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SPACE STATION STRUCTURES AND DYNAMICS TEST PROGRAM

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INTRODUCTION

The design, construction, and operation of a low-earth orbit Space station poses unique challenges for developement and implementation of new technology. The technology arises from the special requirement that the Station be built and constructed to function in a weightless environment, where static loads are minimal and secondary to system dynamics and control problems. One specific challenge confronting NASA is the devopment of a dynamics test program for (1) defining Space Station design requirements, and (2) identifying and charaterizing phenomena affecting the Station's design and developement. A general definition of the Space Station dynamic test program, as proposed by MSFC, forms the subject of this report.

The test proposal, as outlined herein, is a comprehensive structural dynamics program to be launched in support of the Space Station. The test program will help to define the key issues and/or problems inherent to large space structure analysis, design, and testing. Development of a parametric data base and verification of the math models and analytical analysis tools necessary for engineering support of the Station's design, construction, and operation provide the impetus for the dynamics test program. Four test phases are planned:

1) Phase I - Testing of Space Station Applicable Structural Concepts
2) Phase II - Testing of Space Station Prototypes
3) Phase III - Testing of Actual Space Station Structural Hardware
4) Phase IV - On-Orbit Testing of Space Station Construction

The philosopy being to integrate dynamics into the design phase through extensive ground testing and analytical ground simulations of generic systems, prototype elements, and sub-assemblies. On-orbit testing of the Station will also be used to define its capability.

PHASE I - TESTING OF SPACE STATION APPLICABLE STRUCTURAL CONCEPTS

MSFC recognized the need for static and dynamic testing of Large Space Structures applicable to Space Station design at an early stage. The purpose of these tests was to gain insight into the pecularities and requirements of not only the support fixtures, modal excitation, and data acquisition system, but also for the investigation into the static and dynamic behavior of truss structures exhibiting linear and nonlinear characteristics. Tasks have already begun to perform additional testing, modeling, and analyzing of these type structures. Some of the Large Space Structures that have been tested or are in the process of being tested are:

1. 46' Rockwell deployable truss
2. 50'-30" diameter super astromast
3. 20'-30" diameter super astromast
4. SASP truss
5. 16½ meter Grumman beam

46 FOOT ROCKWELL DEPLOYABLE TRUSS TEST - The Rockwell truss is a box structure with telescoping diagonal joints with a housing frame assembly at one end as shown in Fig. 1. The truss has joints at each corner of the 10 bays where the diagonal battens and longerons meet. These joints contain a certain amount of free-play and hence the structures will exhibit nonlinearity with varying stiffness and damping. To reduce the amount of free-play, cables parallel to each of the longerons through each joint can be pretensioned up to 400 pounds each.

A static and dynamic test of this truss has been planned and is currently in progress. The truss will be tested in the horizontal with housing assembly at the free end. The bays will be supported in the vertical such that the loading at the joints will be reduced as much as possible. Static tests will be run laterally, axially, and torsionally. Deflection curves, with incremental loading of the four cables from 0-400 pounds, will be generated to characterize the linearity/nonlinearity of the truss.

After completion of the static tests, a modal survey test will be run to characterize the modes of the truss. Frequencies and damping will be determined for various preloads in the cables and with varying amplitudes to assess the nonlinearity effects. These dynamic tests of the truss will be for both cantilevered and free-free boundary conditions.

20-FOOT 30-INCH DIAMETER SUPER ASTROMAST TEST - The Astro-Research Corporation astromast consists of three continuous glass longerons with glass/epoxy batterns and diagonals. A finite element model of the truss structure and a test setup schematic are shown in Figures 2 and 3. Each end of the truss is attached to a 36-inch thick aluminum plate. The astromast is supported in the vertical by an overhanging beam/plate which is bolted to the top plate of the astromast.

