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ASD TECHNICAL REPORT 61-507

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FLIGHT VIBRATION SURVEY OF
JRB-52B AIRCRAFT

PHYLLIS G. BOLDS
DEPUTY FOR TEST AND SUPPORT

JULY 1961

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AERONAUTICAL SYSTEMS DIVISION

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ASD TECHNICAL REPORT 61-507

**FLIGHT VIBRATION SURVEY OF
JRB-52B AIRCRAFT**

PHYLLIS G. BOLDS
DEPUTY FOR TEST AND SUPPORT

JULY 1961

PROJECT No. 1309
TASK No. 61565

AERONAUTICAL SYSTEMS DIVISION
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

FOREWORD

This technical note was prepared in the Environmental Criteria Branch, Environmental Division, Directorate of Engineering Test, Deputy for Test and Support, under Project 1309, Task 61565. The project engineer on this survey was Mr. Charles E. Thomas of the Environmental Criteria Branch. This technical note is one of a series prepared from data of programs conducted on operational aircraft by Environmental Criteria Branch. This survey is the result of flights made from July to November 1956. The information acquired from this effort was submitted as raw data to the requesting agency upon completion of the tests, and is presented formally in this report for the purpose of wider distribution.

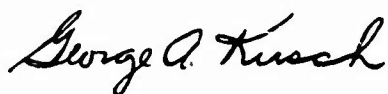
ABSTRACT

The JRB-52B aircraft was surveyed to determine the vibration environment existing throughout the vehicle under all flight conditions expected in service. Approximately 34,000 data points were obtained from 26 separate locations on the vehicle during 7 test flights. The data obtained were evaluated to determine the adequacy of vibration test requirements for long range bomber equipment contained in MIL-E-5272A. The data indicated that the vibration test requirements of that specification were unsatisfactory to simulate the actual environment existing on the JRB-52B aircraft. The revised requirements are contained in Specification Nr. MIL-E-5272C dated 13 April 1959.

PUBLICATION REVIEW

This report has been reviewed and is approved for publication.

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SECTION I

INTRODUCTION

There is a deficiency of necessary data available to define the actual dynamic environment under which the equipment in aircraft and space vehicles must operate. This situation imposes a serious problem in the areas of design, application, testing, and use of airborne equipment. In most cases the lack of data has resulted in either: (1) overdesigning the equipment, levying excessive development cost, time, specimen size and weight, or (2) underdesigning the equipment to the extent of placing dependability and service life in jeopardy.

To change the complexion of this existing problem, Environmental Criteria Branch, Environmental Division, Directorate of Engineering Test, Deputy for Test and Support, has implemented a comprehensive data acquisition program aimed at obtaining vibration data on all available aircraft and missiles.

This is one of a series of reports which presents vibration data measured on the structure of aircraft and missiles. The primary objective of these reports is the dissemination of important dynamics data to those concerned with developing airborne accessories. The data can be used as the basis for preparing design and testing specifications, for estimating environments on air vehicles in the "drawing board" stage, in establishing optimum locations and installation practices, etc. The data in this report was interpreted only with respect to the specific vehicle (JRB-52B aircraft) under study, and no attempt was made to assimilate this information with existing data on similar vehicles or to present complete explanations of all the vibration phenomena involved. It is intended that later reports will be published to interpret the data and to draw comprehensive conclusions concerning vibration generation, propagation, structural response, characteristics, and the like. However, the test instrumentation, procedures, and data reduction methods are covered in considerable detail in this report.

SECTION II

DESCRIPTION OF THE JRB-52B AIRCRAFT

The JRB-52B stratofortress, built by the Boeing Aircraft Corporation, is land-based and of the heavy bombardment class designed for long-range flights at high speed and altitudes. The tactical mission is the destruction of surface objects by bombs. The aircraft is characterized by swept wing and empennage. Eight Pratt and Whitney J57 Turbo Wasp engines rated at 9290 rpm at 100% thrust are used to power the aircraft. These engines are mounted in pairs in four nacelles suspended below the wing. The engine configuration is clean and free from accessories due to the use of an air-bleed system.

The following specifications are applicable to the JRB-52B aircraft:

Wing span	185 ft.
Fuselage	156 ft. 6 in. (with gun)
Height	48 ft. 3 in. (to top of fin)

The aircraft is in the 400,000-pound weight class. It utilizes four M-3 50-caliber guns located in the aft section of the fuselage.

SECTION III

TEST INSTRUMENTATION

The test instrumentation comprised the following: (1) sixty MB Type 124 velocity pickups, (2) one Model 501 Davies Laboratory Inc. 14-channel magnetic tape recorder, and (3) one remotely controlled pickup selector switch. Generally, the pickups were installed in groups of three and oriented to sense vibration along each of the three major axes of the aircraft. These pickups were attached to aircraft structure and engine at 26 points of interest. The locations are shown in Figure 1, Appendix A. A more detailed description of the instrumentation is contained in this appendix.

SECTION IV

TEST PROCEDURE

A total of 7 test flights was conducted during the survey. Vibration records were taken during all of the normal service conditions, such as taxi, ground runup, takeoff, straight and level flight (at various altitudes, airspeeds, and power settings), gunfire, turn, descent, landing, and landing roll. Further information concerning the test procedure is contained in Appendix A.

The reels of recorded data were edited in the laboratory and each sample (approximately 5 seconds in length) was spliced into an endless loop. These loops were then placed on a Model 502 Davies tape playback system, and a narrow bandwidth (10 cycles per second) analysis was conducted simultaneously on 6 of the 12 data channels. The analyzer used is a Model 510 Davies heterodyne type. The analyzed data were recorded on six modified Brown strip chart recorders in the form of a continuous spectrum of frequency (cps) vs. transducer voltage (rms). The data points of interest were then extracted from the strip chart recordings, tabulated, and punched into IBM cards. Corresponding decks of "Master Cards" which contain detailed descriptive information concerning pickup locations, flight conditions, and source and order of vibration were also produced. The data, along with the appropriate descriptive information "Master Cards," were then processed by means of an ERA 1103A computer. Both the vibratory double amplitude in inches and acceleration in g units appear in the completed data card. The data cards were then sorted into the desired order and fed into an automatic plotter for graphic reproduction.

SECTION V

PRESENTATION OF DATA

The plots discussed in this report are summary plots for each structural zone for all of the flight test conditions. It has been found in working with other similar vehicles that this type of data presentation is satisfactory for use in establishing specification requirements and in estimating vibration environments. However, in instances where more detailed analysis of the vibration characteristics is required, it is possible to present graphs showing variations of many parameters affecting vibration conditions in the vehicles. For example, graphs can be made showing variation of vibration as a function of the following parameters: (1) indicated airspeed, (2) altitude, (3) engine RPM, (4) payload, (5) flight condition, (6) engine or propeller order, etc. Additional plots of this type can be furnished if required. A more detailed description of data handling procedures, data analysis, and presentation methods is contained in Appendix A.

