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**Aerospace Systems Division**

Fastener Reduction Vibration Test
Program For ALSEP Array A

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FINAL REPORT

FASTENER REDUCTION VIBRATION TEST
PROGRAM FOR ALSEP ARRAY A

Submitted as Fulfillment of
the Report Requirements of
ALSEP CCP-90
Task III-3

Prepared By: _J. Maszatics_

Prepared By: _J. Brueger_

Approved By: _M. Katz_

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## 1.0 SUMMARY

A series of tests were conducted in order to determine the affect upon the dynamic environment of the ALSEP subpackage #1 subsystems due to reducing the quantity of fasteners used to secure the pallet to the primary structure. The test results indicated that the dynamic response of the system became less severe as the number of fasteners was reduced. The optimum number of fasteners is eleven based upon the vibration data obtained from tests and an analysis dealing with the shock environment.

Since the test article consisted partly of mass model subsystems further testing using qualification hardware is required if the number of fasteners is to be reduced.

## 2.0 INTRODUCTION

### 2.1 Program requirements

In a TWX, reference 6.1, from NASA-MSC the objectives of CCP 90 were redirected to include, among other changes, a test program task under the major fastener reduction analysis task. This major task was associated with an investigation to identify the ALSEP design changes required to permit a reduction in the number of fasteners necessary to be released for ALSEP deployment. This new sub-task required Bendix to "conduct vibration tests on an Array A configuration to confirm the effects of reducing the number of fasteners." The task, as defined in reference 6.1, required a "test report by April 30, 1968 and a "recommendation for changes with associated impacts" by March 15, 1968. The primary objective of fastener reduction is to improve ALSEP lunar deployment time.

### 2.2 Program Plan

In order to accomplish these tests on a timely basis and within program costs it was planned to use the same ALSEP Subpackage 1 hardware assembly used to perform the "Flight Off-loading Qual Confidence Program for Array A." Also, it was planned to perform the tests immediately after completion of the off-loading tests. The use of this off-loading hardware was also desirable to minimize impact on the ALSEP schedule.

It was planned to perform these investigations only on a Subpackage 1 configuration. The aim was to determine how many fasteners could be removed from the sunshield with no other associated design changes in ALSEP. The basis for expecting that such a reduction would be feasible was the previous reduction of ALSEP specification qualification vibration levels from those levels used to establish the original structural design and, consequently, the original number of fasteners.

The effects of fastener reduction were to be established by measuring the resulting vibrational imputs to the ALSEP/experiment interfaces (i.e. at the support brackets). Results of the tests on each reduced fastener configuration would then be compared with the results of the full fastener complement configuration to establish these effects. In addition the results of the full fastener complement configuration would be compared with the Proto A and Qual SA vibration test results to validate the basic test configuration.

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Tests were not planned to be made on a Subpackage 2 configuration because it was not considered feasible to reduce the present number of fasteners without design changes. Also, the potential reduction would not measureably improve ALSEP deployment time.

It was planned to use the same test instrumentation as used in the ALSEP off-load tests, since the data objectives were the same.

Four fastener configurations were identified in reference 6.3 to adequately evaluate the effects of fastener reduction and to provide a basis for recommending a new configuration, if demonstrated to be feasible by the test results. The specific configurations were based on those configurations previously investigated in the ALSEP Program and reported in reference 6.2. These earlier tests were run at the previous higher specification vibration levels and in addition, the test hardware was not sufficiently instrumented to provide data directly related to experiment vibration inputs. It had been concluded from the results of these previous tests that fastener reduction was not feasible.

The current fastener reduction tests were performed in the period of 24 to 26 April 1968. A post-test IST performed on the SWS indicated that it was still in satisfactory condition.

Additional testing was considered at the conclusion of this series to further validate the data obtained. However, it was ultimately decided that this could be accomplished using analytical procedures. The analysis of the vibration data, plus a shock analysis provides the basis for the recommendation of a reduced number of fasteners for Array A.

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## 3.0 TEST DESCRIPTION

### 3.1 Test Article

The engineering fastener reduction vibration tests were performed on the ALSEP Array A Subpackage #1 configuration.  This configuration was assembled from the following basic ALSEP parts:

| Part Name | | Dwg. No. |
| --- | --- | --- |
| Primary Structure | Qual A S/N 2 | 2330203 K |
| Thermal Plate (including dummy electronic packages) | Proto 1 | 2332199 |
| Sunshield Assembly | Qual A S/N 2 | 2330228 G |
| Antenna | Dummy | 2335079 |
| Passive Seismic Experiment (PSE) | Proto 1 dummy | 2334274 |
| Lunar Surface Magnetometer (LSM) | Proto A dynamic model | 2330657 |
| Solar Wind Experiment (SWS) | Rejected Qual unit | 2330658 |

No thermal refelectors, thermal curtains or ancillary equipment were included on the assembly.  Calfax Live-Lock fasteners were used in the sunshield and to tie down the experiments and the antenna.  These were lock-wired where permitted by their locations.  Three center fasteners on the sunshield and two fasteners used to tie down the LSM were not lockwired.

A dynamic model of the SWS was not available for this test. The SWS unit used in the test contained operating electronics, which had been functionally tested and found satisfactory prior to these vibration tests.  It had been rejected as a Qual unit because it did not

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conform to the latest SWS revisions. The use of this unit, while an ex-
cellent dynamic representation of the Qual SA and Flight units, did im-
pose certain constraints on the test program. Installation of the SWS
on the sunshield required preloading of its legs. Also, constant monitor-
ing of the pre-load during vibration testing was required. In addition,
the test environment of the first test series was to be limited to 1 g
sinusoidal vibration sweep to ensure that input levels to the SWE would
not exceed present interface specification levels.

Assembly of Subpackage 1 was completed and the subpackage was
delivered to the test facility on 22 April 1968. Off-load tests, performed
first, were completed on 24 April 1968 and the assembly was then
available for fastener reduction tests.

3.2   Test Configurations

The specific configurations tested were as defined in reference 6.3
and as modified during the test operations. These configurations are
obtained by the removal of fasteners from the sunshield of the basic
ALSEP Array A Subpackage No. 1 configuration. The configurations
were designated, for identification purposes, as follows:

| Configurations | Fasteners in Sunshield |
| --- | --- |
| $\alpha_1$ | 19 |
| $\delta_{1A}$ | 14 |
| $\delta_{1B}$ | 12 |
| $\delta_{1C}$ | 9 |
| $\delta_{1D}$ | 17 |
| $\delta_{1E}$ | 9 (one fastener located differently than $\delta_{1C}$) |

These configurations are defined in Figure 3-1.
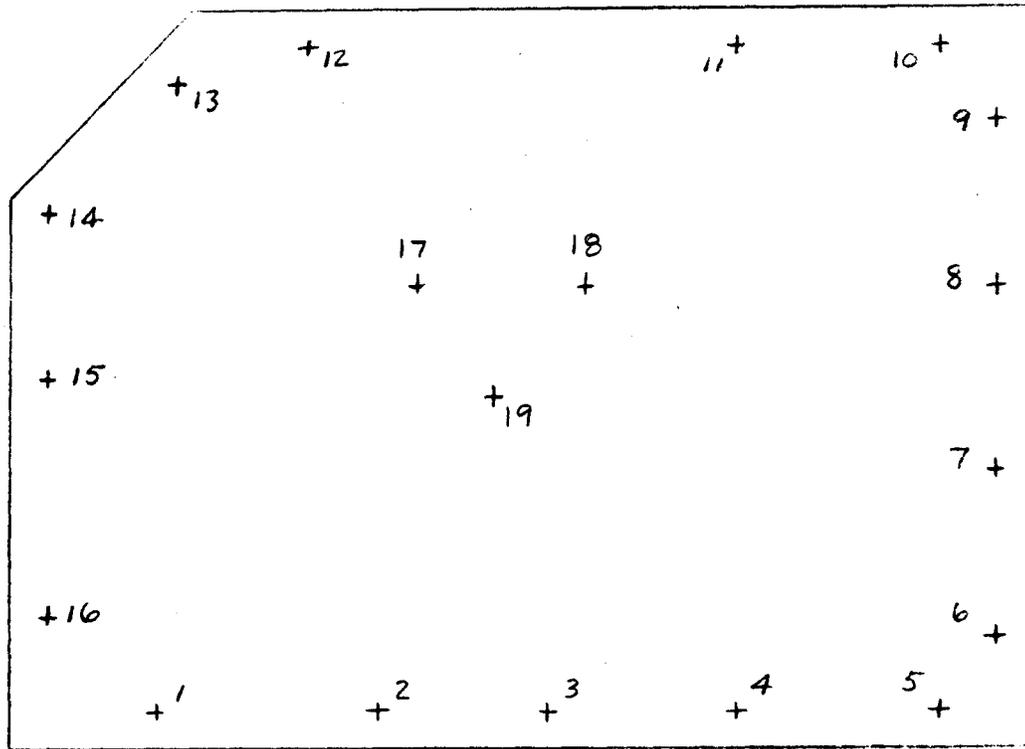
| CONFIGURATION | FASTENERS REMOVED | NO. OF FASTENERS REMAINING |
|---|---|---|
| $\alpha_1$ (REF) | NONE | 19 |
| $\delta_{1A}$ | 18, 13, 8, 4, 16 | 14 |
| $\delta_{1B}$ | 18, 13, 8, 4, 16, 6, 10 | 12 |
| $\delta_{1C}$ | 18, 13, 8, 4, 16, 6, 10, 17, 14, 3 | 9 |
| $\delta_{1D}$ | 17, 18 | 17 |
| $\delta_{1E}$ | 18, 13, 8, 4, 16, 6, 10, 17, 14, 2 | 9 |

FIGURE 3-1

FASTENER LOCATIONS

FOR TEST CONFIGURATIONS

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Configurations $\delta_{1D}$ and $\delta_{1E}$ were identified after tests of $\delta_{1A}$, $\delta_{1B}$ and $\delta_{1C}$ had been completed and preliminary data was evaluated. The purpose of $\delta_{1D}$ was to specifically identify the effects of removing only two of the center fasteners on the sunshield. The purpose of $\delta_{1E}$ was to determine the effect of moving one fastener, from its location in $\delta_{1C}$, to obtain a more structurally-symmetrical arrangement.

