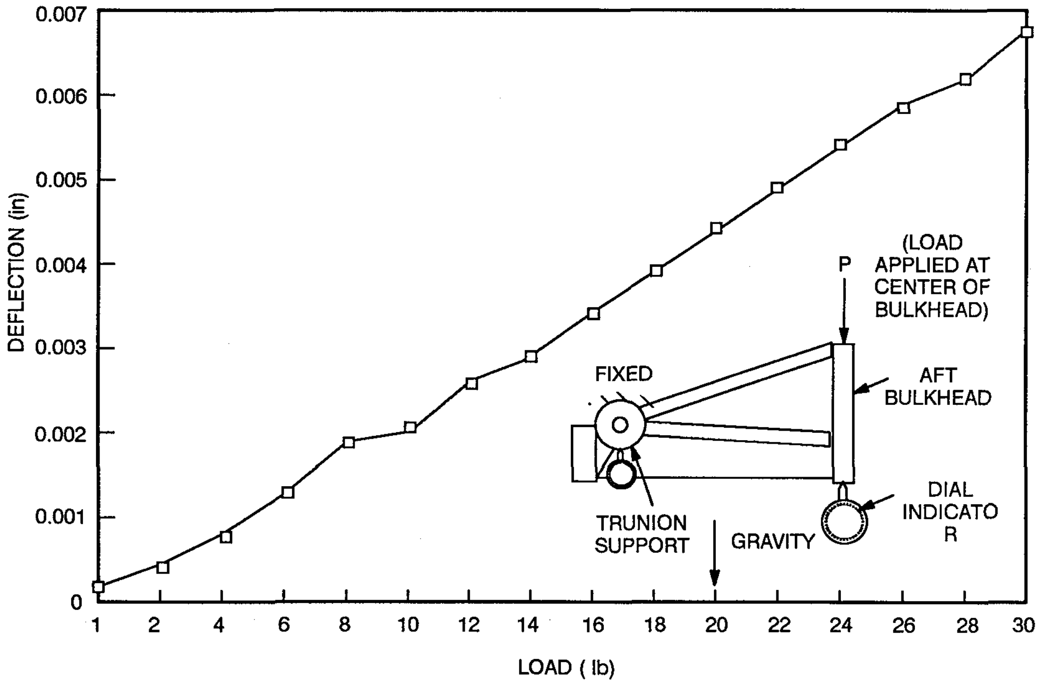


Fig. 6. GTB Test #1 -- load vs deflection.