SECTION VI

RESULTS

During the 7 test flights a total of 34,167 data points was obtained. As evidenced by the graphs contained in Appendix A, the data are, for the most part, characterized as being of the discrete frequency type. The sources of these frequencies are the high-speed rotor and the low-speed rotor of the J-57 twin-spool engine.

Vibration at frequencies which seem to coincide with those produced by both the high- and low-speed rotor appears in the data in varying intensity throughout the entire fuselage, wings, and nacelles. However, closer inspection reveals that these frequencies are produced by items of rotary equipment located throughout the wing and fuselage. These items include such pieces of equipment as alternators and hydraulic power packs. The items produced not only a fundamental frequency which corresponds to their speed of rotation but also quite often produced frequencies which correspond to the first and second harmonics of the fundamental. Frequencies (discrete) are encountered in the extreme aft section of the aircraft which cannot be related to known equipment frequencies. These are assumed to be the localized resonant responses of the aircraft structure upon which the pickups are mounted. Tests conducted with gunfire indicated negligible effects in the forward three-fourths of the fuselage.

The test data indicate that the following vibration test envelope would be satisfactory for items of equipment to be used at any fuselage location or on the inner two-thirds of the wing on the B-52 aircraft:

5 to 6 cps	0.20 inches double amplitude
6 to 15 cps	± 0.40 g's vibratory acceleration
15 to 72 cps	0.036 inches double amplitude
72 to 500 cps	± 10 g's vibratory acceleration

The envelope for the outer one-third of the wing would be as follows.

5 to 16 cps	± 0.50 g's vibratory acceleration
16 to 72 cps	0.036 inches double amplitude
72 to 500 cps	± 10.0 g's vibratory acceleration

SECTION VII

CONCLUSIONS

The vibration data obtained in this survey were utilized in revising Specification MIL-E-5272C, dated 13 April 1959.

Procedure XII of this specification is adequate for the B-52 aircraft except in the low frequency range (below 16 cps).

The large-amplitude low-frequency vibration prohibits the use of low-frequency vibration isolators on equipment on the B-52. The resonant frequency of any isolators used on the B-52 should be in the 15- to 25-cps frequency range to obtain satisfactory operation and service life.

APPENDIX A

1. Instrumentation

MB Manufacturing Co. Type 124 velocity pickups were mounted in clusters at 26 separate test points to sense vibration along each major axis of the aircraft engines and structure. The locations are summarized in Table I and depicted in Figure 1. The Type 124 velocity pickup has the following characteristics:

Nominal sensitivity	96.4 mv (rms) per in. per sec.
Usable frequency range	5 to 2000 cps
Temperature range	-50 to 250° F

TABLE I
PICKUP LOCATIONS

PUID	Location	Direction	PUID	Location	Direction
01	Structure of Left Wing Tip	Vert	32	Brush Band Section of Rt. Rear	Vert
02		F/A	33	Alternator - Sta. 615	Lat
03		Lat	34	Case of Rt. Rear Alternator Drive	Vert
04	Structure of Left Outrigger Wheel Well	Vert	35	Unit - Sta. 637	F/A
05		F/A	36		Lat
06		Lat	37	A/C Fuselage Rt. Side - Sta. 705	Lat
07	On Case of #5 Hydraulic Pack	Vert	38	A/C Fuselage Rt. Side - Sta. 715	Lat
08		F/A	39	Structure of Forward Rt. End of	Vert
09		Lat	40	Bomb Bay - Sta. 785	F/A
10	Wing Structure Trailing Edge Aft of	Vert	41		Lat
11	#2 Fuel Meter Pump	F/A	42	Structure of Aft Rt. End of Bomb	Vert
12		Lat	43	Bay - Sta. 958	F/A
13	Forward Edge of Fwd Compressor	Vert	44		Lat
14	Section #4 Engine	Lat	45	A/C Fuselage Rt. Side - Sta. 1009	Lat
15	Acc'y Seat of #4 Eng. Fwd Right	Vert	46	A/C Fuselage Rt. Side - Sta. 1277	Lat
16	Side	Lat	47	On Case of #10 Hydraulic Pack -	Vert
17	#4 Engine in Plane of Main Hangars	Vert	48	Sta. 1573	F/A
18		Lat	49		Lat
19	Pilot's Inst. Panel Top Center -	Vert	50	A/C Structure (Main Longerons)	Vert
20	Sta. 115	F/A	51	Below #10 Hydraulic Pack -	F/A
21		Lat	52	Sta. 1540	Lat
22	A/C Structure at Base of Pilot's	Vert	53	A/C Fuselage Rt. Side - Sta. 1542	Lat
23	Seat - Sta. 180	F/A	54	A/C Structure in Aft Sect. Below	Vert
24		Lat	55	Collins Radio Equip. - Sta. 1719	F/A
25	Structure of Radio Equip. Rack Aft	Vert	56		Lat
26	of Pilot - Sta. 302	F/A	57	A/C Fuselage Left Side - Sta. 1818	Lat
27		Lat	58	A/C Structure Above Tail Gunner's	Vert
28	A/C Fuselage Rt. Side Rack Aft -	Lat	59	Position; Aft of Jettison Point -	F/A
29			60	Sta. 1870	Lat
30	A/C Structure (Main Longerons) in Fwd	Vert			
31	Rt. Wheel Well - Sta. 548	F/A			
		Lat			