All experiments listed above were left on the sunshield in each configuration. In removing the fasteners, only the studs (bolts) were removed; the unused fastener receptacles (nut plates) were left on the test article.

## 3.3   Test Environment

Although it was originally planned to subject each of these configurations to the ALSEP sinusoidal and random vibration qual levels, the use of the SN-5 SWS unit necessitated an initial constraint on these levels. In order to ensure that input levels at the Bendix/SWS interface did not exceed present specification levels, the configurations were first vibrated at a 1 g sinusoidal level from 5 to 2000 cps at a rate of 3 octaves/minute, (Figure 3-2). This seemed justifiable since the resulting transmissibility data would adequately show the basic effects of fastener removal, even at a 1 g level vibration input. The results would also give some indication of any changes in natural frequency from that of the "full-up" fastener configuration. The results, from a selected number of accelerometer data in each test run, were evaluated and one configuration, $\delta_{1C}$, was selected on the basis of acceptable vibrational inputs to the experiments and the minimum number of fasteners. This $\delta_{1C}$ configuration was then subjected to the sinusoidal and random qualification levels shown in Figures 3-3, 3-4, 3-5 and 3-6, as defined in reference 6.12.

The fastener configurations (except $\delta_{1D}$ and $\delta_{1E}$) were subjected to the inputs described above in each of the three (3) ALSEP axis, as defined in Figure 3-7. The $\delta_{1D}$ and $\delta_{1E}$ configurations were subjected to the 1 g sinusoidal vibration sweep input in the X direction only.

## 3.4   Test Instrumentation

Accelerometers were mounted on the test article to provide data on the vibration input to each of the experiments mounted on the test