The joint test performed was dynamic, with the truss supported vertically. A single point random testing technique was used to calculate the bending, torsional, and axial modes of vibration. Good agreement between the analysis and test was

INSTRUMENTATION LOCATIONS ON 46–FOOT TRUSS

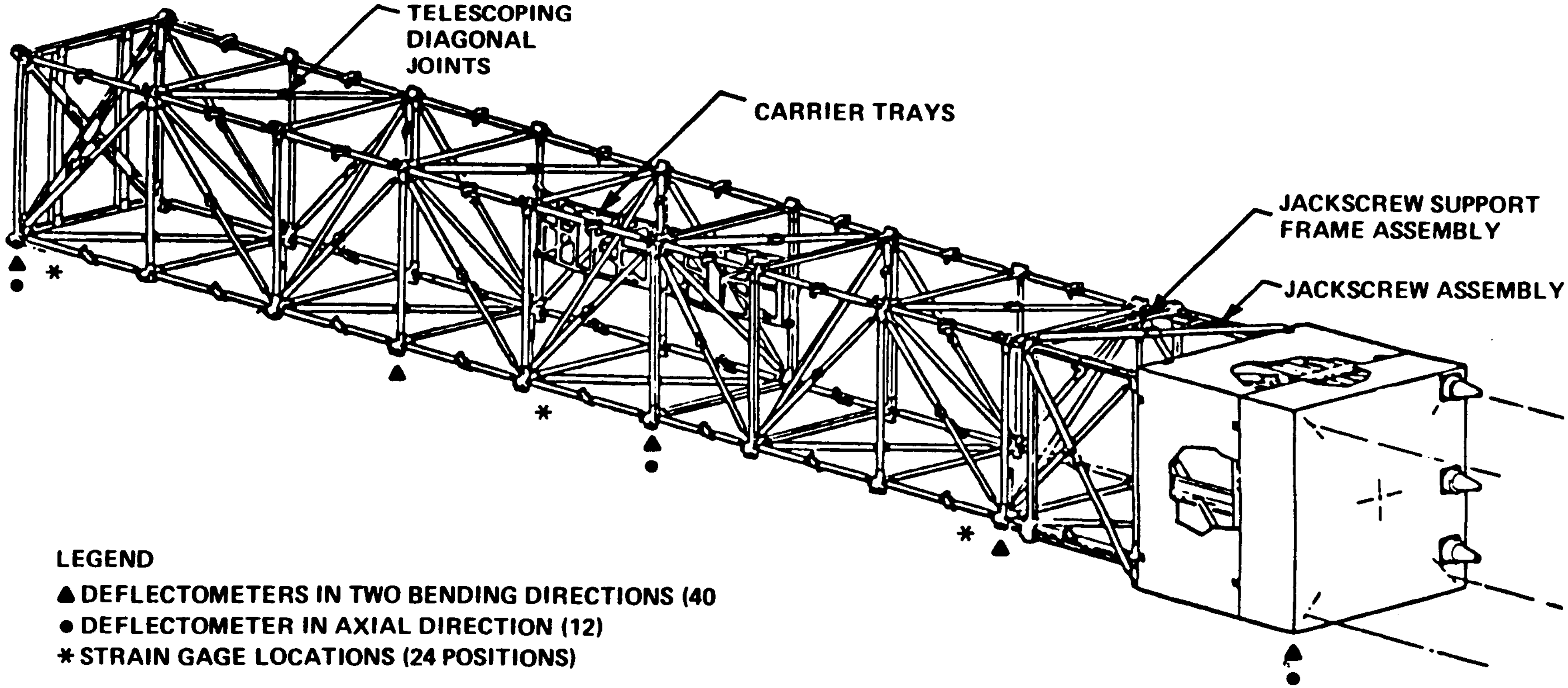

FIGURE 1.