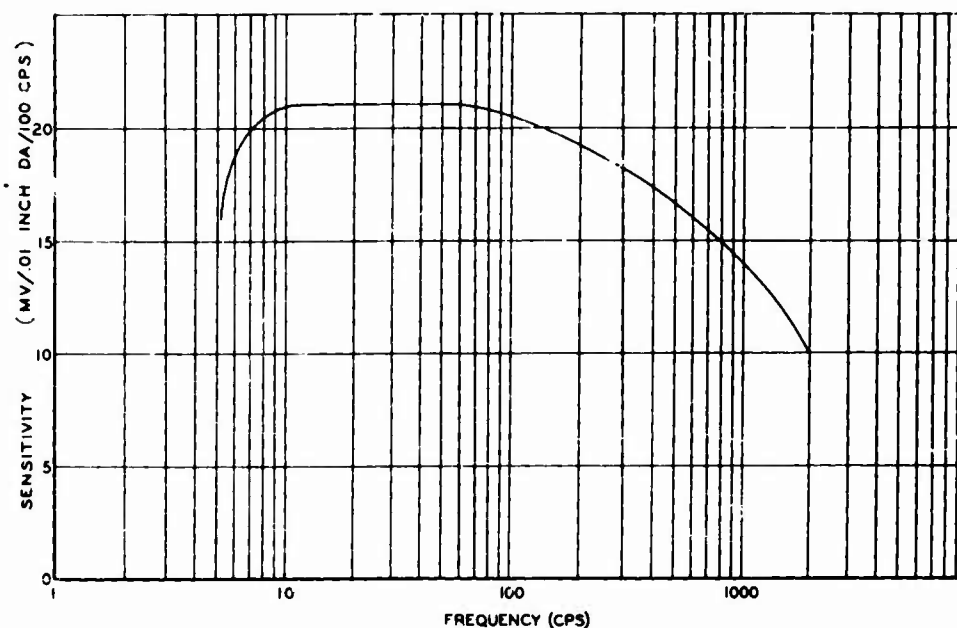


Figure 2. Frequency Response of M. B. Type 124 Vibration Pickup

The recorder was preset for a recording time of five seconds. The Model 501 Davies recorder is an FM type having the following characteristics: (1) FM carrier frequency of 10 KC, (2) intelligence frequency response of 3 to 2000 cps, (3) dynamic recording range of 45 db, (4) tape speed of 15 inches per second, (5) total recording time of approximately eight minutes, (6) weight of 55 lbs., and (7) overall dimensions including shock mount are 10-1/2 by 11 x 21 inches. The twelve data-channels have an input impedance in excess of 100,000 ohms. The thirteenth channel has an input attenuation of approximately 45 to 1 and is designed for direct connection to the engine-tachometer generator. The fourteenth channel is used to record the output from an internal 10 KC (crystal controlled) oscillator; this channel is used during tape playback to control the playback speed by means of a servo, and it is also utilized in the electronic compensation of the tape playback and analysis system. The recorder uses 1-3/4-inch wide magnetic tape in 400- to 600-foot reels.

2. Test Procedure

A total of 7 test flights was flown during this survey. A summary of the test conditions experienced is shown in Table II. The test plan was based on requirements of interested laboratories of Aeronautical Systems Division and on information obtained from USAF flight-test pilots. Data were obtained during all of the normal operational configurations which the aircraft could be expected to encounter. The data also include gunnery missions to determine the effects of vibration produced by gunfire. Test conditions were also established which would permit the evaluation

of variables, such as altitude, indicated airspeed, engine thrust, and the effects of using speed brakes, gear and other control surfaces at various airspeeds. Prior to each flight the test pilot was thoroughly briefed on the desired flight-test conditions and was given the appropriate flight-test data card. As soon as the desired flight-test conditions were realized, the output of each of the 60 pickups was recorded in successive groups of twelve each; this was done by means of a remotely controlled selector switch. A total of 1152 records was made during the 7 flights. The reels of recorded data were returned to the laboratory for analysis.

TABLE II
FLIGHT CONDITIONS FOR THE JRB-52 AIRCRAFT

<u>Flight Attitude</u>	<u>%RPM</u>	<u>IAS</u>	<u>ALT x 10³</u>	<u>EPR</u>	<u>% Thrust</u>
Taxi	59	30	00	0.00	000
Ground Runup With Flaps Extended	100	50 - 80	00	2.12 - 2.20	85 - 93
Takeoff Roll	100	100 - 140	00	2.12 - 2.20	85 - 93
Takeoff	100	100 - 140	00	2.12 - 2.20	85 - 93
Climb	89 - 100	220 - 344	03 - 44	1.90 - 3.00	72 - 100
Cruise Normal	76 - 97	205 - 298	05 - 45	0.00 - 3.00	00 - 98
Cruise With Speed Brakes, Gear and/or Flaps Extended	78 - 95	170 - 235	02 - 40	1.20 - 1.75	10 - 60
Cruise With Gunfire	88 - 92	228 - 283	30 - 43	2.10 - 2.20	45 - 61
Normal Descent	79	225	34	1.35	10
Normal Descent With Speed Brakes, Gear and/or Flaps Extended	60 - 91	135 - 308	01 - 30	0.00 - 1.80	0 - 61
Touchdown	58 - 90	120 - 135	00	00 - 130	0 - 15
Landing Roll	58 - 60	90 - 135	00	0.00	000
Drag Chute Release	58	90	00	0.00	000
Bomb Bay Open	86 - 88	208 - 233	42 - 45	2.26 - 232	55
Cruise Turbulent Air	91 - 95	215 - 280	29 - 45	2.45 - 2.80	75 - 85
Turn With 1 g or Less	84 - 89	227 - 232	4 - 40	1.29 - 2.25	10 - 57

3. Data Processing

The reels of tape were edited and each five-second record was spliced into a continuous loop and properly labeled. These records were analyzed by means of a Model 510 Davies automatic analyzer which was used in conjunction with a Davies Model 502 magnetic tape playback system. The complete playback and analysis system is shown in Figure 3.



Figure 3. Automatic Tape Playback and Analysis System Equipment

The Model 502 Davies magnetic tape playback system had been modified to provide playback at either 15 or 30 inches per second. The tape playback contains a servo-control system which permits playback of the tape within very close tolerances of its original recorded speed. During playback the output from all fourteen tracks is fed back simultaneously into the fourteen FM playback discriminators. The output signal from each of the 12 data-channels is a 1 to 1 reproduction of the original analog signal. An important feature of the playback system, i.e., electronic compensation, should be discussed briefly at this point. During the data recording process, the input to the #7 tape track (channel) is the voltage from a

very stable, crystal-controlled, reference frequency oscillator contained within the recorder. During playback a portion of this 10-KC signal is fed into a standard FM discriminator channel. Assuming there were no wow and flutter during playback, the output voltage from this particular discriminator (channel seven) would be zero. Therefore, if any voltage were obtained from this channel during playback, it would be an "error" voltage produced by wow and flutter. This "error" voltage with its phase shifted 180° is fed simultaneously into the output stage of each of the twelve data-channels. Prior to playback of data, each of the data-channels is adjusted for optimum cancellation (approximately 40 db). Hence, an overall dynamic range of 45 db (recorded through playback) can be maintained consistently. Table III contains a summary of pertinent facts pertaining to the Model 502 Davies magnetic tape playback system and the Model 510 Davies automatic wave analyzer.