SWEEP RATE  3 OCTAVE/MINUTE

g PEAK  TOLERANCE  ± 10%

X, Y, Z  AXES
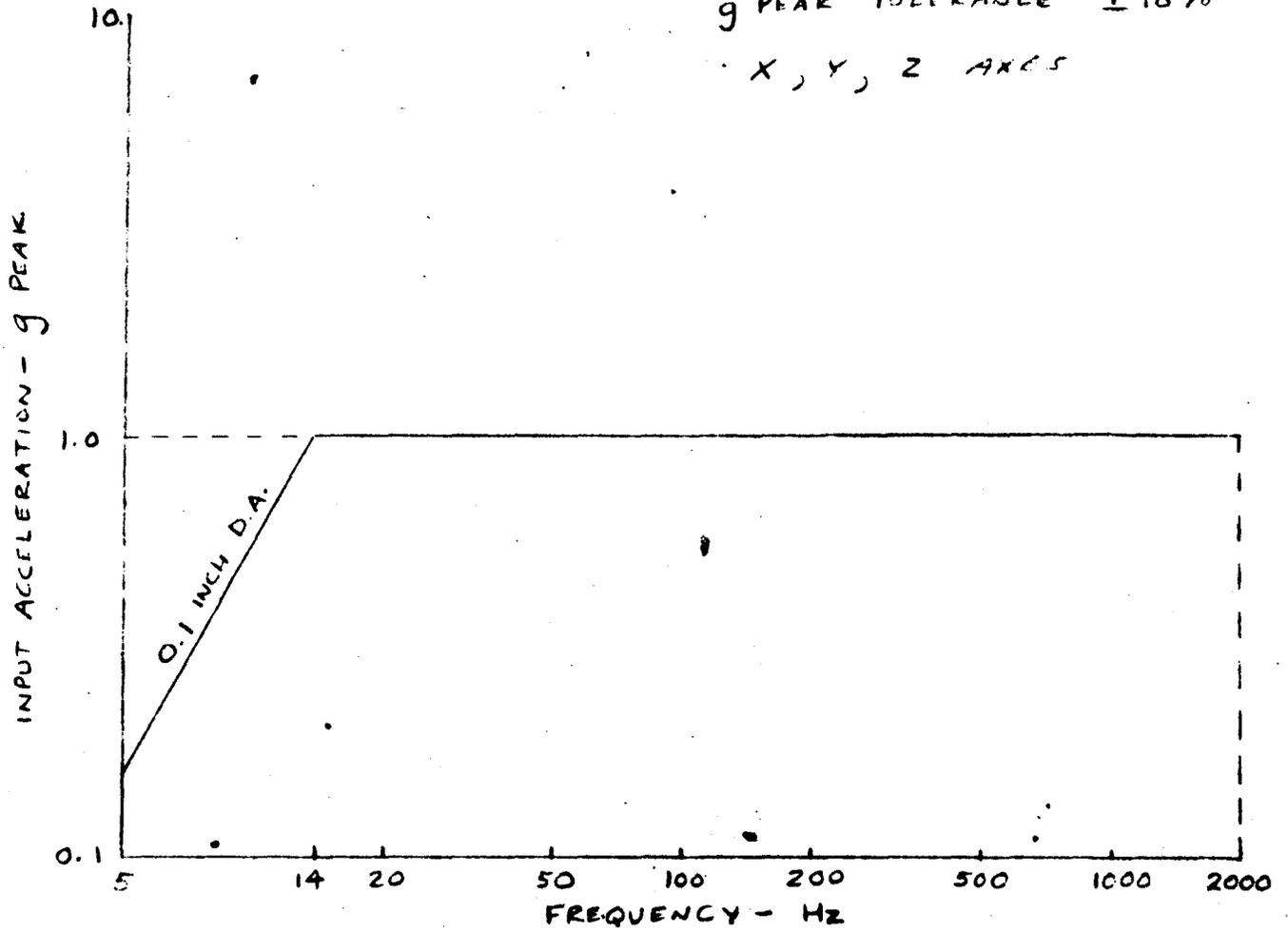
FIGURE 3-2

INPUT SINUSOIDAL VIBRATION LEVELS

# FIGURE 3-3

## SINUSOIDAL VIBRATION

## X, Y, Z  - AXES

SWEEP RATE :  3/4 OCT/MIN

1 SWEEP REQ'D :  5-100 CPS
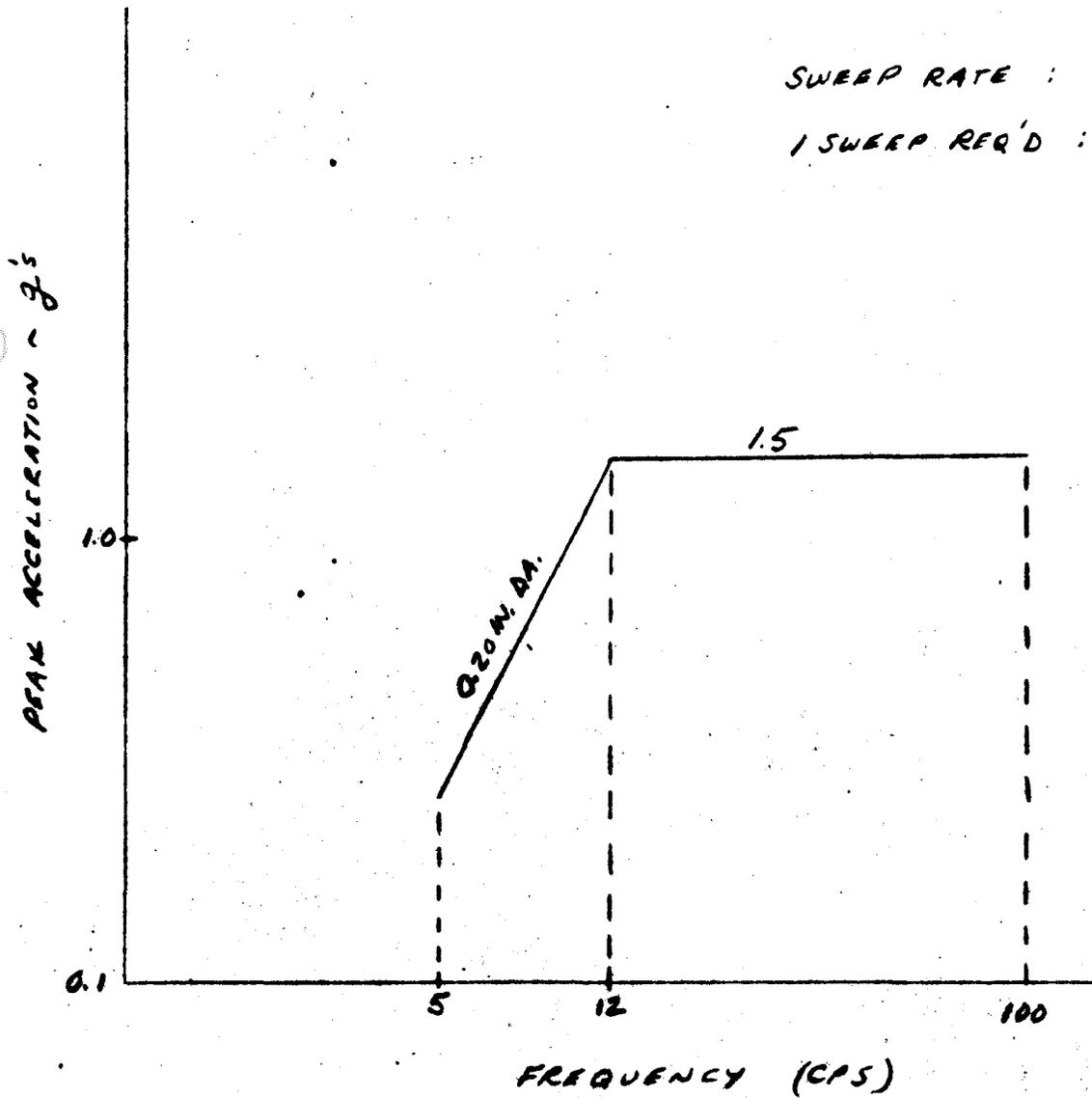
FIGURE 3-4
RANDOM VIBRATION
X - AXIS

FIGURE 3-5
RANDOM   VIBRATION
Y-AXIS

DURATION :  AS REQD
OBTAIN  10 SEC
TAPE LOOP

0.01

0.01

3db/oct

9db/oct

g²/cps

0.01

0.001

20                    200                1500 2000

FREQUENCY (CPS)
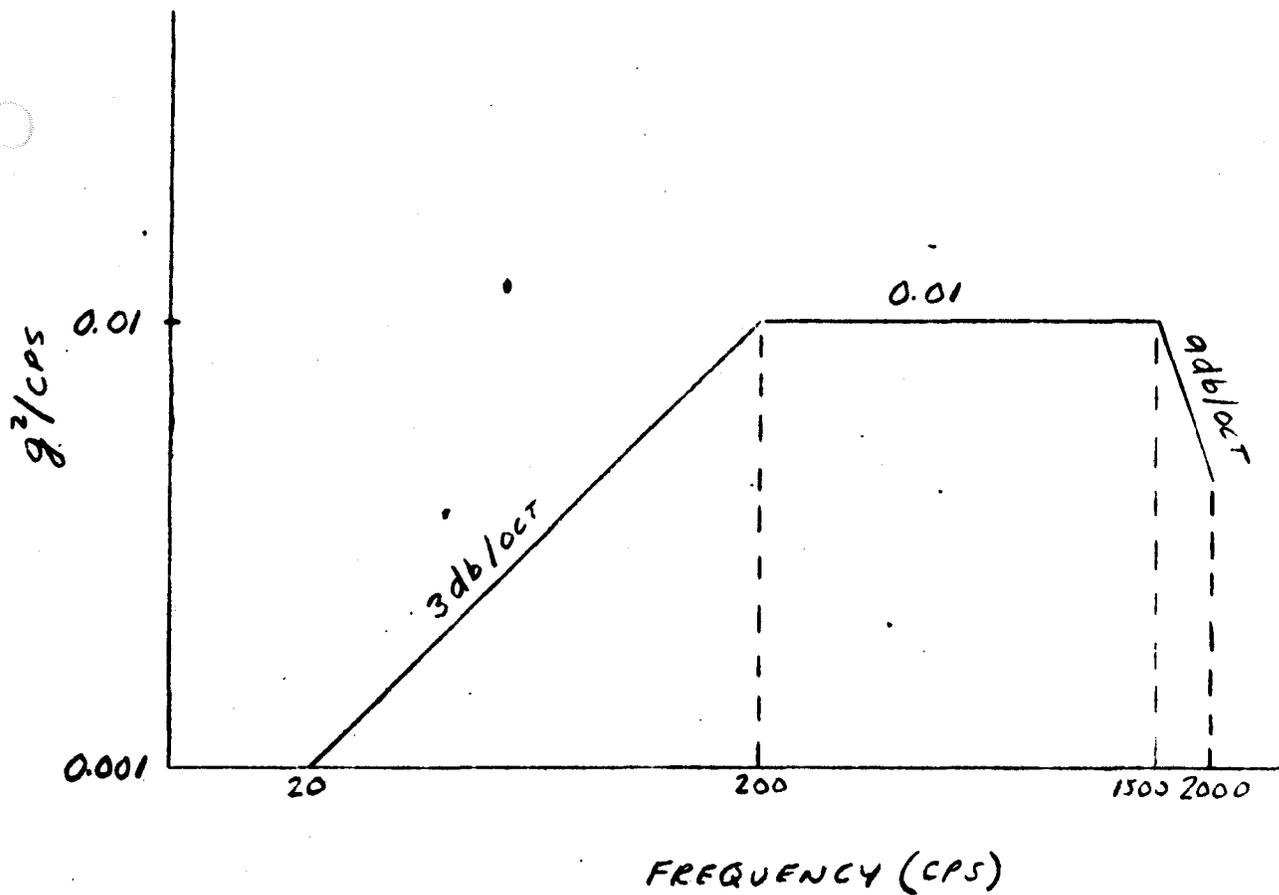
FIGURE 3-6
RANDOM VIBRATION
Z-AXIS

DURATION: AS REQ'D TO
OBTAIN 16 SEC
TAPE LOOP

VIBRATION
TEST FIXTURE

INPUT CONTROL
ACCELEROMETER
MOUNTING BLOCK

ALSEP
SUB·PACKAGE 1

+X

+Y

+Z
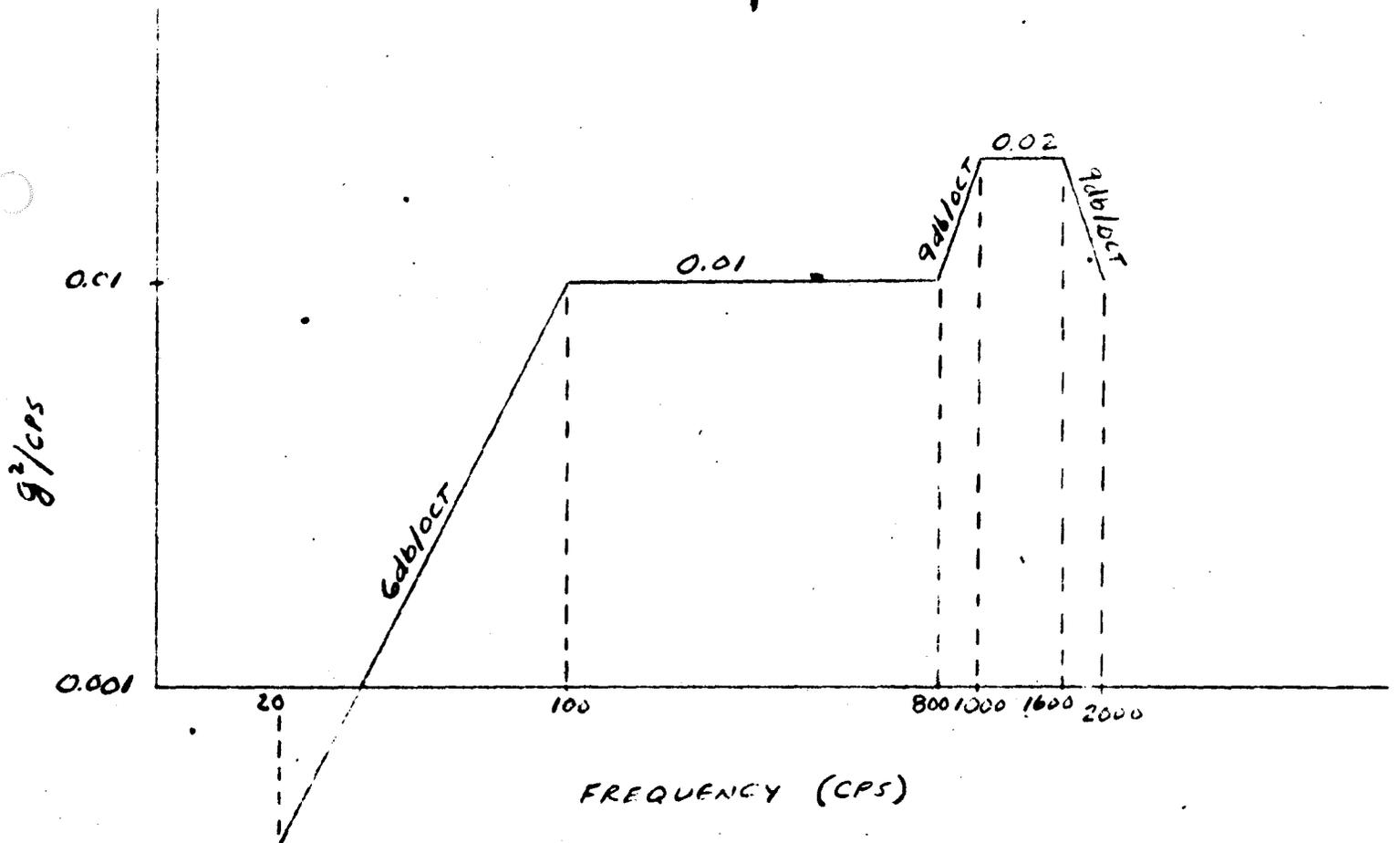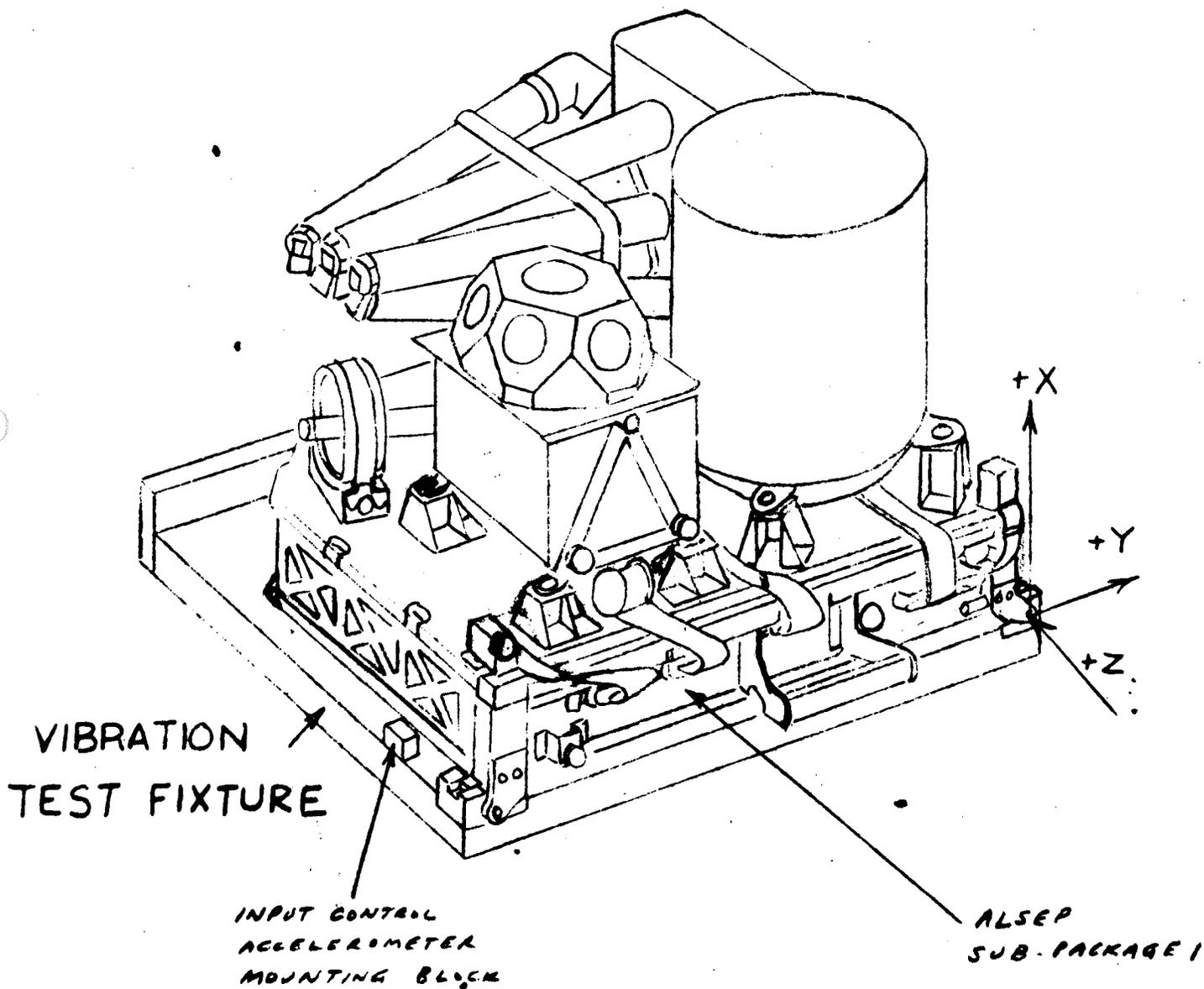
FIGURE 3-7

