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STRUCTURAL DEFORMATIONS IN THE  
SATURN INSTRUMENT UNIT

By Larry A. Kiefling  
Aero-Astroynamics Laboratory

NASA

*George C. Marshall  
Space Flight Center,  
Huntsville, Alabama*

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STRUCTURAL DEFORMATIONS IN THE SATURN INSTRUMENT UNIT

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Larry A. Kiefling

George C. Marshall Space Flight Center

Huntsville, Alabama

ABSTRACT

During the Saturn V dynamic test, local deformations of significant amplitude were measured at the flight sensor locations in the instrument unit. These local deformations were previously thought to be negligible. The cause is identified as a radial force component at the joint of the LM adapter cone and the instrument unit cylindrical shell due to the axial resultants from the bending moment. The deformation patterns for a shell analysis of the structure are shown. The local deformation is found to be proportional to the bending moment only and the proportionality constant is determined for three instrument locations. Typical amplitudes for Saturn V modes and a selection of points from the Saturn IB dynamic test program are presented.

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STRUCTURAL DYNAMICS SECTION  
DYNAMICS ANALYSIS BRANCH  
DYNAMICS AND FLIGHT MECHANICS DIVISION  
AERO-ASTRODYNAMICS LABORATORY  
RESEARCH AND DEVELOPMENT OPERATIONS

## TECHNICAL MEMORANDUM X-53673

### STRUCTURAL DEFORMATIONS IN THE SATURN INSTRUMENT UNIT

#### SUMMARY

The local deformations at the instrument unit measured during the Saturn V dynamic test are found to be proportional to the bending moment. Shear has no effect. The deformation is due to radial force components of the axial stress which carry the bending moment at the joint between the LM adapter cone and the instrument unit cylindrical shell. The proportionality constants for the deformations at the top and bottom halves of the EDS cold plate for pitch vibration and at the ST-124 stable platform for yaw vibration are derived from plots of the test data. The amplitude of the local deformation is shown to be comparable to that of the bending deflections for the Saturn V modes. The data points from the Saturn IB test program indicate that the same local deflection phenomena occur for that vehicle.

#### I. INTRODUCTION

The Saturn launch vehicles depend on a thrust vector control system for attitude control. Position and rate signals come from sensors located in the instrument unit. Since the sensors measure the total motion at their mounting point, their output signal is the total due to vehicle rigid body motion plus overall vehicle vibration modes plus local deformations. Filter systems, designed from analytical bending mode predictions, are usually needed to prevent structural feedback instability of the bending modes. The Saturn V dynamic test program verified the accuracy of the analytical methods used to calculate the overall bending modes, but the local deformations, which were previously thought to be negligible, were found to be significant. This report presents the local deformations which were measured, explains the cause, and provides the data needed to predict local deformations for the flight vehicles.

## II. DISCUSSION

Locations of the instrumentation are shown in figure 1. During pitch excitation, the ST-124 is on the neutral axis, and the EDS gyro cold plate is on the axis of motion. At the beginning of testing, gyro measurements were made at the following locations:

- (1) Top of ST-124 stable platform.
- (2) Wall bracket above ST-124.
- (3) EDS flight rate gyro location (Box A in figure 1), values are referred to as "top half of plate" in text.
- (4) Location "C" on EDS cold plate, a test backup instrument.

Later, a decision was made to locate the flight EDS rate gyro at point "B." No significant differences in the pitch rate reading of locations "B" and "C" were observed. The measurements at these points will be used interchangeably in the text and referred to as "bottom-half-plate" values. Notice that the cold plate is mounted at five points.

The gyro readings at the ST-124 wall bracket locations were in close agreement with the centerline slopes. The measurements at the EDS gyro location differed significantly from the centerline values, and the measurements on the bottom half of the cold plate also differed, but to a lesser extent. Since the differences did not appear to be frequency-dependent, a quasi-static cause was sought.

Two causes seemed possible: the shear and bending moment loads applied to the instrument unit by the payload. The shear and moment loads required to produce a unit local deflection at the top half of the plate were calculated for three modes at three time points for the first stage vehicle (see figure 2). The local deformation is found to be a function of bending moment only.

The mechanism of the deformation is shown in figure 3. The bending moment is carried by compressive stresses on one side of the neutral axis and tensile stresses on the opposite side. These stresses are proportional to the distance from the neutral axis. The stresses on a segment of wall will produce forces  $F_c$  and  $F_t$  acting on the top of the instrument unit with each of these forces having components  $F_a$  and  $F_r$ . The radial component causes a local deformation in the instrument unit and SLA wall. The bending shear is carried primarily by the shell near the neutral axis and produces no effect at the EDS gyro location.

A preliminary calculation of the local deformation is shown in figure 4. Centerline and wall deformations were found from a shell analysis (reference 1). The complex curvature at the top of the IU is caused by the stiffening ring at this location. The locations of a rigid EDS cold plate rigidly attached at the four corner mountings and a cold plate hinged in the middle are shown as datum configurations. The local deflections derived from this approximate preliminary analysis are from two to four times too large due to the simplifying assumptions made.

Bending moments were calculated from a curve fit of the experimental mode shapes and the mass distribution. Moment values are given in reference 2. The equation for the bending moment,  $M$ , is

$$M = \sum m' y \tilde{x},$$

where  $m'$  is the lumped mass,  $y$  is the modal deflection, and  $\tilde{x}$  is the distance from the mass point to the top of the instrument unit. The summation is taken for all mass points above the instrument unit. The sign convection is shown in figure 5. For the mode shown,  $y''$  is always positive and hence the moment is positive also. The centerline slope is positive, and the measured slope is also positive and larger than the centerline slope; therefore, the local angular deflection,  $\Delta\phi$ , is also positive. All modes were normalized for a positive bending moment, but the test amplitude was used.

Local deflections at the top half of the cold plate measured during the Saturn V dynamic test are plotted in figure 6 as a function of bending moment. The local deflection is taken as the difference between the gyro readings at the top half of the EDS cold plate and at the ST-124. The use of the difference of two values as a variable tends to cause some scatter in the data. A line has been drawn through the configuration I data. (Configuration I is a simulation of the vehicle during S-IC stage burn and configuration II a simulation of the S-II burn.) The constant is slightly different from that given in figure 2 since the first mode values, with the greater moments, are emphasized in figure 6. Slope data were taken from references 3 and 4. The local angular deflections at the bottom half of the cold plate are shown in figure 7. Scatter of the data is more evident at the larger scale used in this figure. The local deformation at the bottom half of the EDS cold plate are about a third of those at the top half.

Local deflections for other dynamic tests of Saturn V and uprated Saturn I vehicles are shown in figure 8, along with the curves from the previous two figures. During the first test on the Saturn V, large local effects were found. Since the EDS cold plate was found to be loose, the test was rerun. The same condition may have occurred during the SA-202D first stage tests since the point fell near the same curve. The SA-202D second stage and SA-500D third stage results indicate that the cold plate was properly mounted. The bottom-half-plate values were plotted for the SA-500D third stage since reading for the top half plate gyro appeared bad. Data for the uprated Saturn I was taken from references 5 through 11.

For yaw vibrations, a similar local effect occurs at the ST-124. Values measured during the Saturn V dynamic test are shown in figure 9.

The significance of the local deformations during pitch vibrations can be seen in figures 10 through 13 (see reference 12 for analysis values for these plots). The local deformations are obviously of significant amplitude when compared to the total deflection.