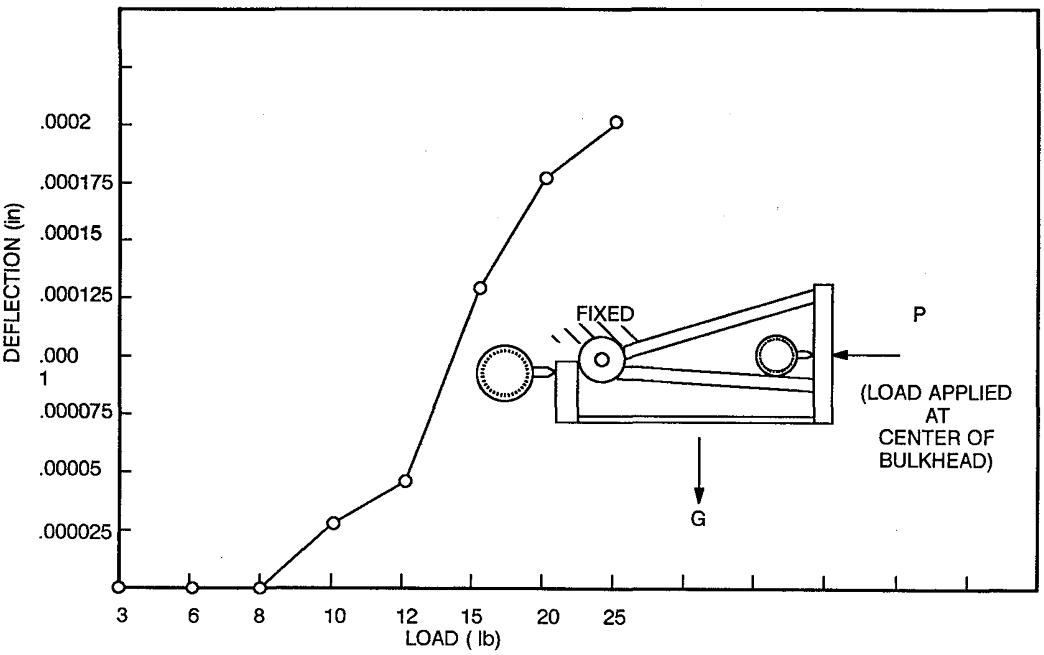


Fig. 7. GTB Test #2 -- load vs deflection.

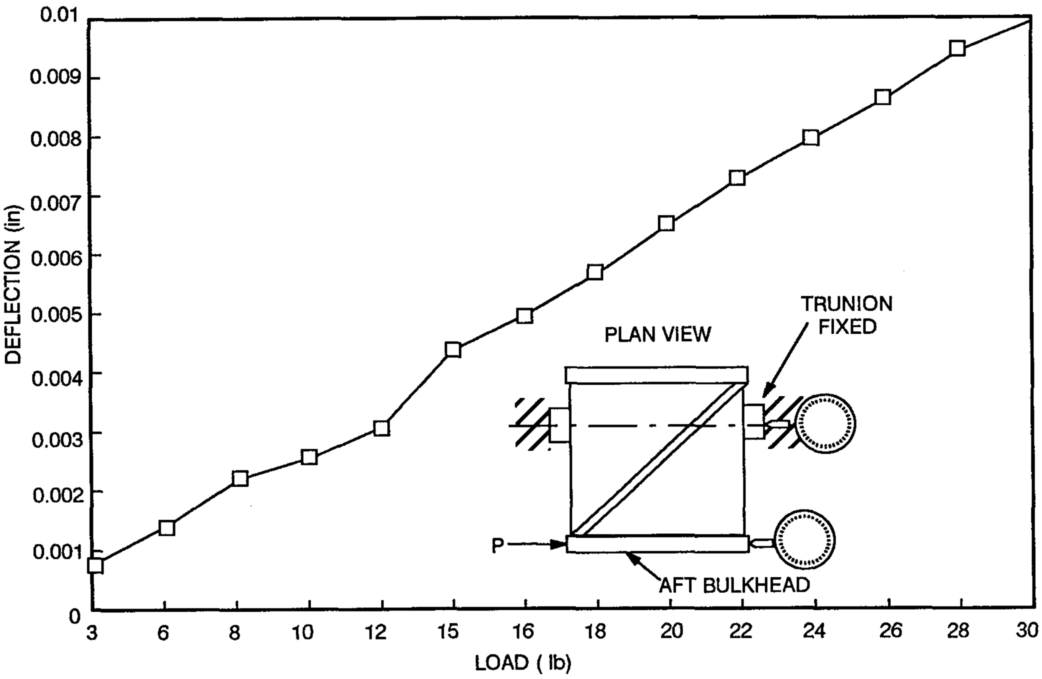


Fig. 8. GTB Test #3 — load vs deflection.

4. SUMMARY

All of the goals for the telescope were met (i.e., resonant frequency, weight, fabrication, and maintenance of optical alignment) and the actual telescope weight was 2 lb below the goal, and actual truss weight, 3 lb under goal.

The goal of having a minimum resonance of 75 Hz was met within 4%; this equivalent is based on the measured deflection. The predicted NASTRAN value of 79 Hz is within 10% of the equivalent value of 72 Hz and is indicative of good fidelity and confidence in the model and in the design of the structure. Structures of this type normally have first resonances of 10% less than design values due to losses in joints.

The challenge of designing and fabricating an ultra lightweight, stiff, all-beryllium telescope worthy of space flight was successfully demonstrated.