IDENTIFICATION OF ALSEP AXES
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article. The accelerometers were mounted at the locations shown in Figure 3-8. The triaxial accelerometers for the LSM input were mounted on the LSM pedestal near the pedestal interface with the LSM. The single axis and triaxial accelerometers for the SWS and PSE were mounted on the appropriate support brackets near the bracket interface with the respective experiments.

In addition, a control accelerometer was mounted on the vibration test fixture to which the ALSEP subpackage itself was mounted.

3.5 Test Procedure

The test was initiated on 23 April 1968 and was run in the sequence described below:

a. 1 g Sinusoidal (5-2000 Hz) (Figure 3-2)

$$X \text{ axis} \qquad \delta_{1A}$$
$$\delta_{1B}$$
$$\delta_{1C}$$
$$Y \text{ axis} \qquad \delta_{1A}$$
$$\delta_{1B}$$
$$\delta_{1C}$$
$$Z \text{ axis} \qquad \delta_{1A}$$
$$\delta_{1B}$$
$$\delta_{1C}$$

b. Sinusoidal (5-100 Hz) and Random Qual Levels (Figures 3-3, 3-4, 3-5 and 3-6)

$$Z \text{ axis} \qquad \delta_{1C}$$
$$Y \text{ axis} \qquad \delta_{1C}$$
$$X \text{ axis} \qquad \delta_{1C}$$

LUNAR
SURFACE
MAGNETOMETER

SOLAR
WIND
EXPERIMENT

PASSIVE
SEISMIC
EXPERIMENT
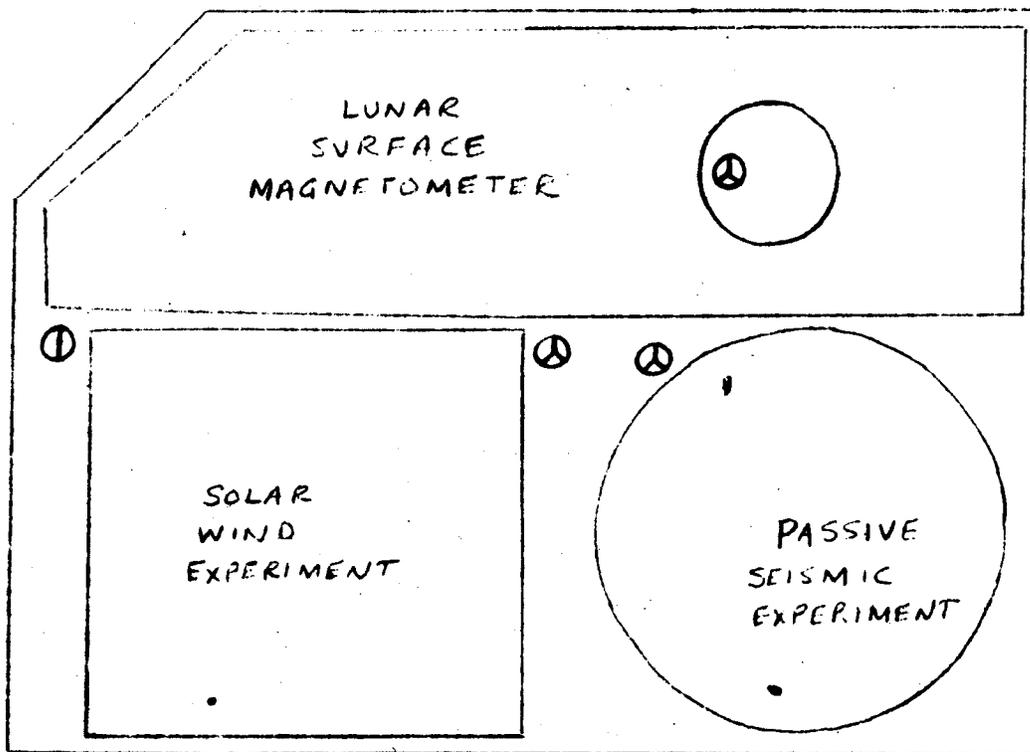
① SINGLE AXIS ACCELEROMETER (ALIGNED WITH INPUT AXIS)

⊕ TRIAXIAL ACCELEROMETER

ACCELEROMETERS LOCATED ON SUPPORT BRACKETS OR
PEDESTAL, AS CLOSE TO BENDIX / EXPERIMENT INTERFACE
AS POSSIBLE.

FIGURE 3-8

INSTRUMENTATION   LOCATION
SUBPACKAGE 1

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c.  1 g Sinusoidal (5-2000 Hz) (Figure 3-2)

$\qquad$ X axis $\qquad$ $\delta_{1D}$

$\qquad\qquad\qquad\qquad$ $\delta_{1E}$

Data from all accelerometers was recorded for the full duration.
of the sinusoidal runs and, for the random runs, long enough to produce
a 10 sec tape loop.

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## 4.0   TEST RESULTS

Reference 6.5 contains all the vibration data recorded during the tests. The following is a condensation and evaluation of the total data package.

### 4.1   Center and Edge Fasteners

Table 4-1 lists the first mode natural frequencies and corresponding transmissibilities at each location for configuration $\alpha_1$, $\delta_{1C}$, $\delta_{1D}$, and $\delta_{1E}$.

Table 4-1   Fundamental Mode Transmissibilities (X-response/X-input)

| Location No. | Experiment | Transmissibility $(TR_1)$ | | | | Frequency $(f_{n1})$ | | | |
|--------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|
| | | $\alpha_1$ | $\delta_{1C}$ | $\delta_{1D}$ | $\delta_{1E}$ | $\alpha_1$ | $\delta_{1C}$ | $\delta_{1D}$ | $\delta_{1E}$ |
| 1 | LSM | 4.0 | 1.9 | 4.1 | 3.0 | 47 | 43 | 55 | 49 |
| 2 | SWE | 4.1 | 3.2 | 3.5 | 3.6 | 52 | 42 | 56 | 51 |
| 3 | SWE | 6.5 | 3.4 | 8.0 | 5.4 | 52 | 44 | 57 | 51 |
| 4 | PSE | 5.9 | 2.8 | 7.0 | 4.4 | 52 | 43 | 44 | 50 |

Comparing the $\delta_{1D}$ data with that of $\alpha_1$ shows that transmissibilities increase significantly when center fasteners are removed; especially at locations near the center of the pallet.

Configurations $\delta_{1C}$, $\delta_{1D}$, and $\delta_{1E}$ have the same center fasteners but different edge fasteners. A comparison of data shows a shift in the fundamental frequency to a lower value and a significant reduction of the corresponding transmissibility as the number of edge fasteners is reduced.

At all locations the fundamental frequency and transmissibility is higher for $\delta_{1E}$ than for $\delta_{1C}$. As expected not all edge fasteners affect the system dynamics equally. Fastener No. 3 has a greater influence on the pallet edge condition and stiffness than does fastener no. 2.

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4. 2    Effect of Removing Edge Fasteners

The variations of fundamental frequency ($f_{n1}$) and corresponding transmissibility ($TR_1$) with the number of edge fasteners ($N_E$) are shown in figures 4-1, 4-2, and 4-3. In figure 4-1 it is seen that for X-response and X-input there are significant decreases in both frequency and transmissibility as the number of edge fasteners is reduced. For Y-response to Y-input figure 4-2 shows that fundamental frequency decreases significantly and the transmissibilities decrease slightly as the number of edge fasteners is reduced. Figures 4-3 shows fundamental frequencies and transmissibilities as functions of number of edge fasteners for Z-response to Z-input. The variations in transmissibilities and frequencies with the number of edge fasteners is insignificant.

Figure 4-4 shows the in-axis non-fundamental mode transmissibilities as functions of the number of edge fasteners. The data shown is incomplete because much of the non-fundamental mode transmissibility values are so low that their variation with $N_E$ is of no importance. The significance of this data is that it shows there is no large scale transfer of energy from the first mode to later modes.

The cross-axis transmissibilities as functions of the number of edge fasteners are shown in figure 4-5. The first mode transmissibilities show a significant tendency to decrease as $N_E$ is decreased, while the later mode transmissibilities usually remain unchanged. Notice that the energy of vibration is not transferred to cross-axis motion as $N_E$ is reduced.