#### CONCLUSIONS

A local deformation, proportional to the modal bending moment, has been shown to exist in the Saturn instrument unit. Values for the proportionality constant are listed below.

| <u>Point</u>           | <u>Bending Direction</u> | <u>Constant (rad/lb-in)</u> | <u>Constant (rad/N-m)</u> |
|------------------------|--------------------------|-----------------------------|---------------------------|
| EDS Cold Plate, Top    | pitch                    | .32 x 10 <sup>-10</sup>     | .28 x 10 <sup>-11</sup>   |
| EDS Cold Plate, Bottom | pitch                    | .96 x 10 <sup>-10</sup>     | .85 x 10 <sup>-11</sup>   |
| ST-124 Stable Platform | Yaw                      | .62 x 10 <sup>-10</sup>     | .55 x 10 <sup>-11</sup>   |

Because the local deformations for most of the modes are of a significant amplitude, they must be included in calculations of modal data for design purposes.

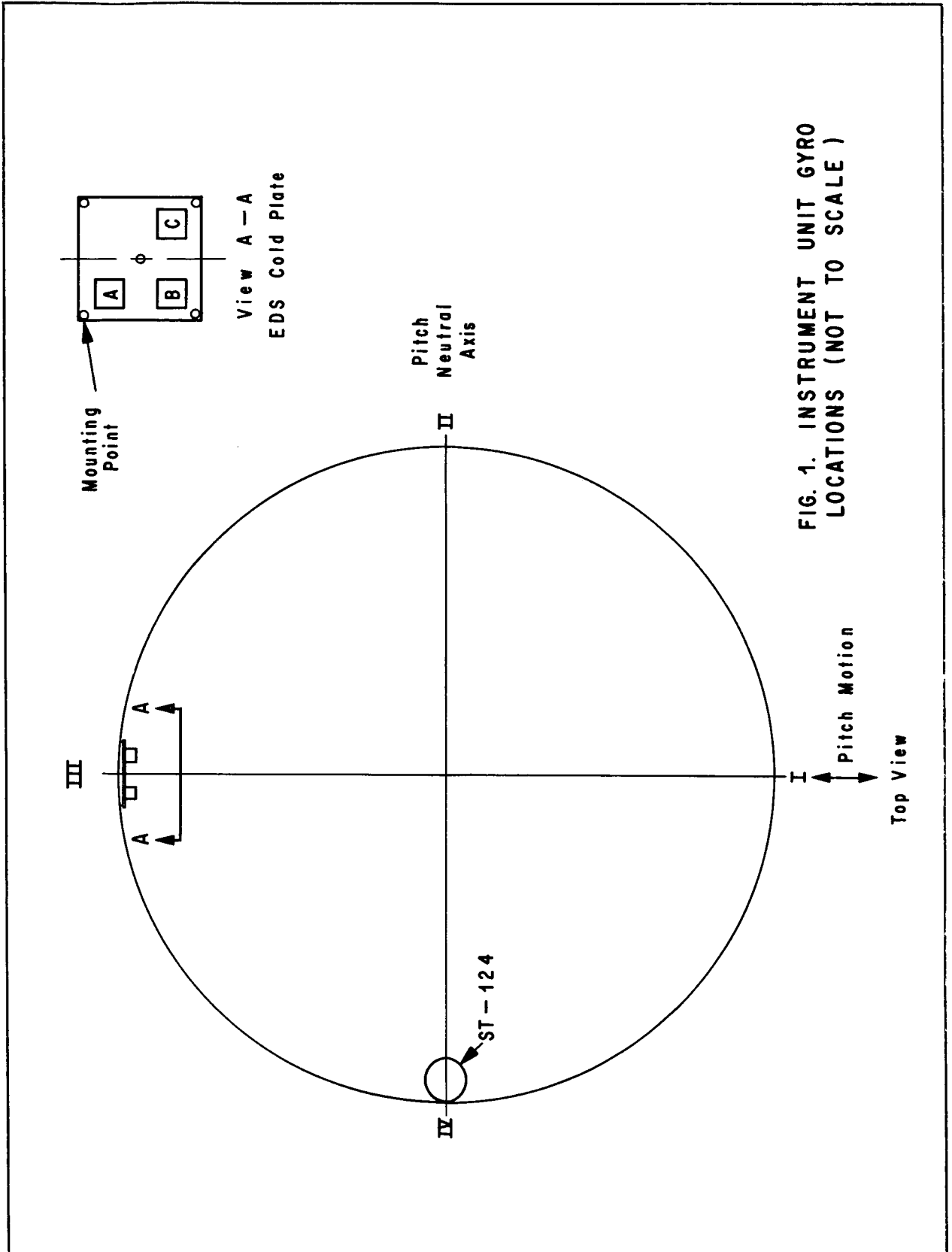


FIG. 1. INSTRUMENT UNIT GYRO LOCATIONS (NOT TO SCALE)



Shear ( $10^7$  lb.)