TABLE III

SPECIFICATIONS FOR DAVIES LABORATORIES
MODEL 502 MAGNETIC TAPE PLAYBACK
AND MODEL 510 AUTOMATIC ANALYZER

Frequency Range	3 cps to 2,000 cps
Frequency Accuracy	0.2 cps from 3 to 40 cps 0.5% from 40 to 2,000 cps
Input Voltage Range (2-position switch)	1.0 volt or 10 volts rms maximum
Amplitude Accuracy	5% of reading or 0.2% of full scale
Selectivity	Narrow Range - continuously variable from 1/2 to 8 cps Broad Range - continuously variable from 8 to 45 cps
Scanning Speeds, Motor Drive	Speed Range 25:1 - continuously adjustable Minimum Sweep Time - 15 minutes Maximum Sweep Time - 6 hrs. and 15 min.
Recorder Speed of Response	2 seconds for 90% full scale
Tape Speed	15 or 30 inches per second
Loop Length	Approx. 2-1/2 ft. to at least 75 ft.
Tape Width	1 and 1-3/4 inch

The Model 510 Davies automatic analyzer is a constant-bandwidth, heterodyne analyzer complete with motor-driven, variable-frequency oscillator. The system has six separate analyzers and can analyze six data-channels simultaneously. Both the oscillator scanning rate and analyzer bandwidth are adjustable within the following limits: (1) scan rate range of 0.3 to 3.0 cps/sec, and (2) bandwidth range of 1 to 40 cps.

The output of the six wave-analyzer-channels is fed into six modified Brown strip-chart-recorders. Continuous spectrum plots of frequency (cps) vs. voltage (rms) are produced by the strip-chart-recorders. The chart speed is servo controlled and can be varied from 0.08 inches per minute to 13.5 inches per minute. The voltage is plotted on a logarithmic scale and the time required for full-scale deflection, i.e., zero to one volt, is approximately two seconds. A sample analysis of a 100-cps square wave is shown in Figure 4. In selecting the bandwidth to be used in an analysis of this type, one must consider the following: (1) the frequency resolution desired, (2) the rate of scan, (3) the length of the data sample, (4) the time available for data analysis, (5) the quantity of data to be analyzed, (6) the type of data being analyzed, and (7) the type of presentation of the completed data. Based on a consideration of these variables, a bandwidth of ten cycles per second was selected for these analyses.

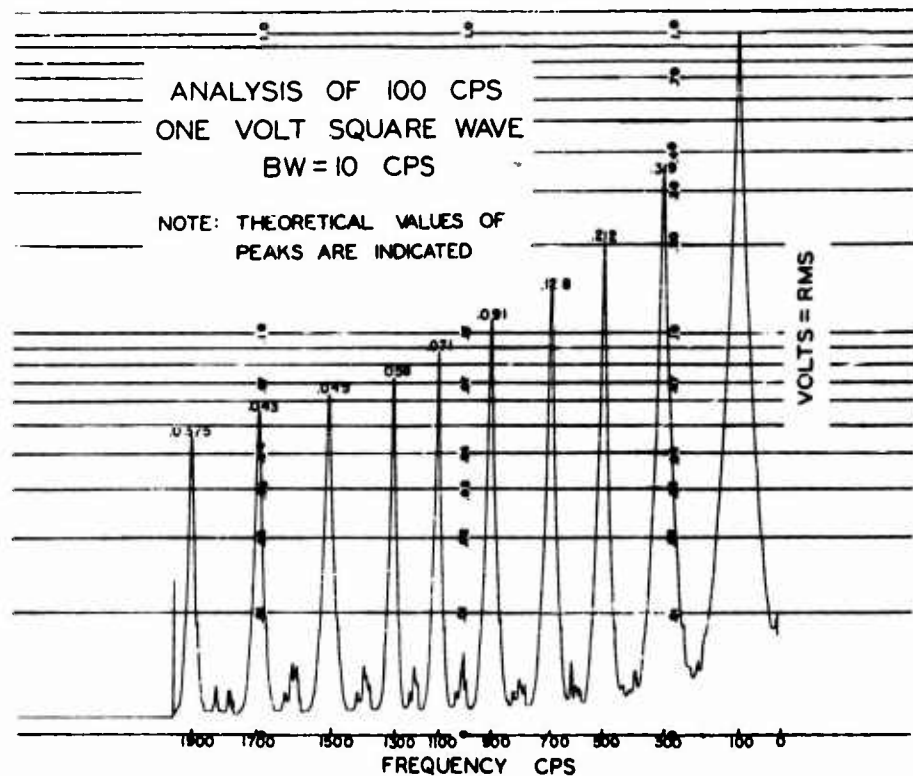


Figure 4. Analysis of 100 cps One Volt Square Wave

Following the harmonic analysis, the Brown strip-chart-recordings were edited and voltage peaks of interest were marked. Each of these peaks constitutes a data point. The corresponding values of frequency and voltage for each of these peaks were tabulated and subsequently punched into IBM cards. Each data point was recorded on a separate card. Then, these cards were processed through the ERA 1103A scientific computer at the rate of ninety cards per minute. Prior to processing each set or flight of data cards through the computer, a series of three sets

of "Master Cards" was prepared and fed into the computer. These sets of "Master Cards" are:

(1) The "Flight Condition Masters" which contain all of the necessary flight parameters, i.e., altitude, indicated airspeed, power, etc., associated with each of the data cards. The information is obtained from the flight-test data card.

(2) The "Pickup Location Masters" which contain the information required to identify each data point of each channel and record number with a particular pickup.

(3) The third set of "Masters," which is known as the "Source and Order Masters," contains sufficient information to identify specific vibration frequencies with known orders of engine and propeller unbalance and the blade passage frequencies of the propeller or rotor blades, as the case may be.

As the data cards were processed, a new and complete "answer" card having the following information was produced: (1) the computed values of double amplitude in inches and acceleration in g units and their corresponding natural logarithms; (2) all of the data on the original data card; (3) all of the appropriate data obtained from the "Master" cards. The order and limits of the information in the final analysis are shown in Table IV.

After the computations were completed, all of the data cards were arranged in the desired sequence by means of an IBM sorter. Then a multi-copy IBM listing was made of all data. These listings were used in detail studies of the data and in checking the accuracy of the completed graphs.

Automatic plotters utilizing IBM card input were used to plot the graphs of frequency in cycles per second vs. vibratory double amplitude in inches. The plotting rate ranged from 30 to 60 points per minute. Three types of graphs were prepared:

- (1) summary (all test conditions on all flights) plots for each vibration pickup;
- (2) summary plots for each cluster (2 or 3) of pickups;
- (3) summary plots for each structural zone.

Each of the three graph types included all of the data obtained on the seven test flights. No plots were made to indicate the effects of such variables as power, altitude, indicated airspeed, etc. Plots of this type can be obtained upon request.

The Type 1 graphs permit a detail study of the vibration characteristics along a single axis at a particular location in the test vehicle. The Type 2 graphs present the overall vibration-environment measured under all test conditions at each of the 26 test points; generally, these include all data obtained from the 2 to 3 pickups in each cluster.