4. 3    Sinusoidal and Random Vibration Tests

Since the sinusoidal and random vibration test were made only with the $\delta_{1C}$ configuration, no direct comparison of results is possible. However, the data can be evaluated by comparing the sinusoidal results for $\delta_{1C}$ with the transmissibility survey results for $\alpha_1$ and comparing the random results with that obtained from the Proto-A tests.
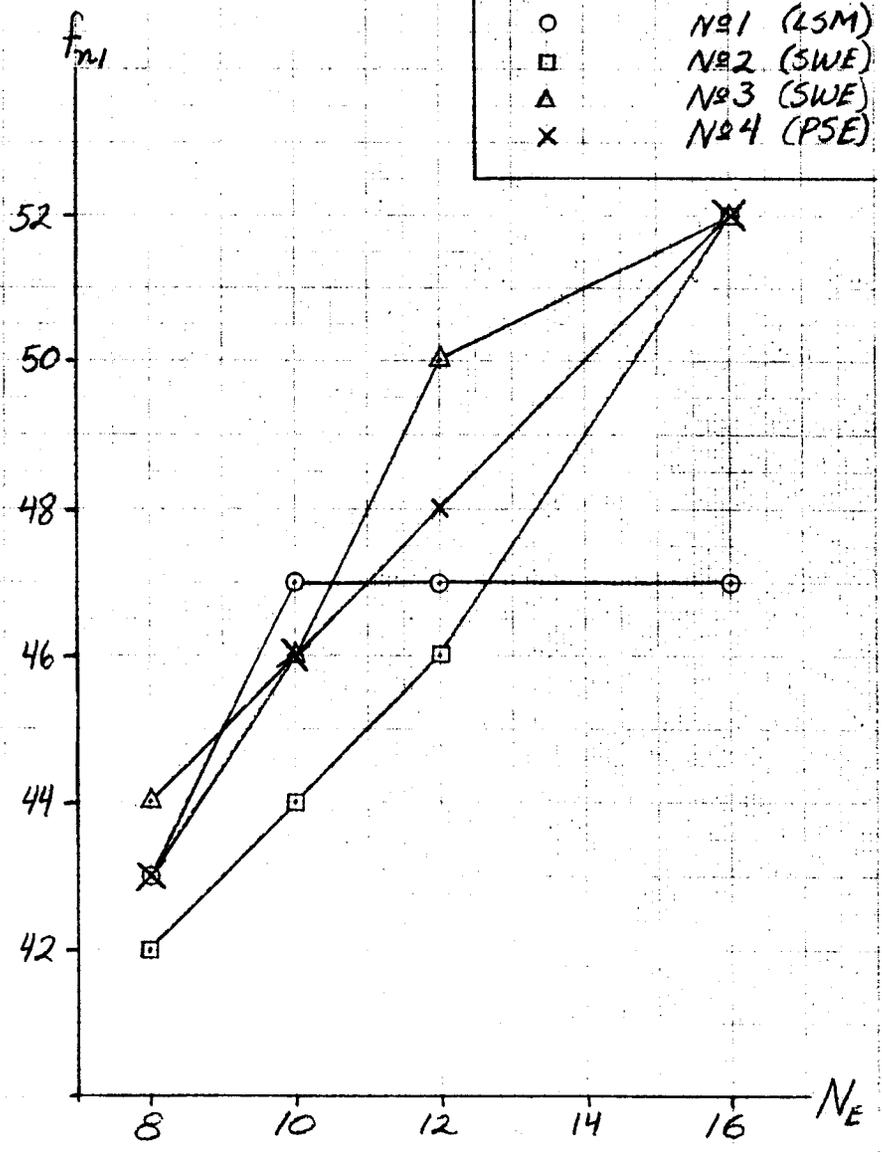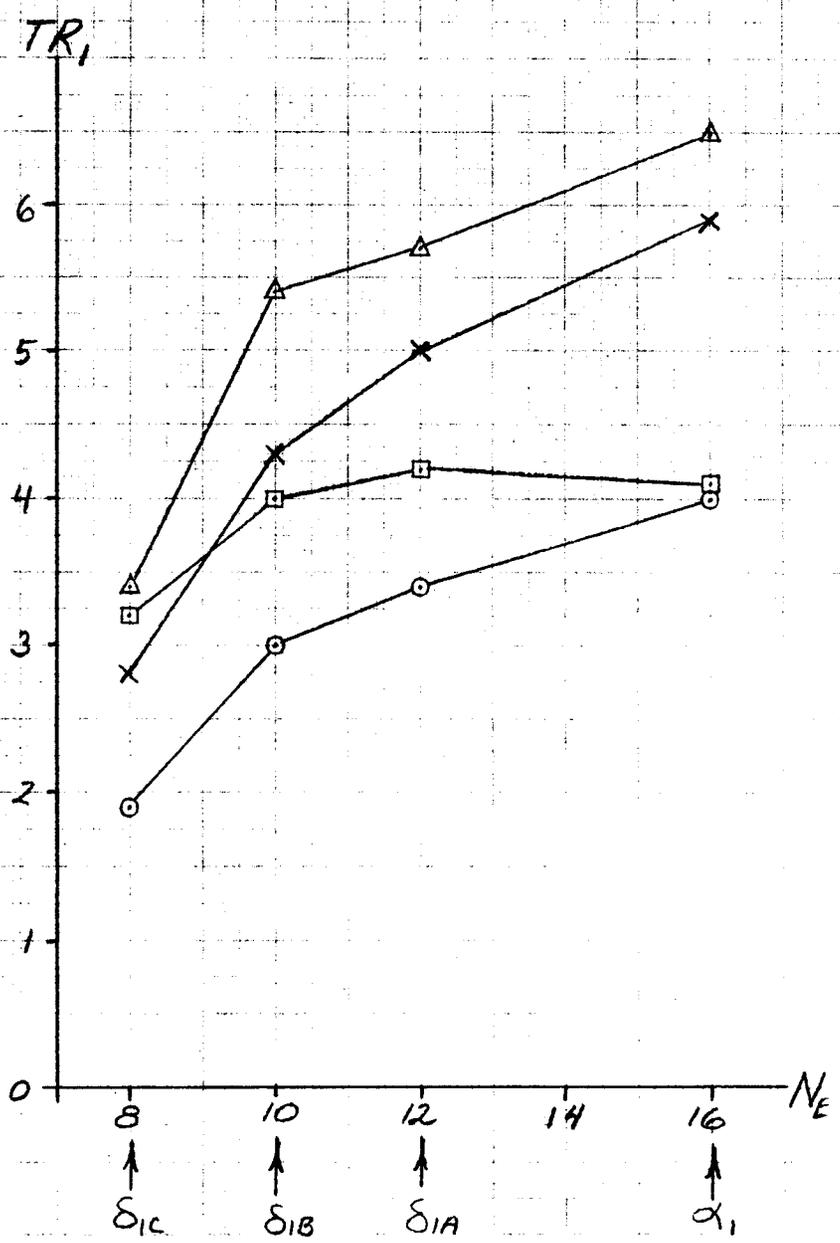
FIG. 4-1