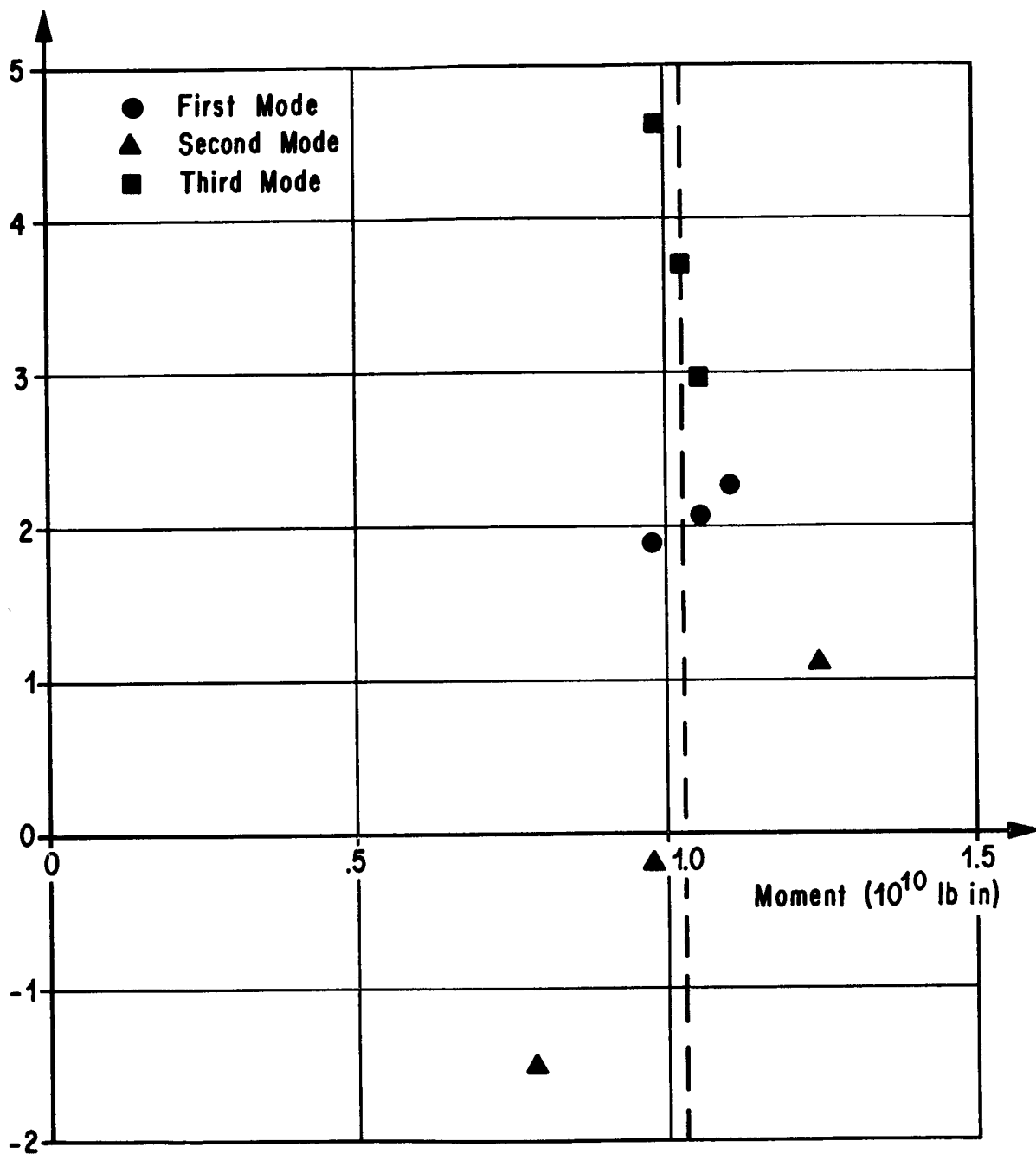
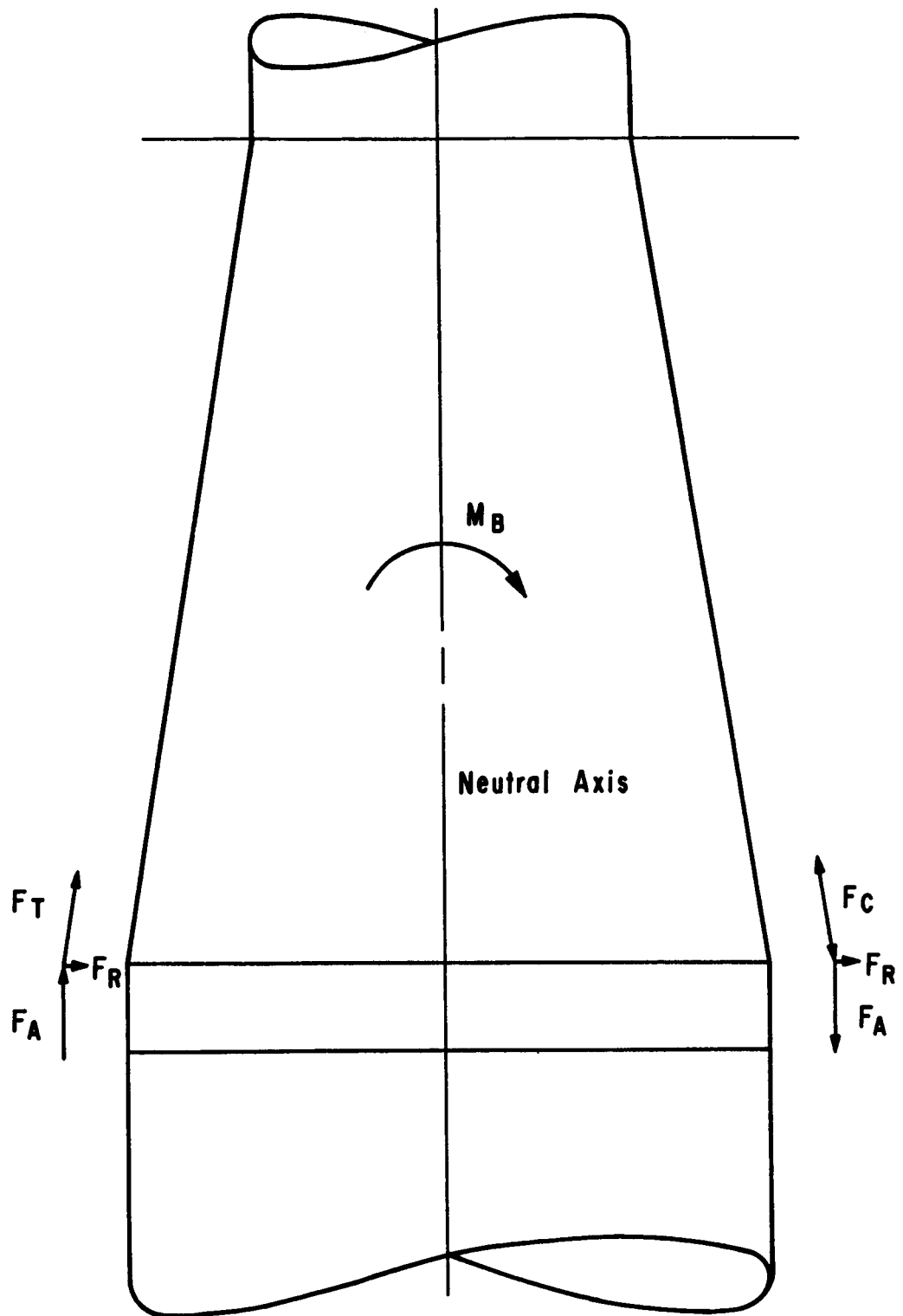