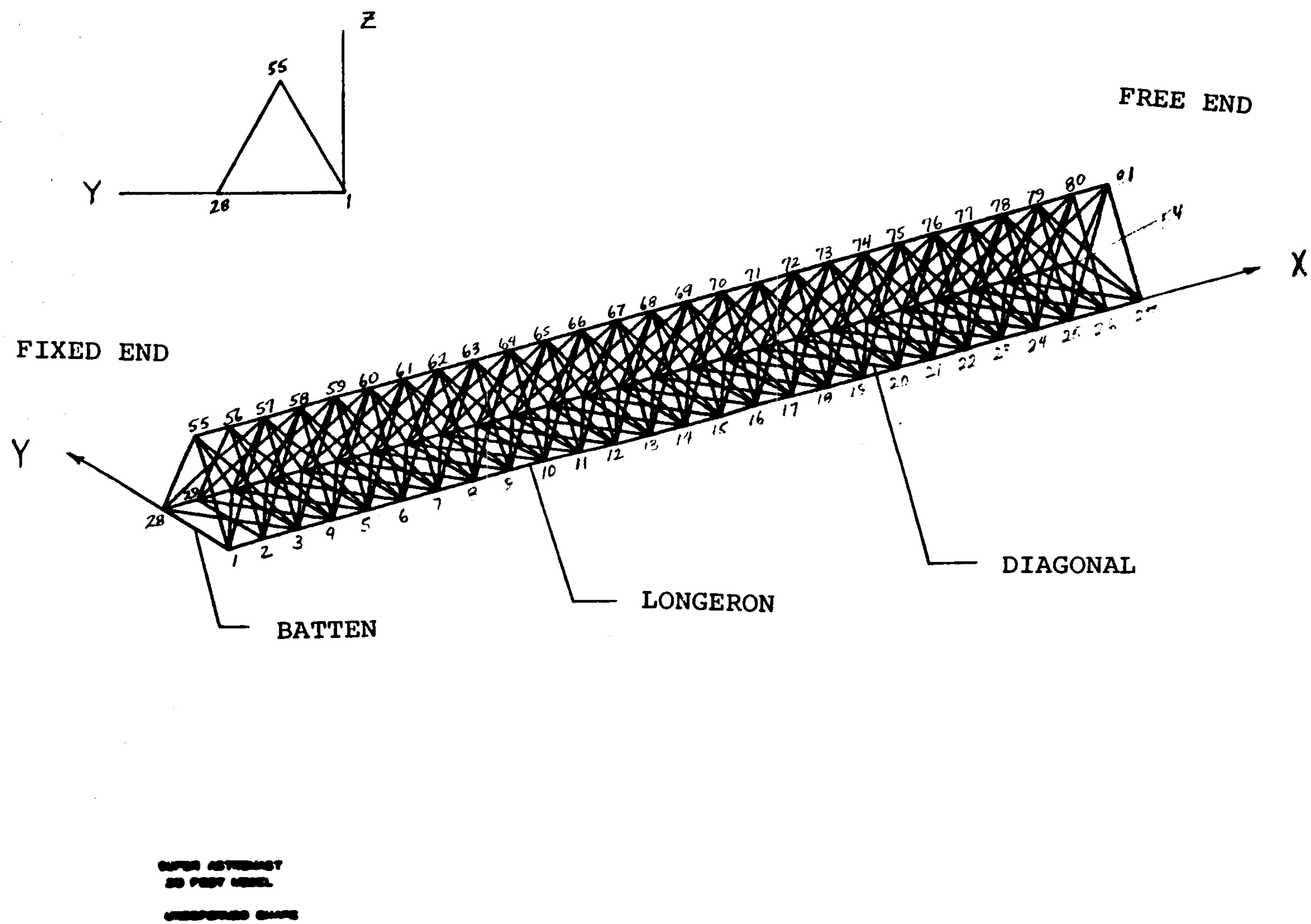

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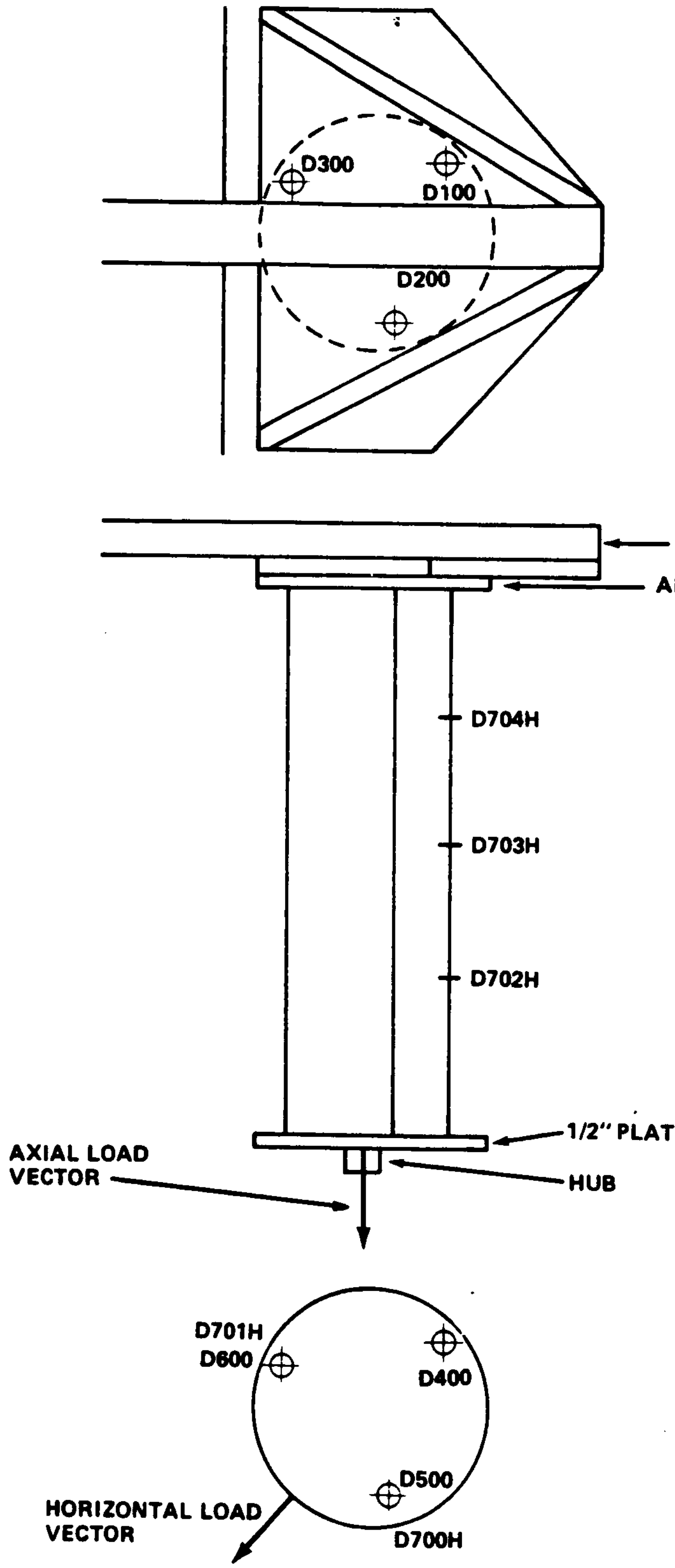
FIG. 2. 20-FOOT SUPER ASTROMAST NASTRAN PLOT

20' SUPER ASTROMAST STATIC TEST SETUP*



*NOT TO SCALE

FIGURE 3 TEST SETUP

obtained except for the axial mode (see Table 1). The predicted frequency of 59.8 Hz did not agree with the test frequency of 37.7 Hz. After considerable analysis and some additional testing, it was found that the 1/2-inch aluminum plate at the free end, where the shaker was attached, had an inplane frequency of 37.7 Hz. As a result, the test personal were unable to shake out the higher first axial mode. A 2-inch plate was subsequently bolted to the 1/2-inch plate and the test was repeated. For this configuration, the first axial mode was easily obtained and compared well with analysis.

The static test followed the dynamic testing. Using the same configurations and boundary conditions, as in the dynamic test, axial and lateral static tests were conducted. For the axial test, loads up to 1200 pounds in increments of 200 pounds were applied in the center of the 1/2-inch plate attached to the free end. Several interesting results arose from this test:

a) The three longerons which ideally carried the total axial load in fact did not. The load in the longerons was also unsymmetric which caused seemingly random deflection patterns as shown in Fig. 4. This was caused by the following factors: 1) bowing of the bottom base plate introduced loads in the diagonals, 2) small off-set c.g. loading of the plate, 3) bending of the truss support beam, and 4) deflections observed between the 1/2-inch aluminum plate and the support beam/plate (A random bolt pattern was used for the attachment of the top plate to the support plate on the beam).

b) Due to the above problems, the stiffness of the longerons were recalculated by determining the load and deflections in each longeron separately. The results are plotted in Fig. 5. Although this technique required additional instrumentation, the findings are conclusive.

For the horizontal test, loads up to 100 pounds were applied in 20- pound increments. The bending of the upper beam support was again a factor and resulted in a 25 percent larger deflection than predicted.

For future testing of truss support structures, having proper boundary conditions and understanding these boundaries is a must. Static tests should always precede dynamics test. It is also recomended that the diagonals and longerons be instrumented with strain gages to better understand the load path.