Y-RESPONSE / Y-INPUT
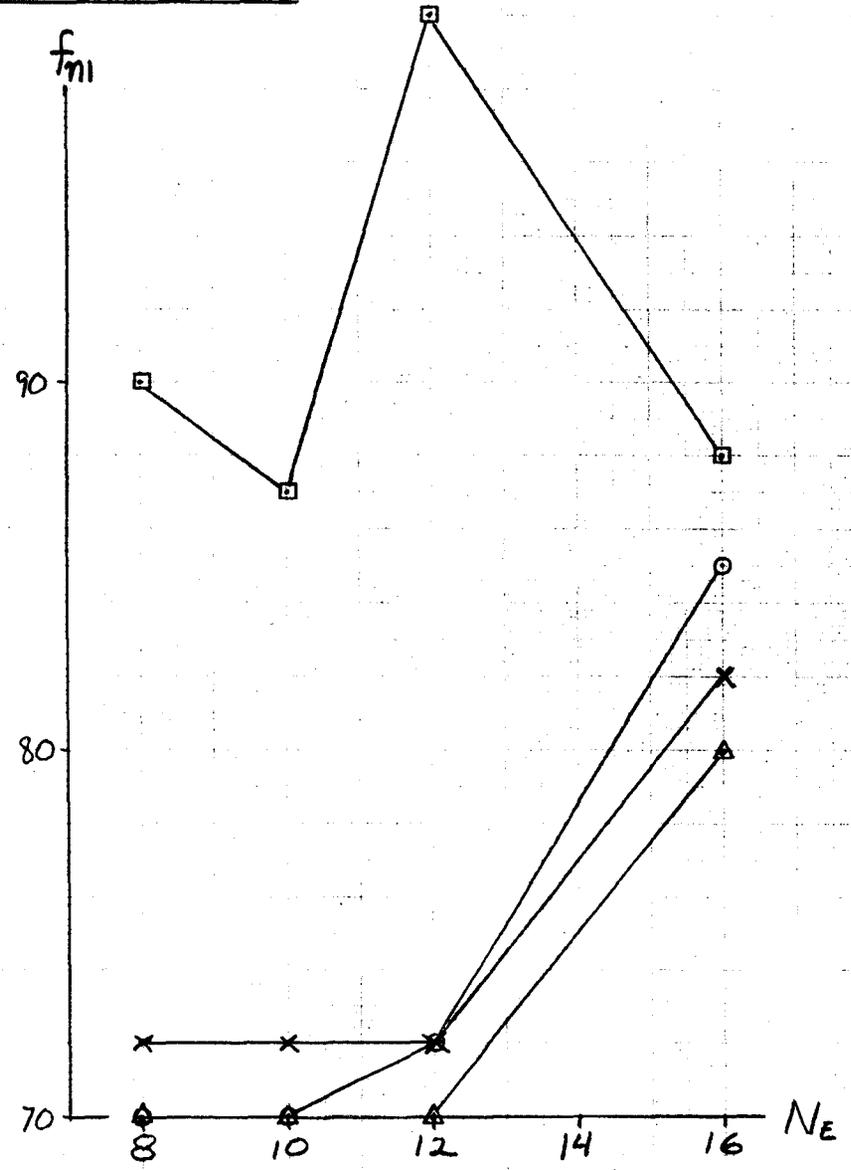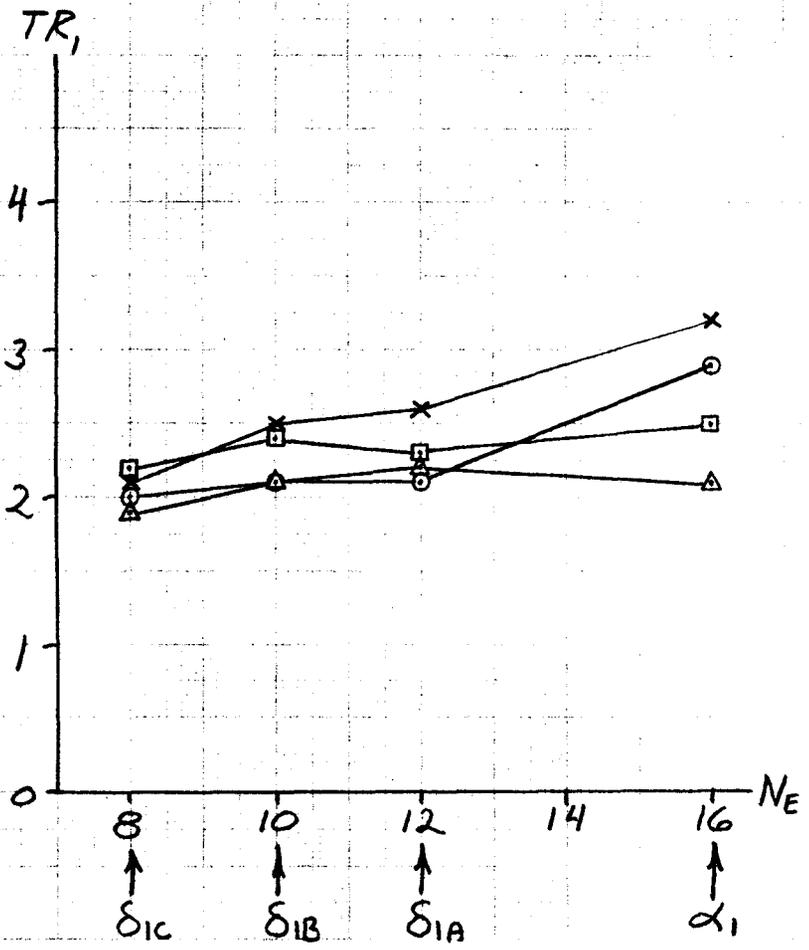
FIG. 4-2
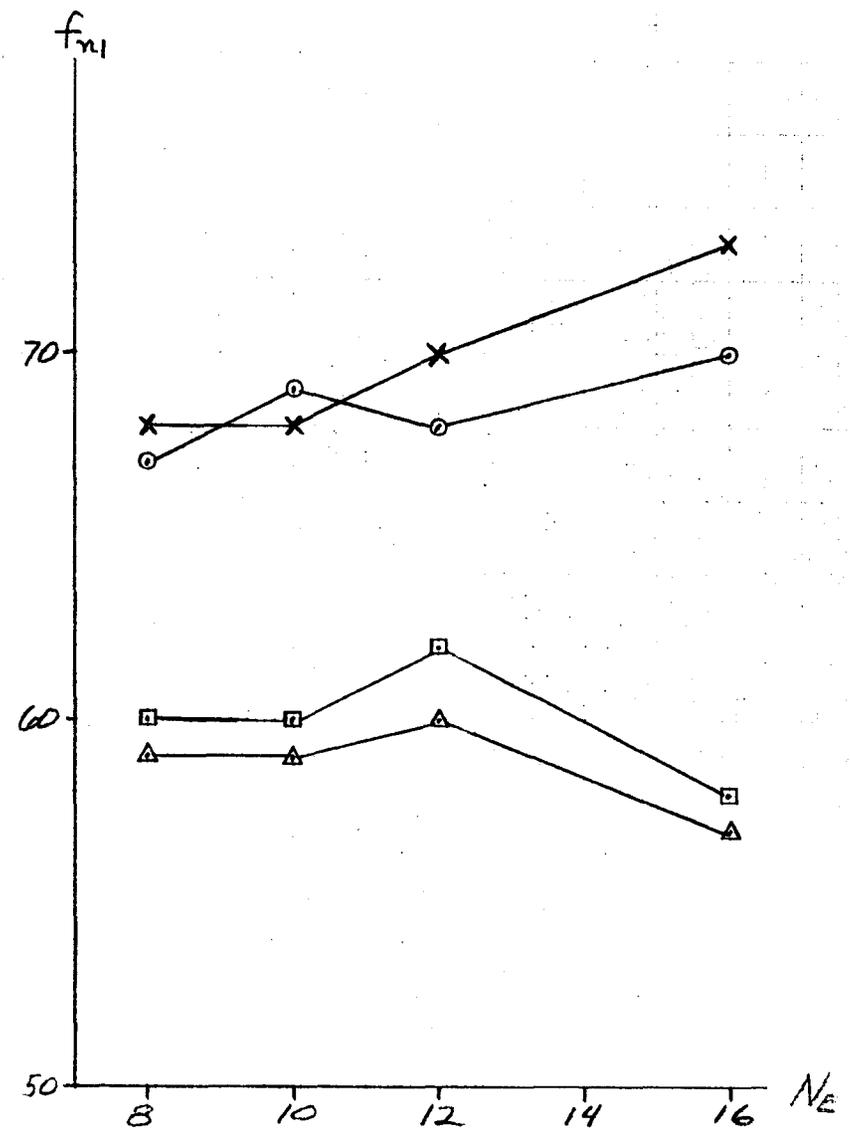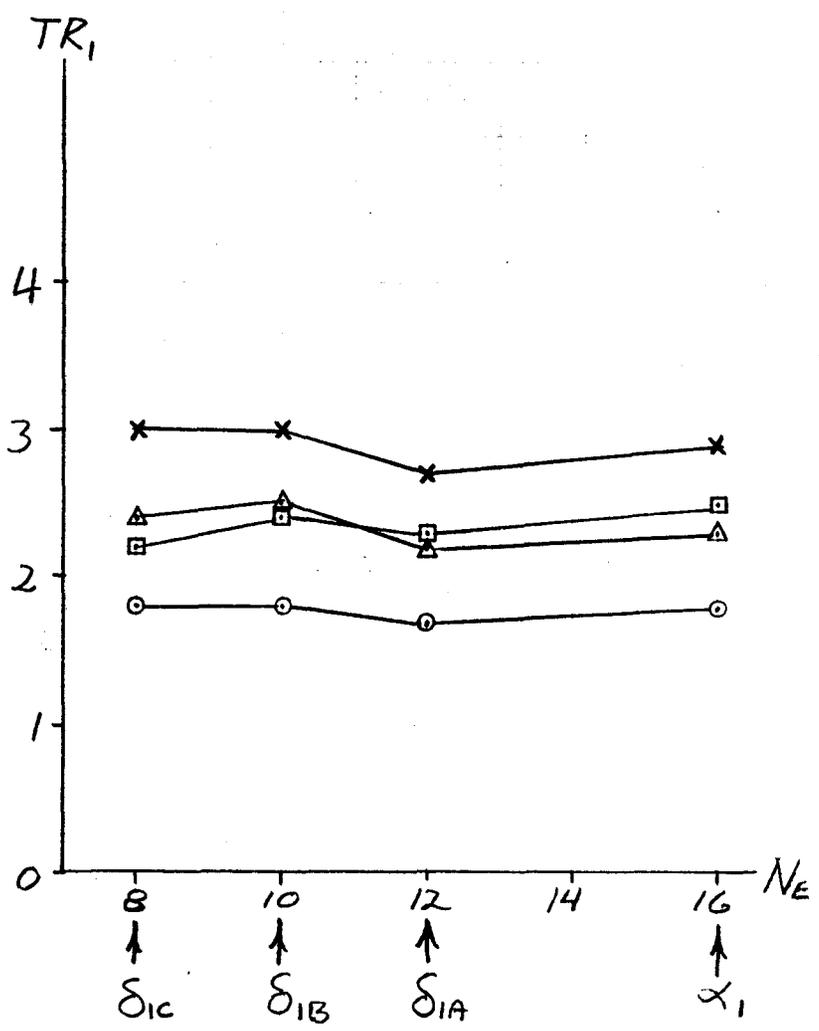
FIG. 4-3