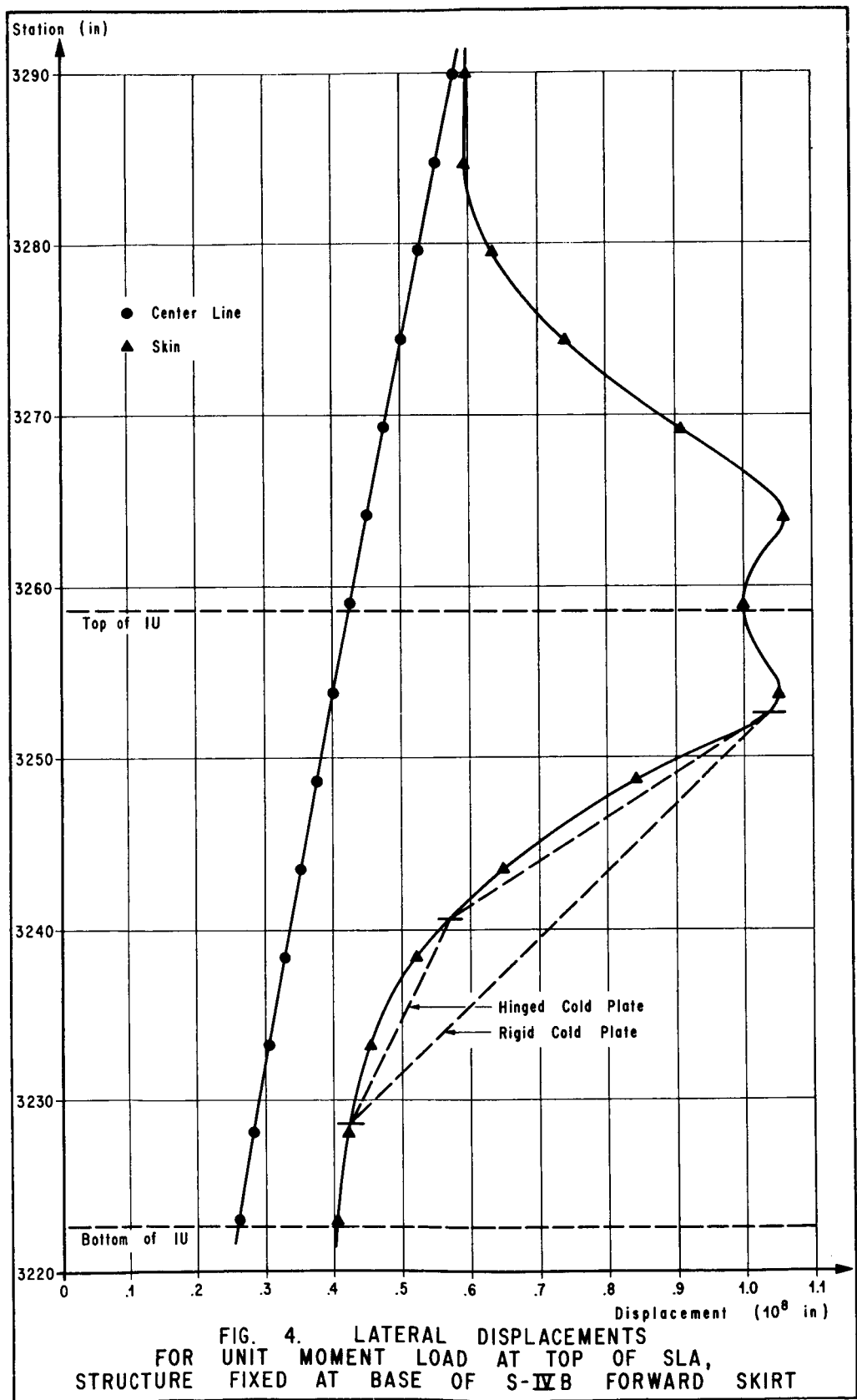
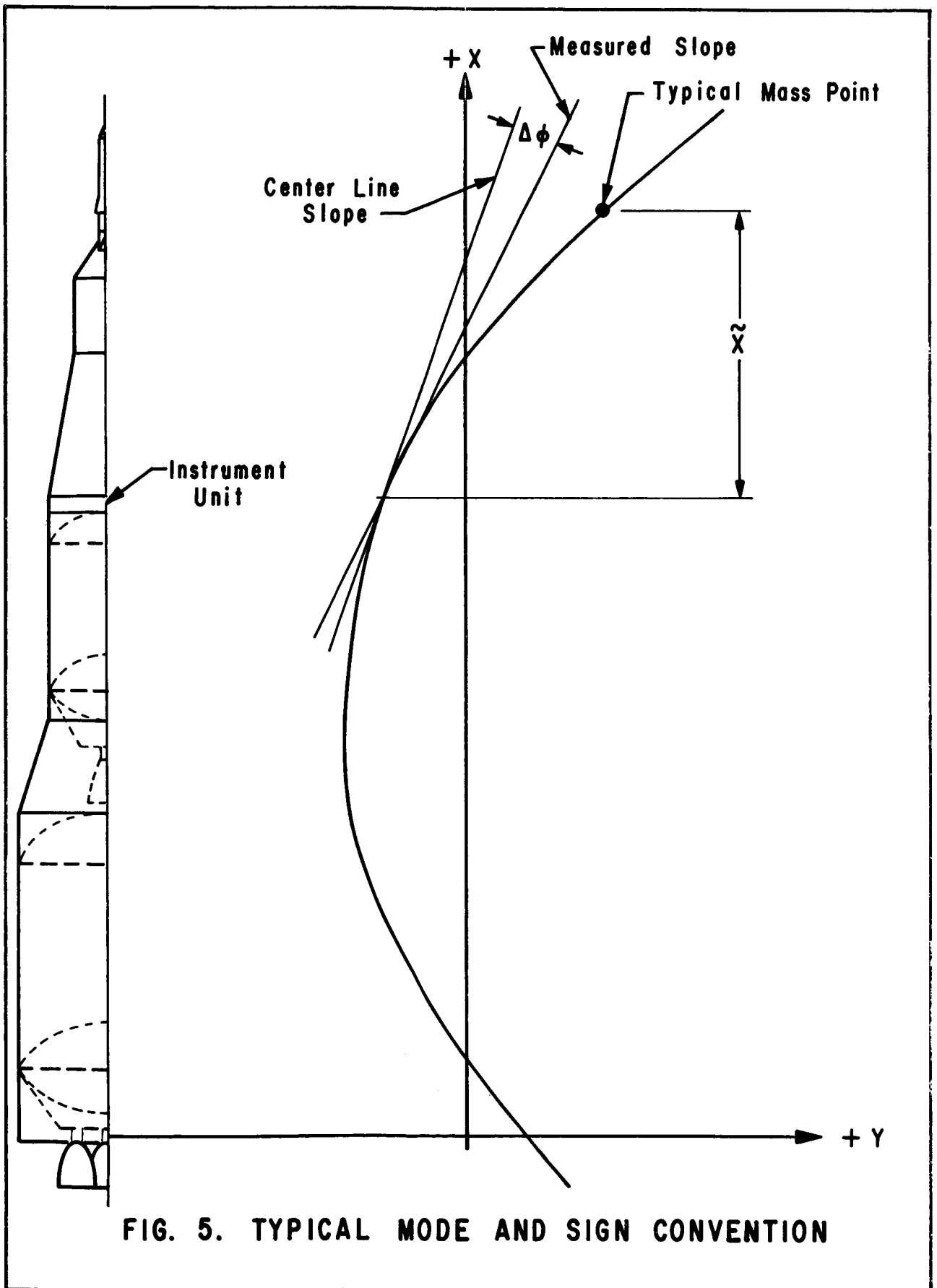