TABLE IV
SUMMARY OF INFORMATION ON IBM CARDS

<u>Card Column</u>	<u>Range</u>	<u>Category</u>
1 - 2	0 - 99	Pickup Location
3 - 4	1 - 31	Day
5 - 6	1 - 12	Month
7 - 8	1 - 24	Time
9 - 10	1 - 12	Channel Number
11 - 12	0 - 99	Record Number
13 - 16	0 - 2000	Frequency in cps
17 - 20	0 - .9999	Voltage
21 - 23	0 - 285	Engine Speed
24 - 26	0 - 999	IAS in Knots
27 - 28	0 - 60	Altitude in 1000 feet
29 - 30	1 - 12	Source
31 - 32	0 - 24	Order
33 - 34	1 - 63	Flight Condition
35 - 36	N. A.	Blank
37 - 41	0 - .9999	Double Amplitude in Inches
42 - 45	0 - 99.99	Acceleration in g
46 - 50	N. A.	Log of Frequency
51 - 55	N. A.	Log of Double Amplitude
56 - 60	N. A.	Log of Acceleration
61 - 62	0 - 45	Aircraft L.D. Number
63 - 65	0 - 100	Man. Pres. -- in. Hg
66 - 68	0 - 150	Power Lever Angle in Degrees Percent of Rated H. P. Percent of Rated Thrust
69 - 70	1 - 27	Structural Zone
71 - 80	N. A.	Blank

Where the overall vibration-environment for a generalized structural zone, e.g. forward quarter of the fuselage, is desired, the Type 3 graphs are the most useful. The structure of the test vehicle has been arbitrarily divided into 9 major areas. Each of these major areas has been further subdivided into the following three categories: (1) vehicle structure, (2) rigidly mounted equipment, and (3) shockmounted equipment. A complete listing of these "structural zones" is contained in Table V. Figure 5 presents a typical basic distribution of seven aircraft structural zones.

TABLE V
CODE FOR STRUCTURAL ZONE OF A/C

<u>Code Nr.</u>	<u>Structural Zone</u>
01	Forward Quarter of Fuselage
02	Center Half of Fuselage
03	Aft Quarter of Fuselage
04	Vert. & Horiz. Stab Incl. Rudder & Elevators
05	Outer one-third of Wing
06	Inner two-thirds of Wing
07	Engine
08	Rigidly Mounted Equipment in Forward Quarter of Fuselage
09	Rigidly Mounted Equipment in Center Half of Fuselage
10	Rigidly Mounted Equipment in Aft Quarter of Fuselage
11	Rigidly Mounted Equipment in Vert. & Horiz. Stab. Incl. Rudder & Elevators
12	Rigidly Mounted Equipment in Outer one-third of Wing
13	Rigidly Mounted Equipment in Inner two-thirds of Wing
14	Rigidly Mounted Equipment in Engine
15	Shock Mounted Equipment in Forward Quarter of Fuselage
16	Shock Mounted Equipment in Center Half of Fuselage
17	Shock Mounted Equipment in Aft Quarter of Fuselage
18	Shock Mounted Equipment in Vert. & Horiz. Stab. Incl. Rudder & Elevators
19	Shock Mounted Equipment in Outer one-third of Wing
20	Shock Mounted Equipment in Inner two-thirds of Wing
21	Shock Mounted Equipment in Engine
22	Engine Accessory Section
23	Main Rotor Transmission Case
24	Rigidly Mounted on Engine Accessory Section
25	Rigidly Mounted on Main Rotor Transmission Case
26	Shock Mounted on Engine Accessory Section
27	Shock Mounted on Main Rotor Transmission Case