EFFECT OF NUMBER OF FASTENERS UPON NON-FUNDAMENTAL MODE TRANSMISSIBILITIES
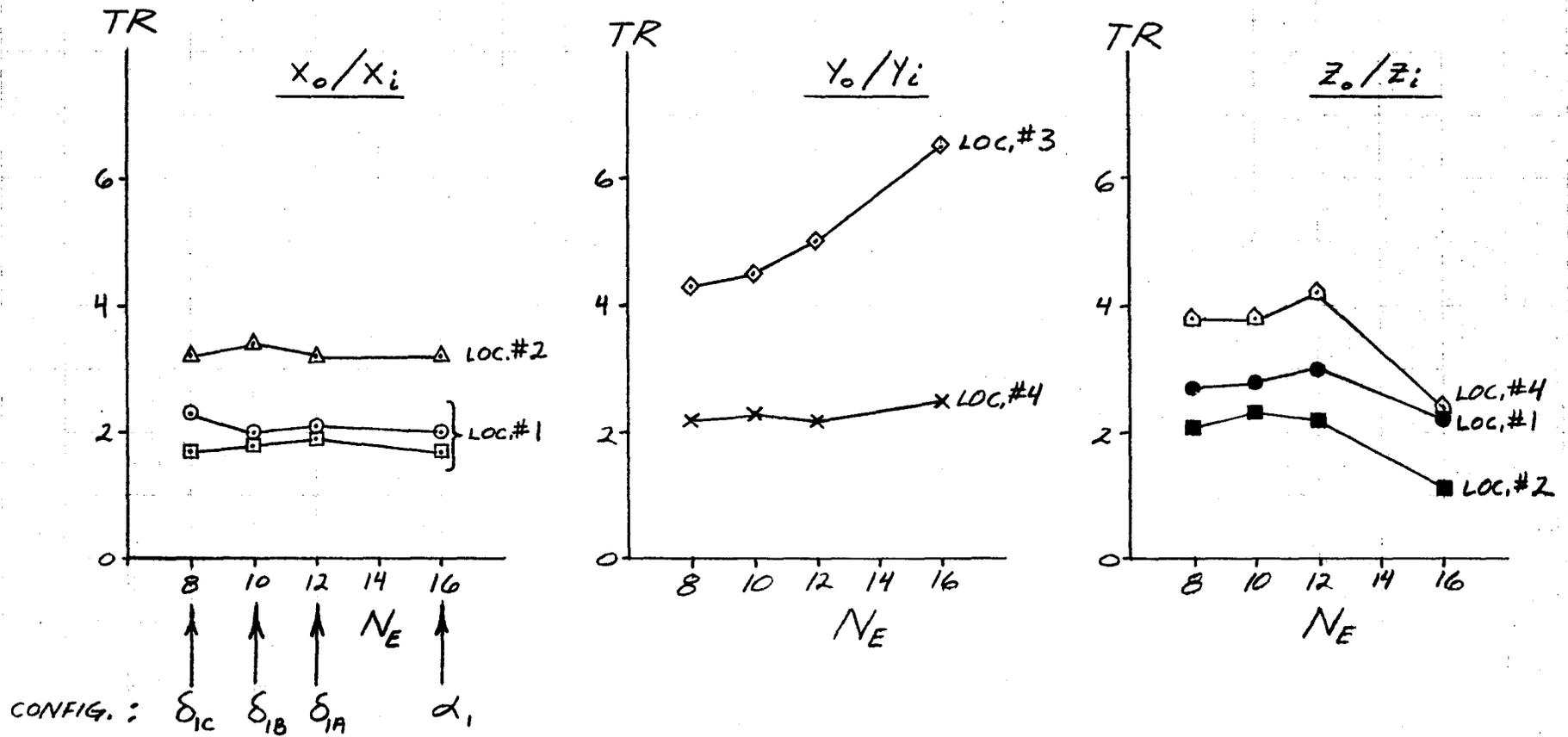
FIG. 4-4

CROSS AXIS DATA (TR vs. $N_E$)
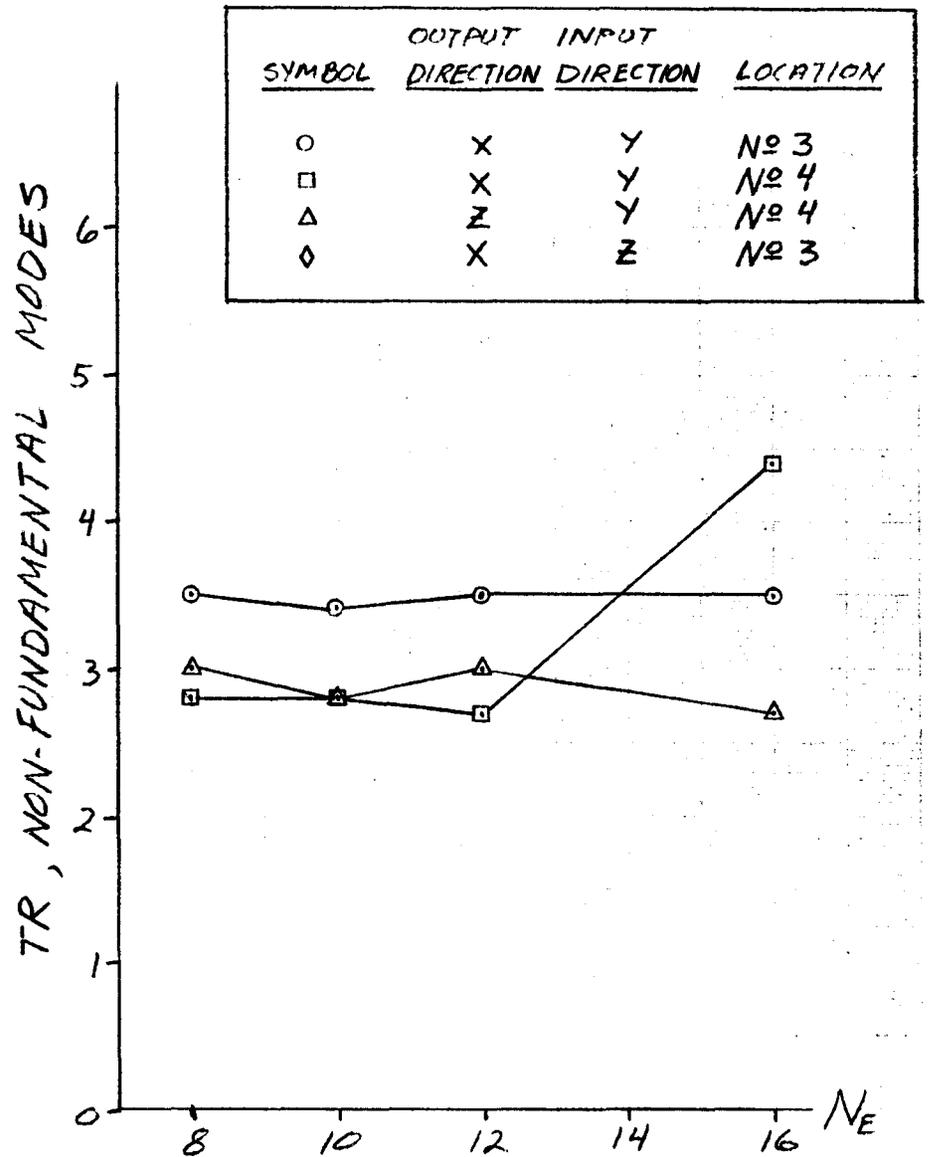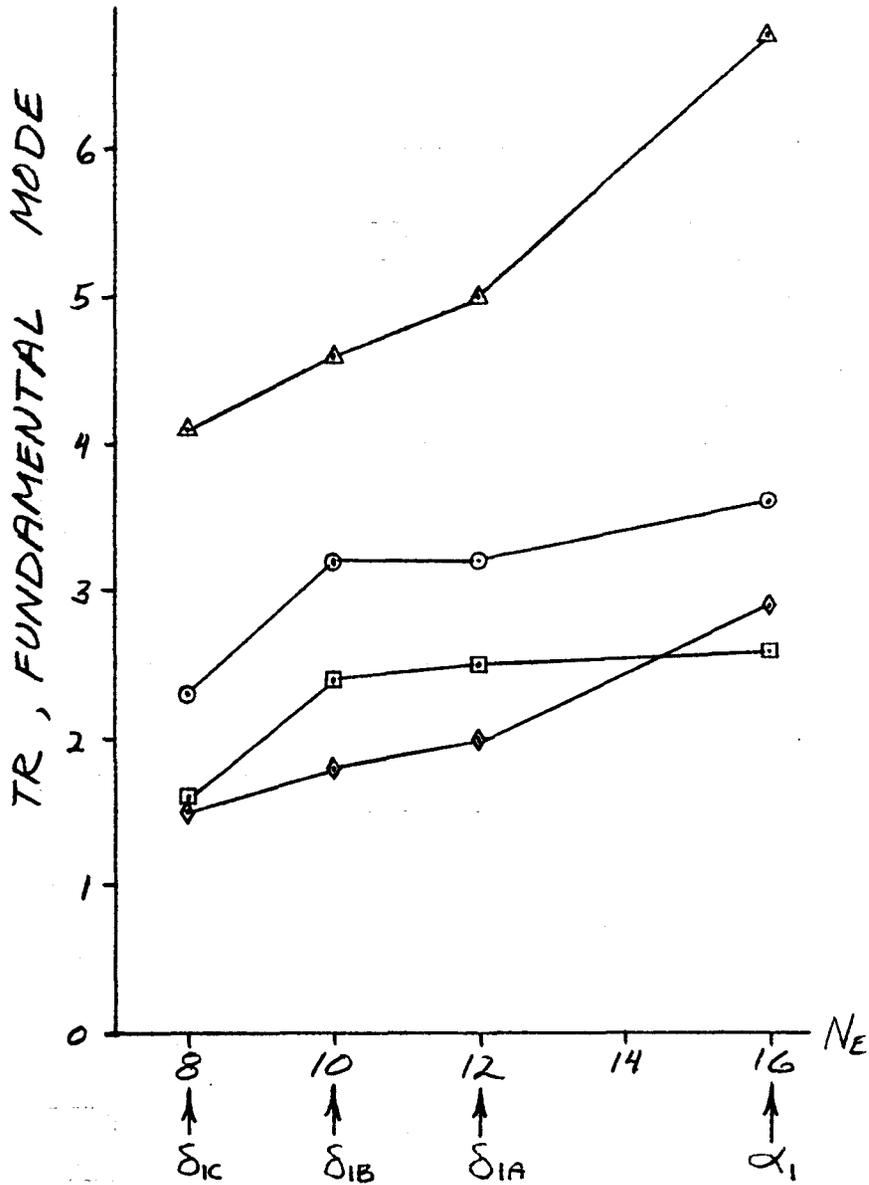
| SYMBOL | OUTPUT DIRECTION | INPUT DIRECTION | LOCATION |
|---|---|---|---|
| ○ | X | Y | № 3 |
| □ | X | Y | № 4 |
| △ | Z | Y | № 4 |
| ◇ | X | Z | № 3 |

FIG. 4-5

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Table 4-2 lists the maximum transmissibilities for the $\alpha_1$ configuration with a 1 g sinusoidal input at 3 octaves per minute sweep rate and for the $\delta_{1C}$ configuration with a 1.5 g sinusoidal input at 3/4 octaves per minute.