FIG. 2. SHEAR AND MOMENT FOR UNIT LOCAL DEFORMATION AT UPPER HALF OF EDS COLD PLATE SATURN V FIRST STAGE



**FIG. 3. COMPONENT FORCES ACTING ON TOP OF INSTRUMENT UNIT DUE TO MOMENT LOAD**





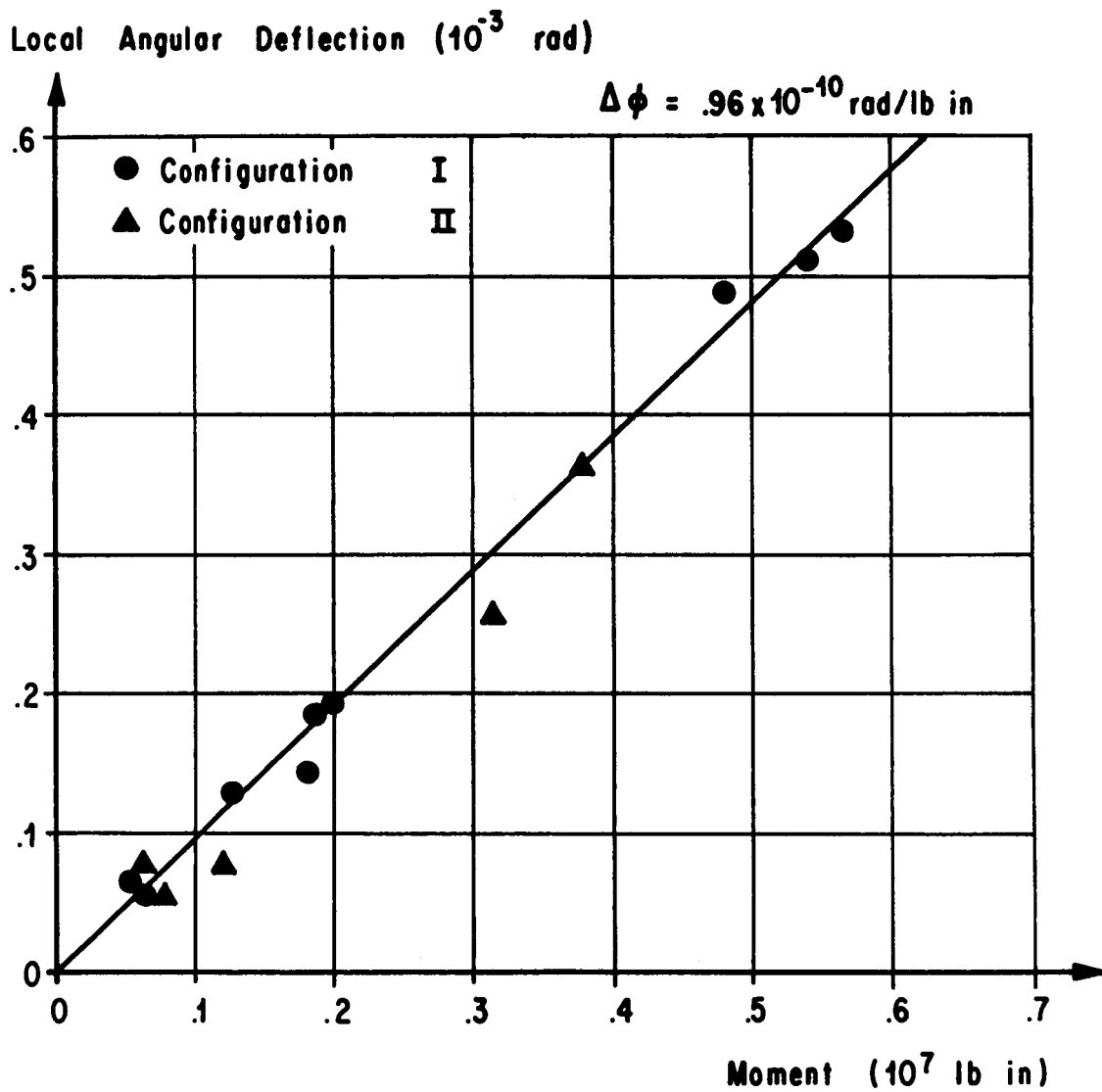


FIG. 6. LOCAL DEFLECTION AT UPPER HALF PLATE AS A FUNCTION OF BENDING MOMENT

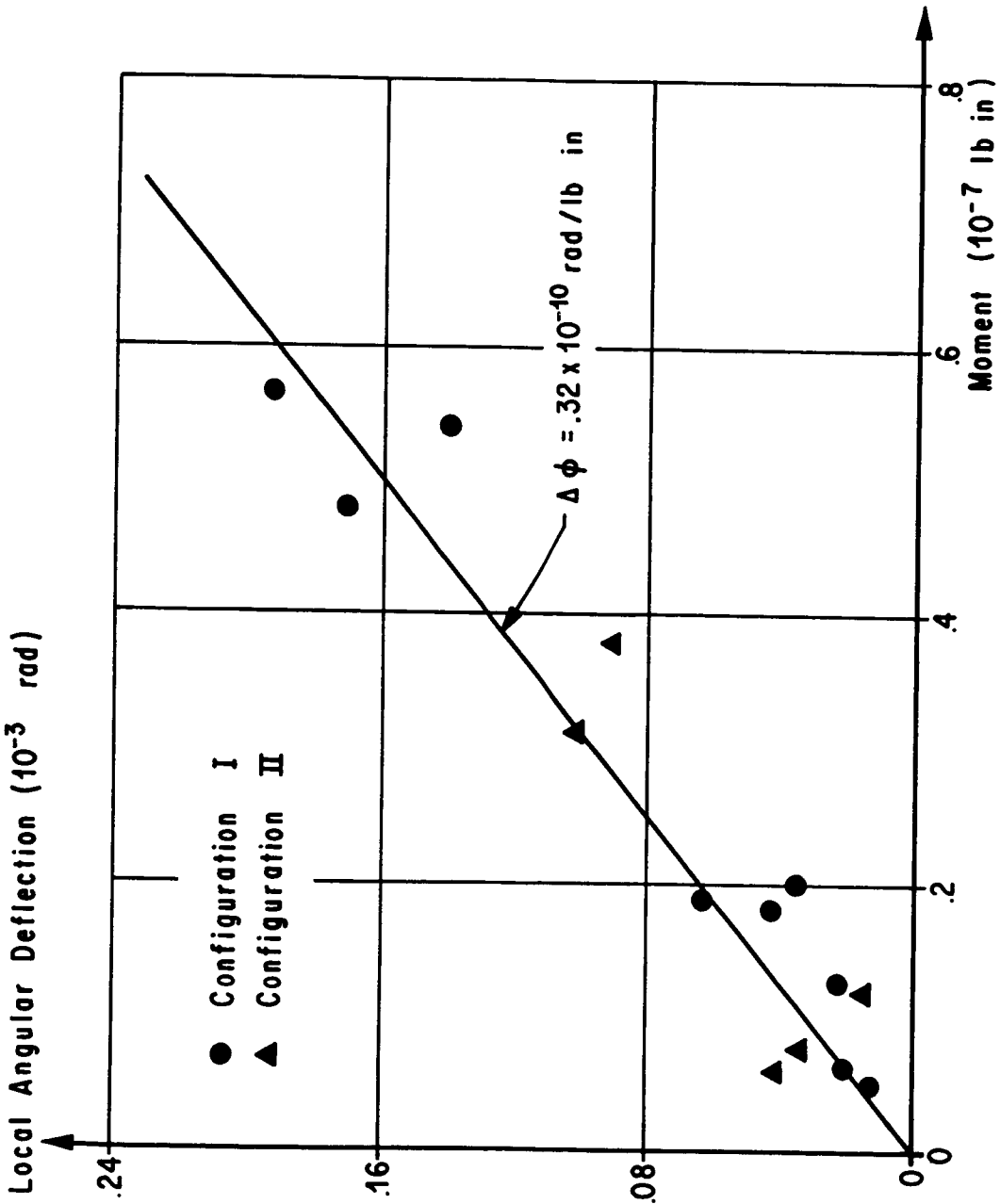


FIG. 7. LOCAL DEFLECTION AT BOTTOM HALF PLATE  
VERSUS BENDING MOMENT

- Saturn V, T.P.2., First Test With Loose Cold Plate
- ▲ SA-202D, T=147
- SA-202D, Second Stage
- ◆ SA-500D, Third Stage (Bottom Half Plate)

Local Angular Deflection ( $10^{-3}$  rad)