TABLE 1

20′ SUPER ASTROMAST
DYNAMIC TEST RESULTS VS. ANALYSIS

MODE NO.	TEST FREQUENCY (Hz)	ANALYTICAL FREQUENCY (Hz)	MODE DESCRIPTION
1	3.7	4.2	1ST BENDING
2	3.7	4.2	1ST BENDING
3	12.4	11.5	1ST TORSION
4	25.8	31.6	2ND BENDING
5	25.8	31.6	2ND BENDING
6	38.9	38.3	2ND TORSION
7	37.7*	57.3	1ST AXIAL

*NOTE: FREQUENCY OF PLATE

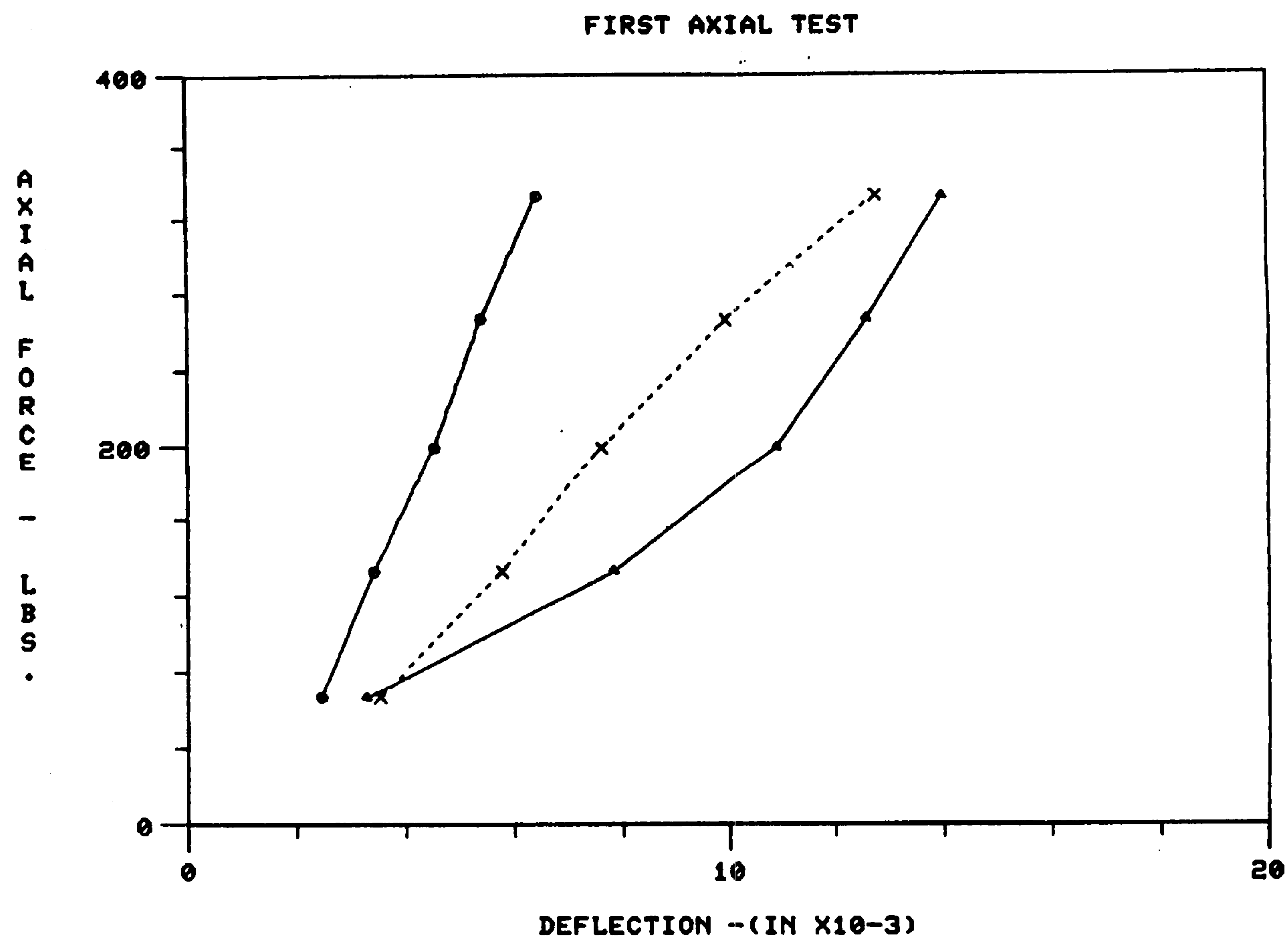


FIG. 4. STATIC FORCE DEFLECTION DATA ASSUMING SYMMETRIC LOADING

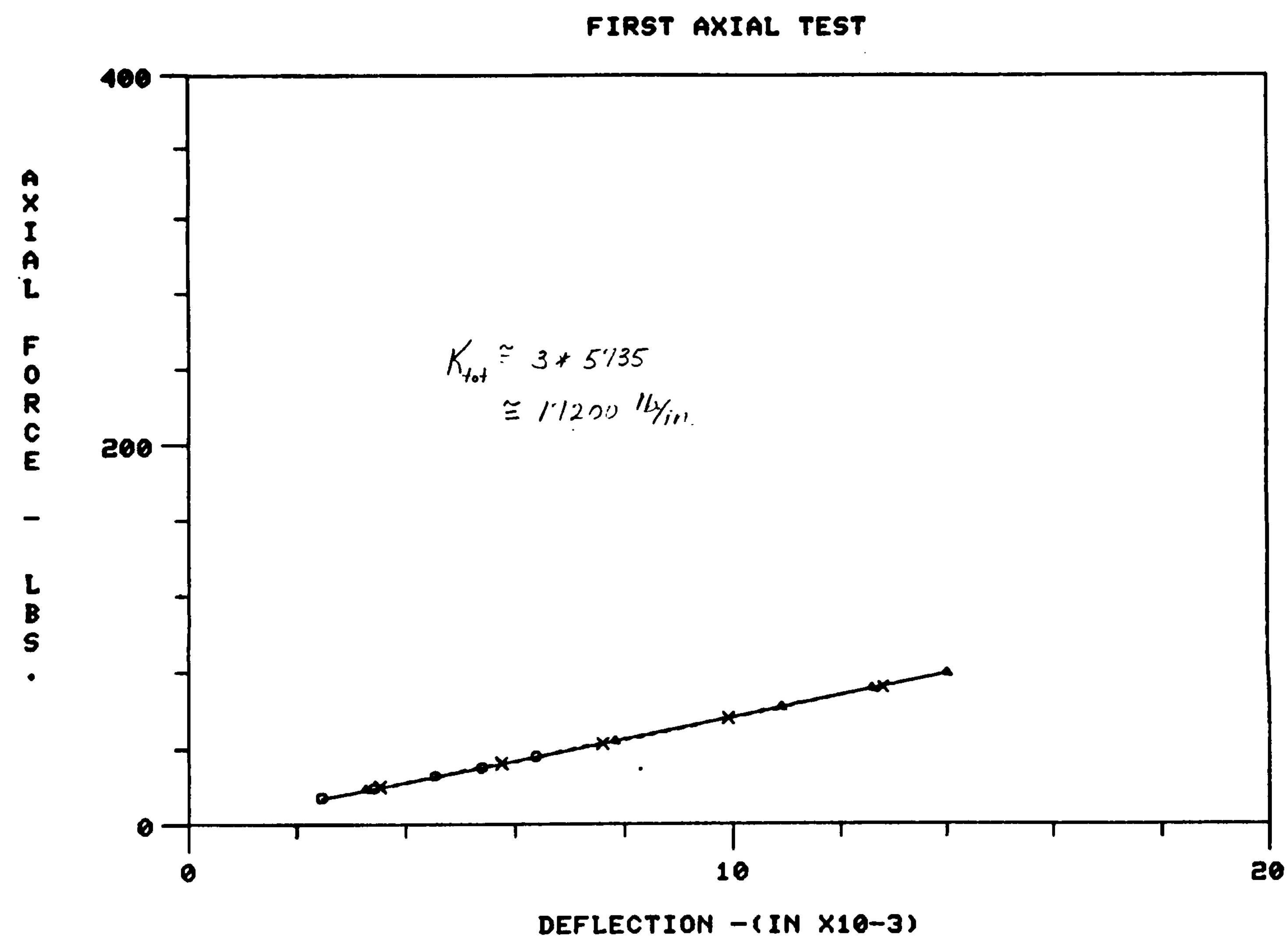


FIG. 5. STATIC FORCE DEFLECTION DATA WITH FORCE CALCULATED FROM STRAIN

PHASE II - TESTING OF SPACE STATION PROTOTYPES

The second phase of the test program will address the structural development and testing of candidate Space Station prototypes and concepts. While Phase I characterized and verified pre-Space Station structures and math modeling techniques, Phase II will characterize specific Space Station structural concepts. For example, the following structural investigation is anticipated.