Table 4-2

| | | Maximum transmissibility | | | | | |
| | | $\alpha_1$ configuration | | | $\delta_{1C}$ configuration | | |
| Location | Experiment | X | Y | Z | X | Y | Z |
|---|---|---|---|---|---|---|---|
| 1 | LSM | 4.0 | 2.9 | 1.8 | 3.4 | 2.1 | 2.2 |
| 2 | SWE | 4.1 | 2.6 | 2.5 | 4.4 | 2.2 | 2.9 |
| 3 | SWE | 6.5 | 2.5 | 2.5 | 4.9 | 2.2 | 3.2 |
| 4 | PSE | 6.0 | 3.0 | 2.9 | 5.2 | 2.3 | 3.2 |

Note: X, Y, Z, denotes input and response direction

A slower sweep rate allows the system more time to respond to the input at any given frequency. Hence it is expected that the transmissibilities resulting from a sinusoidal input at 3/4 octaves per minute would be higher than at 3 octaves per minute. This fact is verified by comparing the $\delta_{1C}$ data in Tables 4-1 and 4-2.

It is significant that, in spite of the much slower sweep rate, most of the transmissibilities recorded during the sinusoidal test on $\delta_{1C}$ are lower than those for $\alpha_1$.

Unfortunately a comparison with Proto-A data is not useful because the test article, which uses some dummy subsystems, is much stiffer than the Proto-A package. The transmissibilities for the $\alpha_1$ configuration are much higher than those found during the Proto-A tests.

Figure 4-6 shows two curves which are the envelopes of all the random vibration response data (regardless of location of instrumentation, input direction, or response direction) recorded for each configuration — $\delta_{1C}$ and Proto-A. It is quite significant that the $\delta_{1C}$ envelope is less

ALSEP SUBPACKAGE #1

RANDOM VIBRATION

ENVELOPE OF ALL RESPONSE DATA
REGARDLESS OF INPUT DIRECTION,
RESPONSE DIRECTION, OR LOCATION
OF INSTRUMENTATION
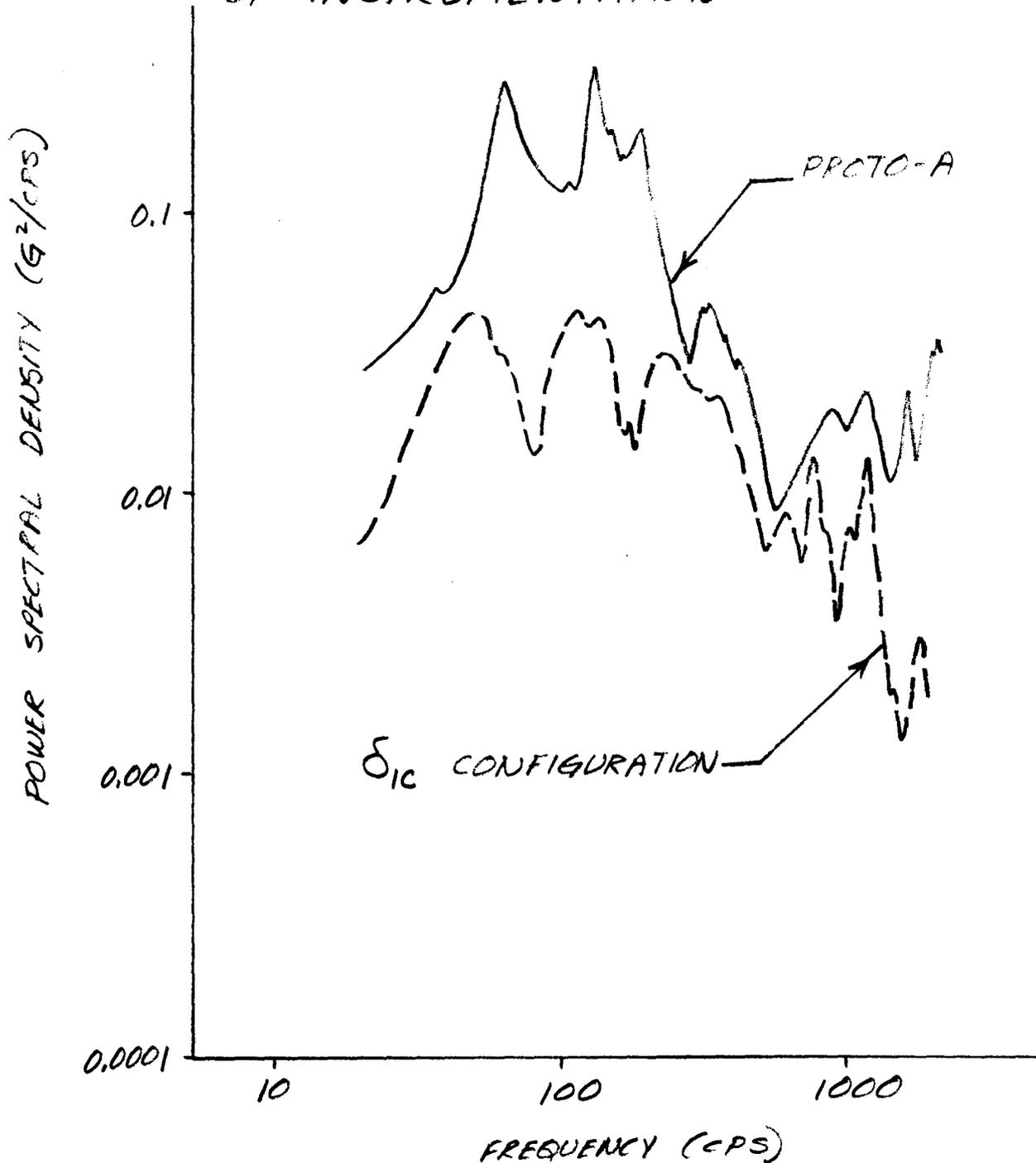


FIG. 4-6

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than the Proto-A envelope at all frequencies. Although $\delta_{1C}$ is much stiffer and has higher transmissibilities than Proto-A, its random vibration characteristics are better than Proto-A due to the absence of the eight edge fasteners. If the same eight were removed from Proto-A (or any subsequent test or flight system) it would be expected that the response to random vibration would be attenuated.

4.4 Shock Environment

The preceeding sections indicate that a reduction in the number of edge fasteners would not increase the severity of the vibration environment of the ALSEP subpackage #1 subsystems. The question remains, however, concerning the ability of a lesser quantity of fasteners to be able to withstand the expected acceleration and shock environments. The most severe requirement would be shock in a lateral (Y or Z) direction.

The pallet and fasteners (19) were designed to withstand a quasi-steady-state load ($L_F$) of 27 g with a safety factor ($S_F$) of 1.5. The 27 g load factor represents a reasonable combination of dynamic environments which were specified at that time. Equating the load per fastener as designed with that which would be seen during a shock sawtooth of 15 g for 11 msec.,

$$\frac{S_F L_F W}{N_o} = \frac{(TR)G_{max}W}{N_{min}}$$

$$N_{min} = \frac{(TR)G_{max}}{S_F L_F} N_o$$

where W is the system weight, $G_{max}$ is the peak shock acceleration, $N_o$ is the original number of fasteners, and $N_{min}$ is the minimum required number of fasteners.

For a shock transmissibility (TR) of 1.3,

$$N_{min} = 9.15$$

Hence the minimum required number of fasteners is ten (10).

It has been assumed in the above calculations that a shock load with a given maximum acceleration level is of equal severity as a steady-state acceleration level. Since the steady-state acceleration would be more severe than the shock, the calculations are conservative -- have a built in safety factor.

5.0   CONCLUSIONS AND RECOMMENDATIONS

Based upon the data obtained the following conclusions have been reached:

(a)   The three center fasteners should be retained.

(b)   Reducing the number of edge fasteners seems to change the edge conditions of the pallet from one approaching a clamped condition towards one approaching a simple support condition. The result is to reduce the fundamental frequency of the system especially in the vertical (X) direction.

(c)   Reducing the number of edge fasteners seems to increase the degree of damping within the system, thereby decreasing transmissibilities. This is probably due to an increase in the friction forces between the pallet and the primary structure.

(d)   The dynamic response of the system under sinusoidal and random vibration test conditions is less severe when the number of edge fasteners is reduced.

(e)   Ten fasteners are sufficient to withstand the specified lateral shock environment.

The following recommendations are therefore presented:

(a)   Remove eight (8) edge fasteners. They are nos. 3, 4, 6, 8, 10, 13, 14, and 16. (i.e., retain nos. 1, 2, 5, 7, 9, 11, 12, 15, 17, 18, and 19).

(b)   Since the test article used to obtain the data, upon which the above conclusions are based, was not a complete simulation of actual hardware; it is recommended that sinusoidal and random vibration tests be made using qualification hardware with the above 10 fasteners removed. Such tests are essential to verify the compatibility of the 10 fastener configuration with actual hardware.

## 6.0   REFERENCES

The following documents are references applicable to the test program reported herein.

6.1   NASA-MSC Houston TWX, Number T64/2-26/72, dated 8 March, 1968, Subject:   Realignment of CCP No. 90.

6.2   Bendix Report, BSR 2178, ALSEP Monthly Progress Review, September 1967.   Appendix:   Minutes 9712-488 dated 9/6/67, "CCP 57 Fasteners Meetings."

6.3   Bendix AER 63, Flight Off-Loading Program for Array A, dated 29 March 1968 (Bendix Memo 9712-755 dated 3-28-68).

6.4   Bendix Memo 9712-828, Addendum to Test Requirements for Off-Loading Program - Array A, dated 4-22-68.

6.5   Bendix TR 3104, Experiment Off-Loading and Fastener Vibration Acceptance, dated 13 May 1968.

6.6   Bendix Dwg 2330200, Subpackage I Assembly Array A (as a reference only, since it does not define the specific Subpackage I assembly tested).

6.7   Bendix Dwg 2330203 (Rev. K).  Primary Structure

6.8   Bendix Dwg 2330228 (Rev. G), Sunshield Assembly

6.9   Bendix Dwg 2332199, Thermal Plate Assembly

6.10   Bendix Dwg 2335079, Antenna Assembly

6.11   Bendix Dwg 2334274, Mock-up (Passive Seismic)

6.12   NASA-MSC Houston Letter TD3/LO23/68/B-26 (JAC) dated Feb. 5, 1968, Subject:   Contract NAS 9-5829, ALSEP Vibration Test Requirements.