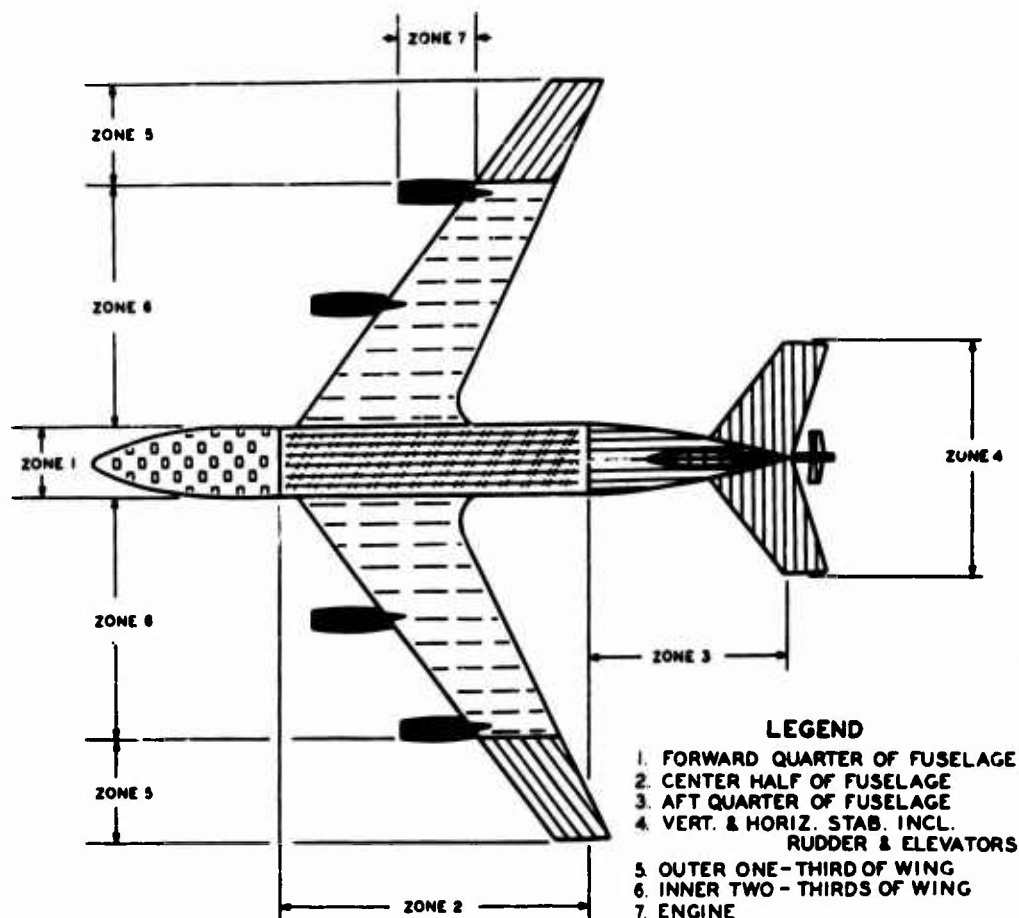


Figure 5. Schematic Presentation of Seven Basic Aircraft Structural Zones

All graphs are log-log (3 x 5 cycle) plots of frequency vs. vibratory double amplitude. As indicated previously, the log of frequency, double amplitude, and acceleration were computed during the computation phase of data reduction. This is required to permit the preparation of automatic plots of frequency vs. double amplitude on a log-log scale. The standard automatic plotters available can not accept linear input and then plot on a log scale. Therefore, by using proper scale factors, the logarithm of the variables to be plotted can be applied to any standard plotter input and the resultant graphs will be log-log plots of the original data. On the log-log plots of the frequency vs. double amplitude, levels of vibratory acceleration appear as straight lines of constant slope. Reference values of ± 0.5 , ± 1.0 , ± 5 and ± 10 have been included on all graphs. This arrangement permits simultaneous readings of double amplitude and acceleration at any given frequency. A more detailed description of the data reduction processes used to reduce the vibration data is contained in WADC TN 59-44, ASTIA Document No. AD-210478, dated February 1959, and entitled "Data Reduction Techniques for Flight Vibration Measurement."

4. Results

A total of 1152 records and 34,167 data points was obtained on the 7 test flights. In general, the data covered the 5-to 600-cps frequency range rather thoroughly. The discussion of the data contained in this report is limited to a consideration of the aircraft by structural zones. However, graphs are included for each of the 20 different test points. The use of the structural zone breakdown is sufficient for fulfilling the purpose for which this report was intended.

As indicated in the section of this report which describes the method of data presentation, the structure of the aircraft has been divided into 9 zones. These in turn have been subdivided into three categories: (1) structure, (2) rigidly mounted equipment, (3) shockmounted equipment. With three exceptions all structural zone plots in this report are for data obtained on the aircraft structure.

Figure 6 shows the data obtained on the structure of the forward quarter of the fuselage (from Sta 0 to 469). The data covers the 5-to 600-cps range rather thoroughly. The peaks which occur in the low frequency range (from 5 to 10 cps) are primarily a result of turbulent air and aerodynamic buffeting. The scattered data points between 10 and 100 cps are very low in vibratory double amplitude (with all values below 0.5 g). At the 100-to 110-cps frequency range, there is a peak condition showing the frequency range (6,100 rpm) of the low-speed rotor of the twin spool J-57 engine. The data occurring in the 140-to 150-cps frequency range is due to the high-speed rotor. The 300-to 310-cps frequency range shows the second harmonic and 450 is the third harmonic of the high-speed rotor frequency. The concentration of data in the vicinity of 300 cps could be attributed to harmonics of both the high- and low-speed rotors. However, past experience has indicated that the most probable source is the high-speed rotor. The limited scatter of points throughout the 100-to 600-cps frequency range is due to the different power settings, most of which occur between 90 and 95% rpm. The gunfire produced no appreciable double amplitudes in this area. There were 1,650 data points obtained in the forward quarter of the fuselage.

Figure 7 shows the vibratory picture of the data obtained on the structure of the center half of the fuselage (Sta 469 to 1408). The lower frequency data are a result of takeoff, turbulent air, and touchdown. The scattered points up to 100 cps are caused by the flight conditions shown in Table II. The higher double amplitudes in this region are caused by takeoff, turbulent air, and touchdown. The peaks occurring at approximately 100, 150, 200, 300, 400, 450, 500, and 600 cps are the fundamental rotor frequencies and their respective harmonics. Gunfire produced a slight increase in amplitude in this area. The center half of the fuselage yielded approximately 4,800 data points.

Figure 8 exhibits the data recorded on the structure of the aft quarter of the fuselage (Sta 1408 to 1878). The aft section of the fuselage shows clearly the frequencies produced by gunfire (30 to 40 cps and 60 to 70 cps). However, the bulk of the data included in the 60 to 70 cps cluster can be attributed to the fundamental frequency of the hydraulic power pack. The low frequencies are due to aerodynamic

turbulence, takeoff, and touchdown. The engine orders occur at the same frequencies as at other stations in the fuselage but are more pronounced, especially the first order of the high speed rotor (150 cps). The g level reaches the ± 8 mark. Approximately 6,400 data points were obtained in this area.

The data of the outer one-third of the wing, as depicted in Figure 9, show a rather even distribution of points. However, the peaks that are produced by the hydraulic power pack's unbalance are present. As expected, the low frequency data, in general, have higher vibratory double amplitude. Approximately 5,250 data points were acquired on the outer one-third of the wing.

Figure 10 shows the data obtained on the inner two-thirds of the wing structure. The number of data points is considerably less (1,500) than the data obtained on the outer one-third of the wing structure. The data is low in vibratory double amplitude in the lower frequencies, below 100 cps; but the higher frequencies (100 to 600 cps) approach the ± 10 -g level. The engine orders are faintly outlined in this area, especially the high-speed rotor frequencies.

The data of the engine area, presented in Figure 11, show clearly the engine order frequencies. The lower frequencies are due to takeoff, turbulent air, and touchdown. There is a void from 20 to 30 cps. Prior to the engine order frequencies, there is a number of data points in the 60- to 70-cps region; these data were obtained during climb, turbulent air, takeoff, and touchdown. The engine orders are present; however, the vibratory amplitude is considerably lower than that produced by data recorded in other areas of the aircraft. There were 4,950 data points obtained in the engine area.

Vibration data measured on rigidly mounted equipment located in the center half of the fuselage are shown in Figure 12. These data are very distinctly confined to the frequencies of gunfire (32 to 38 cps and 60 to 70 cps) and the engine order frequencies of the high- and low-speed rotors. There are 3,450 data points in this region.

Vibration data of rigidly mounted equipment in the aft quarter of the fuselage are shown in Figure 13. The frequencies are very discrete showing the frequencies due to gunfire (30 to 40 cps), hydraulic power packs (60 to 70 cps), and the twin spool J-57 engines with the exception of the low-speed rotor frequency of 100 cps. There are 2,450 data points recorded on the equipment in this area.

Figure 14 shows the vibration data acquired from the shockmounted equipment located in the forward quarter of the fuselage. The relative sparseness of the data is indicated by the presence of only 400 data points. The double amplitude of the gunfire and engine order frequencies are very low. The scattered data at the low frequencies are due to turbulence, takeoff, and touchdown.