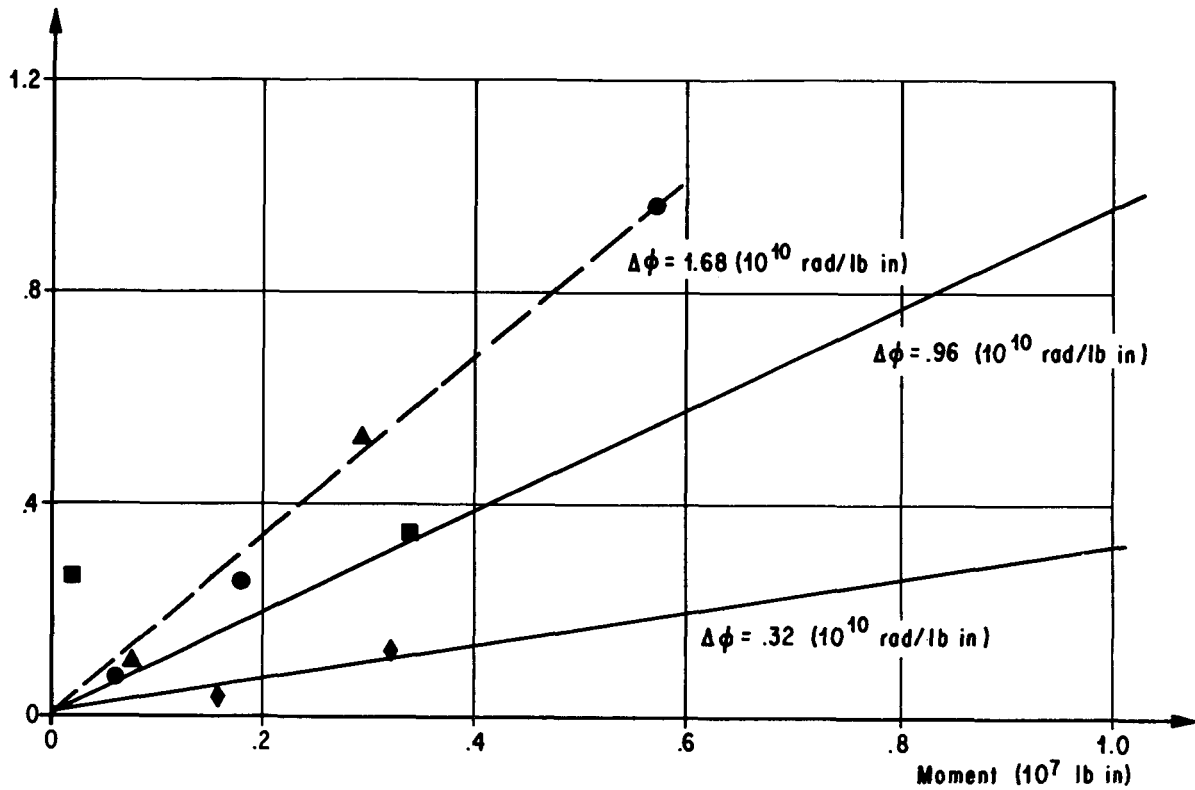


FIG. 8 LOCAL DEFLECTIONS FOR OTHER TESTS

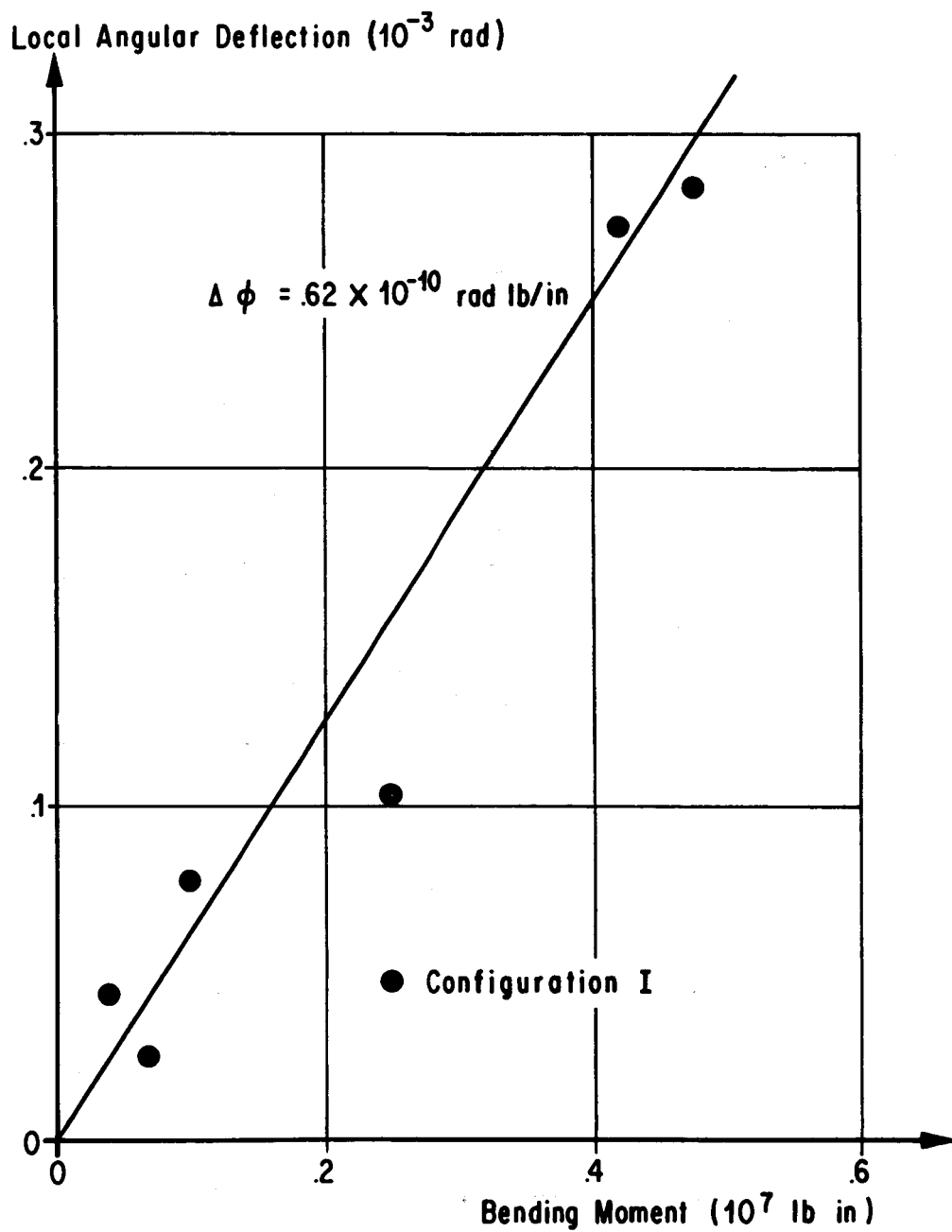


FIG. 9. LOCAL DEFLECTION AT ST-124 DURING YAW TEST



Slope ( $10^{-3}$  rad / in.)