1) Static and dynamic analysis and testing of Space Station erectable and deployable prototype hardware.

2) Static and dynamic analysis and testing of truss members and joint concepts.

3) Experimental and analytical characterization of the truss member buckling phenomenon.

4) Investigation into the applied usage of composite materials for Space Station joint and truss design.

5) Experimental and analytical simulation of Space Station dynamic events such as construction, payload handling, berthing, docking, etc.

The objectives of the phase two test program are as follows:

1) Continued investigation and characterization of nonlinear phenomena on prototype concepts and hardware. For example, define nonlinear load deflection curves and evaluate the influence of structural preloads on these curves.

2) Characterize the amount and types of damping inherent to these structures and investigate methods of increasing damping.

3) Access the effects of nonlinear stiffness and damping on the systems dynamic response in the zero-g environment.

4) Develop and verify with testing nonlinear dynamic structural math models which are suitable for control system studies and evaluation.

5) Develop and verify isolation systems and mechanisms for the low frequency zero-g environment.

6) Develop and pursue dynamic simulation of construction and other dynamic events, which will be encountered in the Space Station working environment. This ground based analysis and experimental simulation capability will verify procedures and loads and develop potential ground capability for mission support.

7) Develop analysis methods and construction methods for the use of composite materials in truss structure joints and members. (It should be noted that the current state of the art for composite structural analysis is based on the Plane Stress assumption, which is not valid for truss joint design. Also, the nature of truss structures is that they produce large concentrated loads. Current composite material construction methods deal well with distributed loads, but a concentrated loads is at this point in time the Achilles' heel of composites.)

PHASE III - TESTING OF ACTUAL SPACE STATION STRUCTURAL HARDWARE

Hardware verification is Phase III of the Space Station test program. The objective being the characterization of flight hardware, verification of math models, and anomaly identification. Three test classifications are envisioned:

Structural Elements - testing of truss elements, for example, short rods, diagonal rods, and joint clusters.

Truss Subassemblies - testing of one bay of the truss structure, five bays, and power boom/keel intersection.

Large Assemblies - testing of keels/end booms/partial power boom and nested common modules with interface structure.

The verification phase of the test program must proceed in stages, as outlined. Since the truss structure is to be made up of multiple elements of the same design, material stiffness variations are expected. Variations in joint combinations for freeplay will also influence modal stiffness. Detail testing, static and dynamic, of individual structural elements and truss assemblies will provide the database necessary for insuring modal/model predictability of the Space Station configuration.

PHASE IV - ON-ORBIT TESTING OF SPACE STATION CONSTRUCTION

Phase IV of the test program addresses on-orbit verification and control of structural design, space construction, ground based math modeling, growth evolution, and structural damage and deterioation. The Space Station is unique in that it will only be totally assembled on-orbit with no possible ground experimental verification for its zero-g environment.

NASA's experience with on-orbit structural dynamic testing began with SAFE (Solar Array Flight Experiment). This experiment showed a larger than anticipated damping and also demonstrated unexpected thermal effects. NASA's experience with the erection of space structures began with EASE/ACCESS (Experimental Assembly of Structures in Extravehicular Activity/Assembly Concept for Construction of Erectable Space Structures). Although the EASE/ ACCESS mission demonstrated space construction, it did not attempt to do any structural testing. NASA's past experience with on-orbit test and construction points the way for future effort.

The first step in on-orbit testing of Space Station applicable structures is at this time envisioned to be a demonstration of onorbit eractable construction of a 5-meter-square cross section truss beam. The 5-meter construction experiment would be tested on-orbit for its dynamic response in the zero-g environment. This testing would allow determination of the Space Station structural damping and the effects of joints in the zero-g environment.

Successful completion of the large construction and testing experiment would allow the initial construction of the Space Station. On-orbit testing would follow a natural progression at the end of each construction phase of the Space Station. The purpose of these tests will be to verify space structural assembly and assembly techniques, and provied basis for verification and revsion of ground based math models. These verified and revised math models will provide a basis for updated control system software and gains.

An on-orbit structural verification and acceptance test will be performed on the Space Station upon completion of the main structural assembly. This testing will be performed prior to the addition of payloads. Also, as the Space Station grows there will be continued on-orbit structural dynamic testing to verify the system capability and to access structural damage over the life of the station. This continued testing will allow verification and update of ground based math models and revision of control systems.