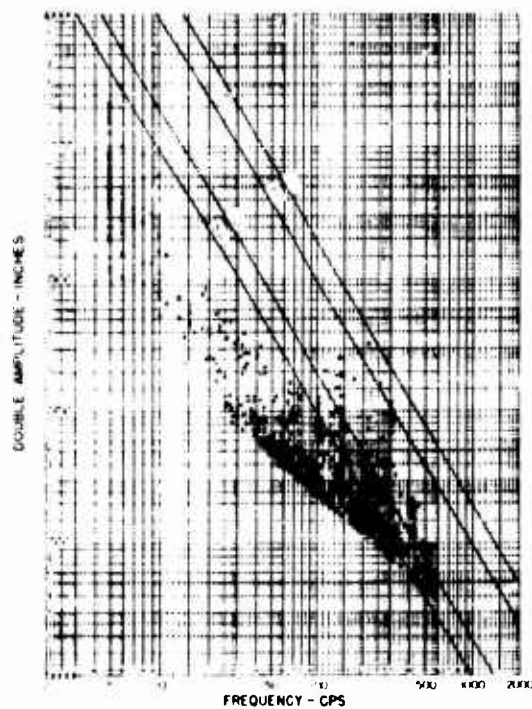


Figure 6. LOCATION: FORWARD QUARTER OF FUSELAGE

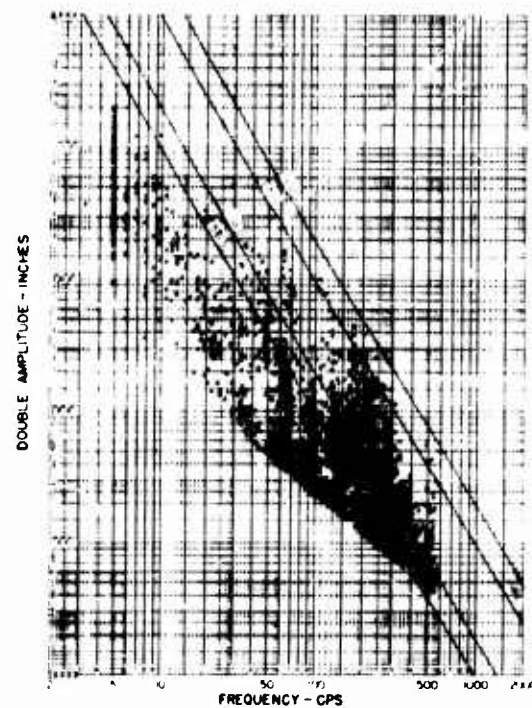


Figure 7. LOCATION: CENTER HALF OF FUSELAGE

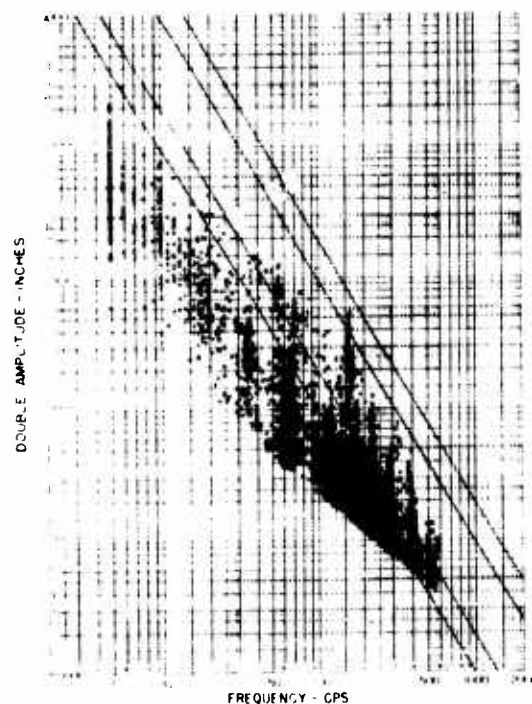


Figure 8. LOCATION: AFT QUARTER OF FUSELAGE

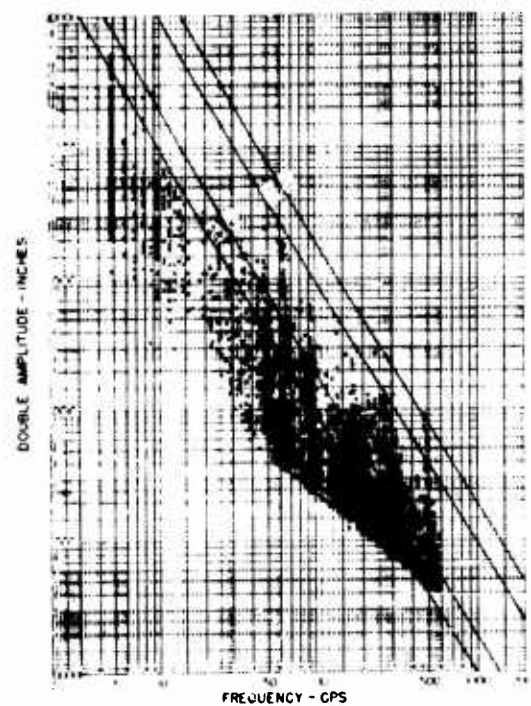


Figure 9. LOCATION: OUTER ONE-THIRD OF WING

Figures 6 to 9. Summary Plots for Structural Zones

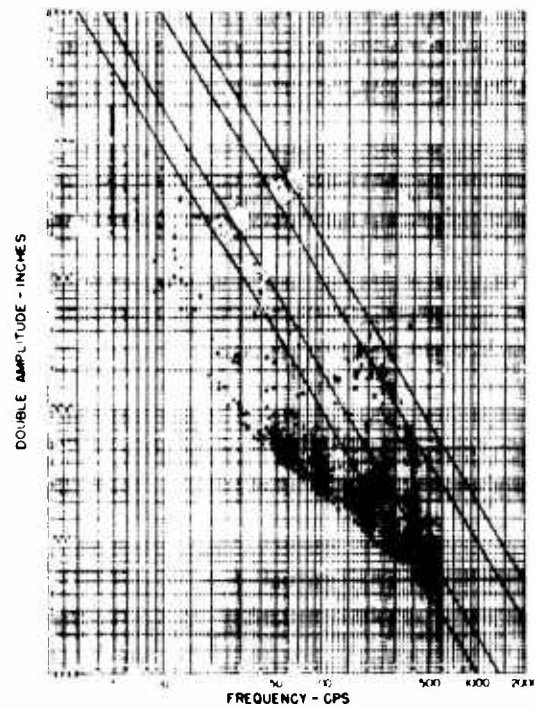


Figure 10. LOCATION INNER TWO THIRDS OF WING

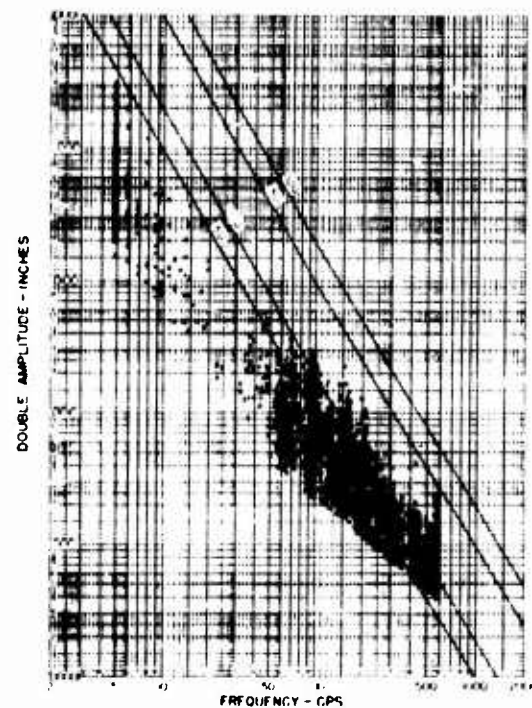


Figure 11. LOCATION ENGINE

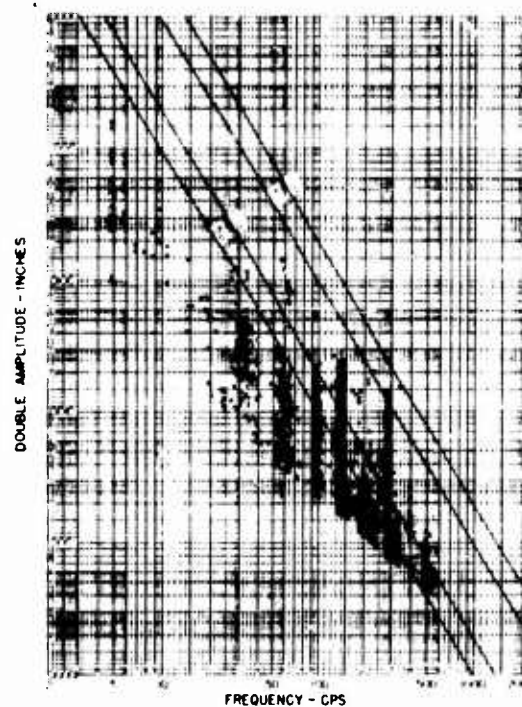


Figure 12. LOCATION RIGIDLY-MOUNTED EQUIPMENT IN CENTER HALF OF FUSELAGE