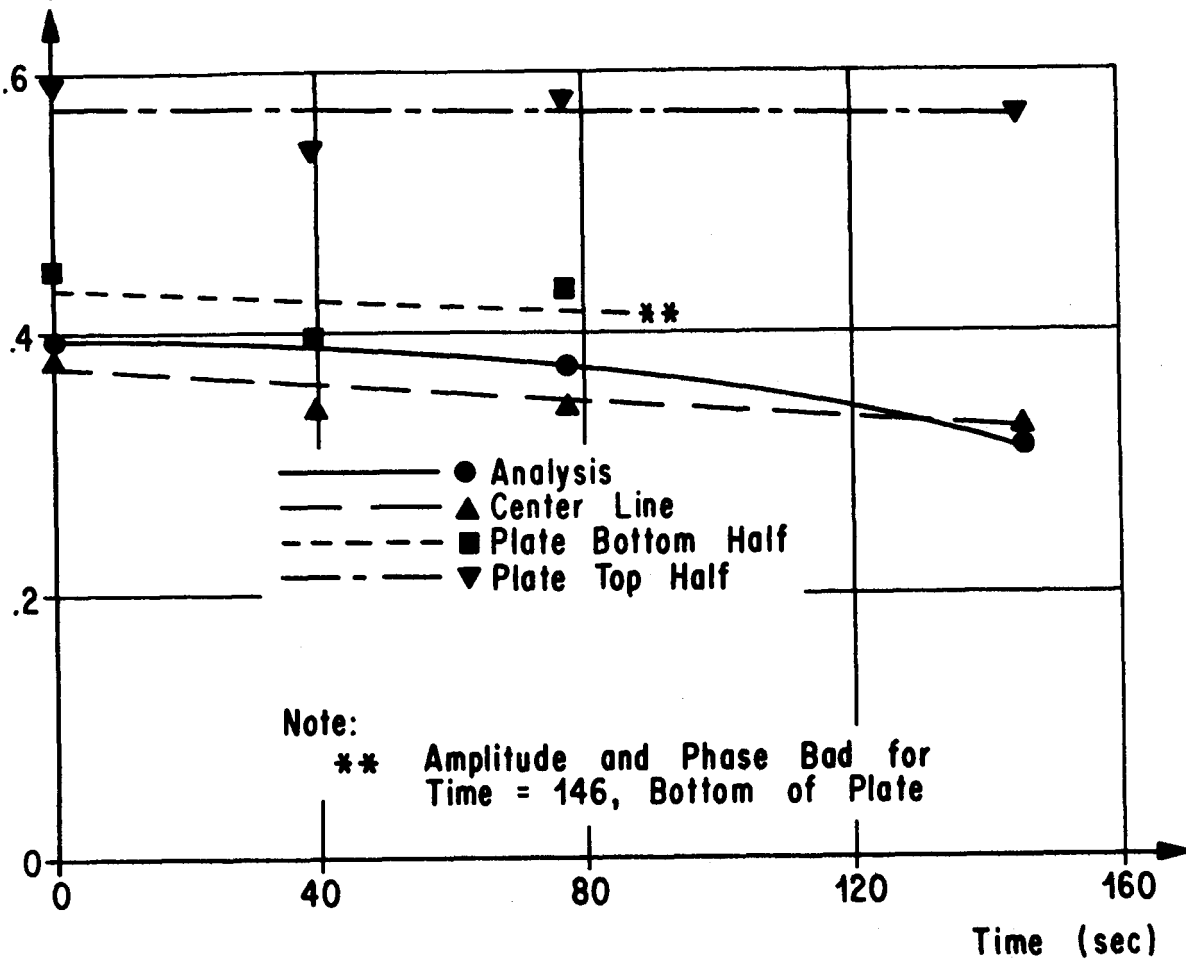


FIG. 10. INSTRUMENT UNIT SLOPES  
(FIRST MODE, DTV) VS FLIGHT TIME

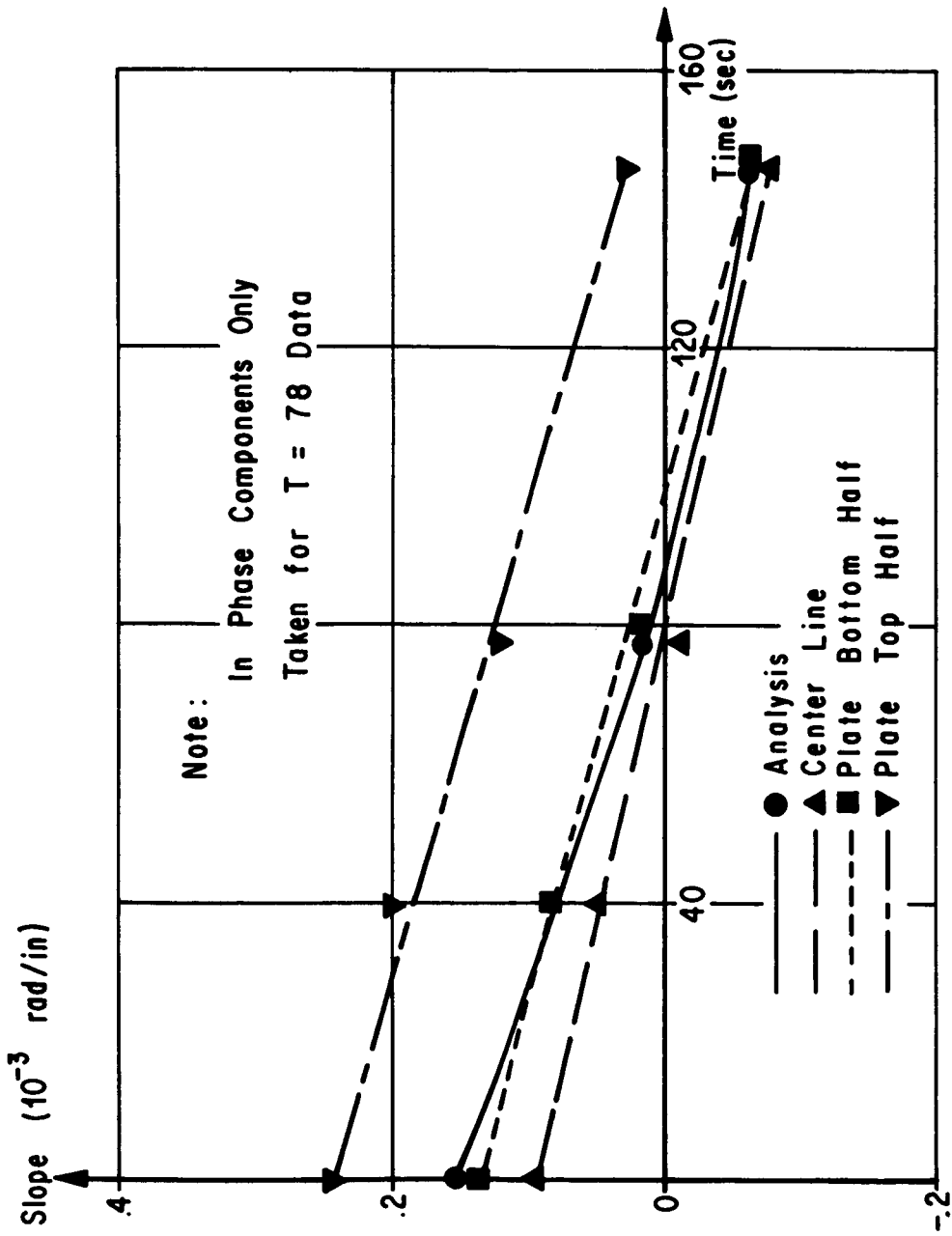


FIG. 11. INSTRUMENT UNIT SLOPES  
(SECOND MODE, DTV) VS FLIGHT TIME

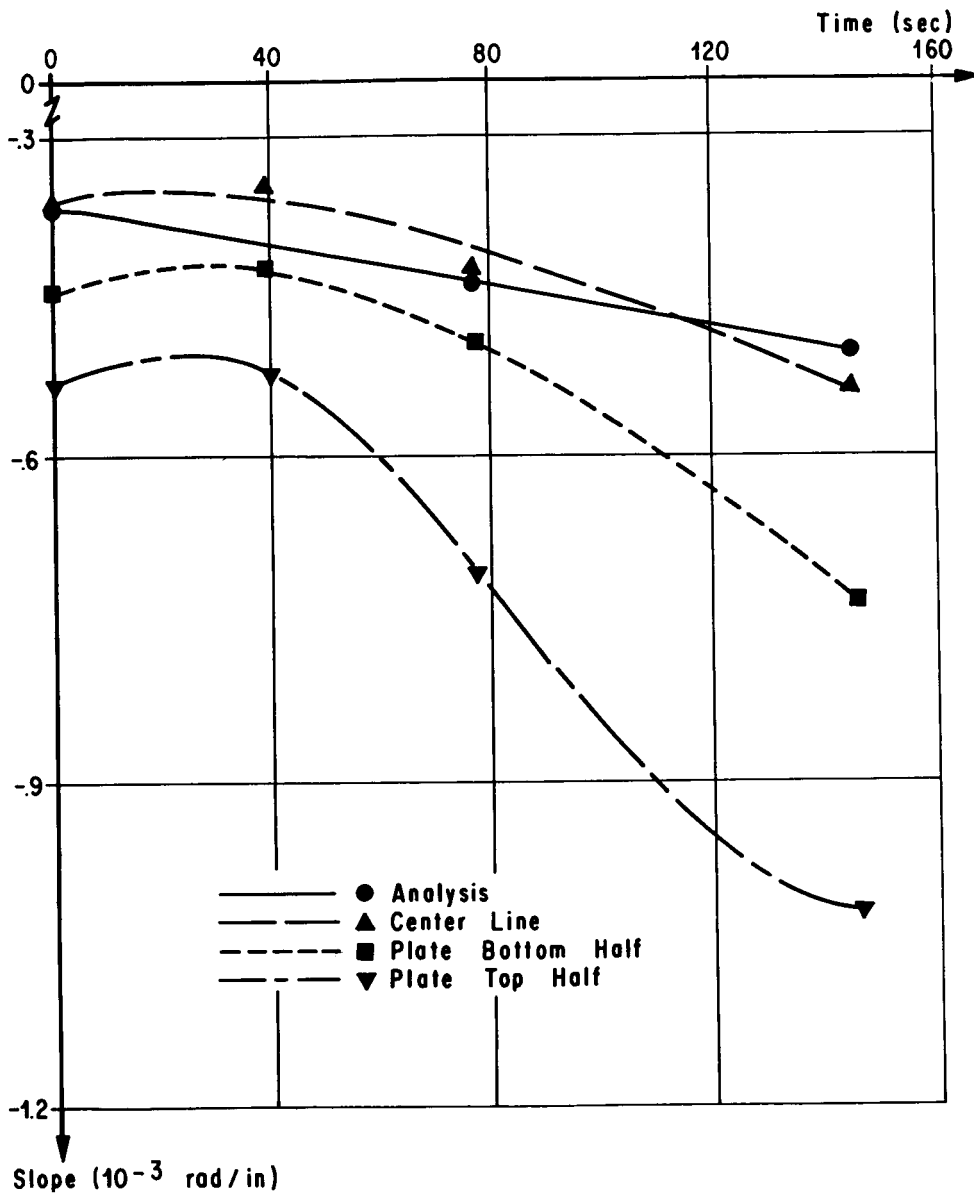


FIG. 12. INSTRUMENT UNIT SLOPES  
(THIRD MODE, DTV) VS FLIGHT TIME

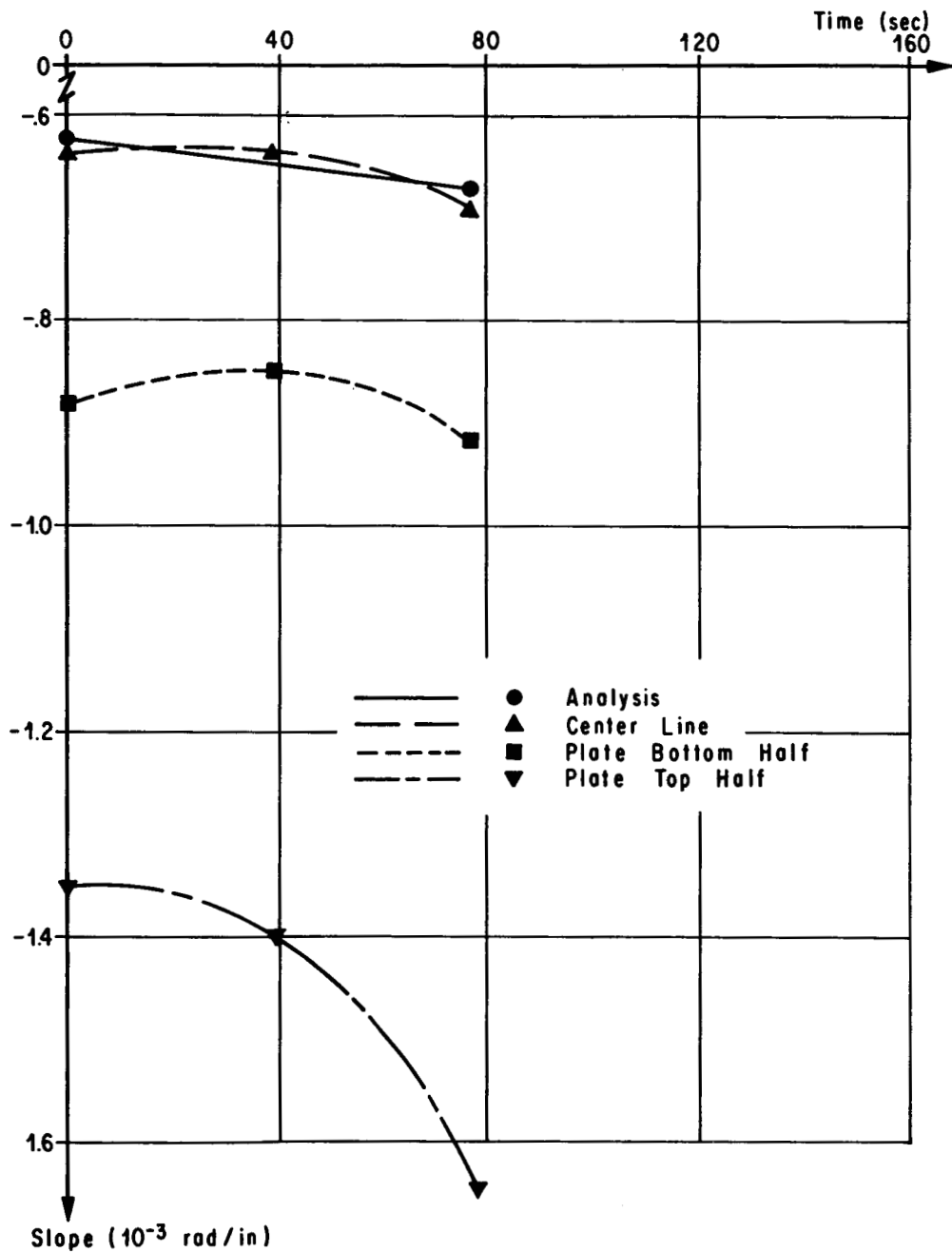


FIG. 13. INSTRUMENT UNIT SLOPES  
(FOURTH MODE, DTV) VS FLIGHT TIME

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6. Chrysler Report, "Transfer Function Report (SA-202 Vehicle, Pitch at 147 Seconds)," Report No. HSM-R607.
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11. Chrysler Report, "Transfer Function Report (Second S-IVB-D, I.U., and Payload Configuration, Pitch at Cutoff)," Report No. HSM-R667.

ERRATA

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## ERRATA

### 1. Page 3

Equation should read:

$$M = \omega^2 \sum m' y \tilde{x}.$$

### 2. Page 4

The proportionality constants for the top and bottom halves of the cold plate have been interchanged in the table. The table should read as follows:

| <u>Point</u>           | <u>Bending<br/>Direction</u> | <u>Constant<br/>(rad/lb-in)</u> | <u>Constant<br/>(rad/N-m)</u> |
|------------------------|------------------------------|---------------------------------|-------------------------------|
| EDS cold plate, top    | pitch                        | .96 x 10 <sup>-10</sup>         | .85 x 10 <sup>-11</sup>       |
| EDS cold plate, bottom | pitch                        | .32 x 10 <sup>-10</sup>         | .28 x 10 <sup>-11</sup>       |
| ST-124 Stable Platform | Yaw                          | .62 x 10 <sup>-10</sup>         | .55 x 10 <sup>-11</sup>       |

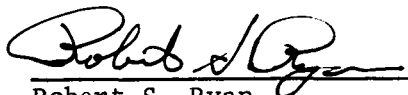
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This document has also been reviewed and approved for technical accuracy.



Robert S. Ryan  
Chief, Dynamics Analysis Branch



for H. J. Horn  
Chief, Dynamics and Flight Mechanics Division



E. D. Geissler  
Director, Aero-Astroynamics Laboratory



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Mr. S. A. Leadbetter  
Mail Stop 244  
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Langley Station  
Hampton, Va. 23365