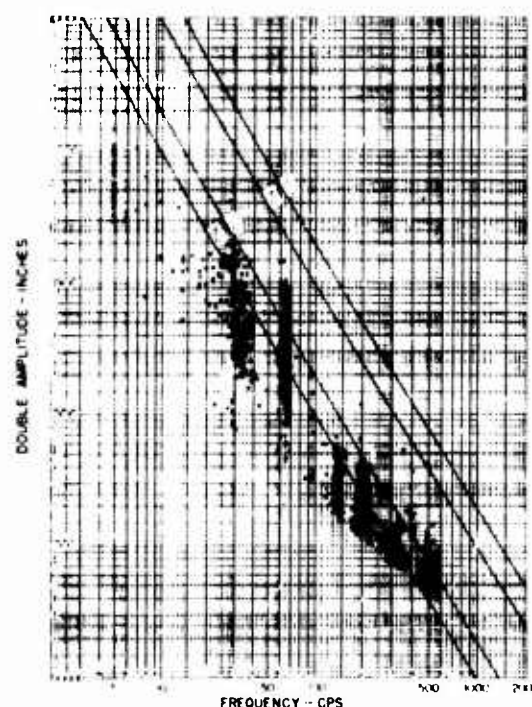


Figure 13. LOCATION RIGIDLY-MOUNTED EQUIPMENT IN AFT QUARTER OF FUSELAGE

Figures 10 to 13. Summary Plots for Structural Zones

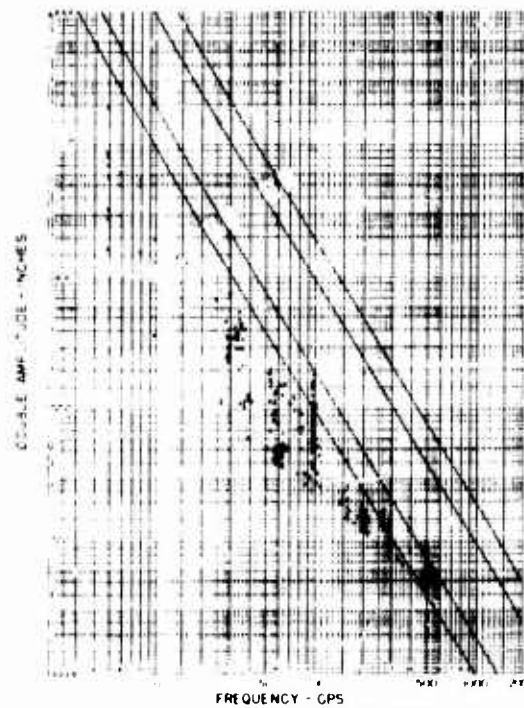


Figure 14. LOCATION: SHOCK-MOUNTED EQUIPMENT IN FORWARD QUARTER OF FUSELAGE

Figure 14. Summary Plot for Structural Zone

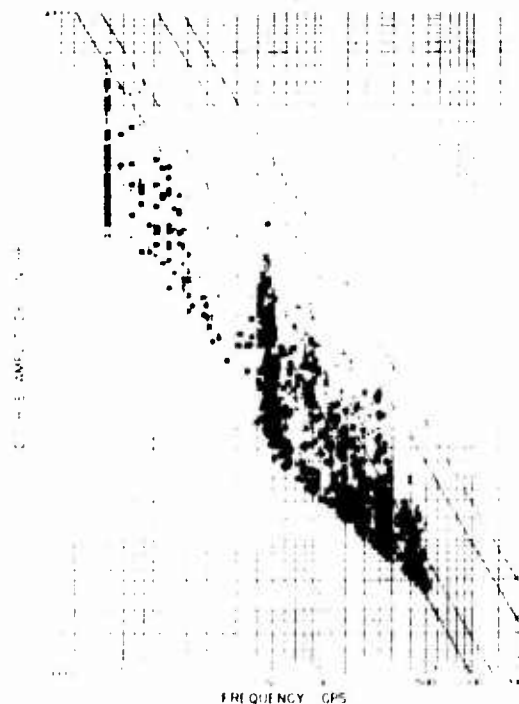


Figure 15. DIRECTION: VERTICAL, *FA: *LATERAL
LOCATION: STRUCTURE OF LEFT WING TIP



Figure 16. DIRECTION: VERTICAL, *FA: *LATERAL
LOCATION: STRUCTURE OF LEFT OUTRIGGER WHEEL WELL

Figures 15 to 16. Summary Plots for Clusters of Two or Three Pickups

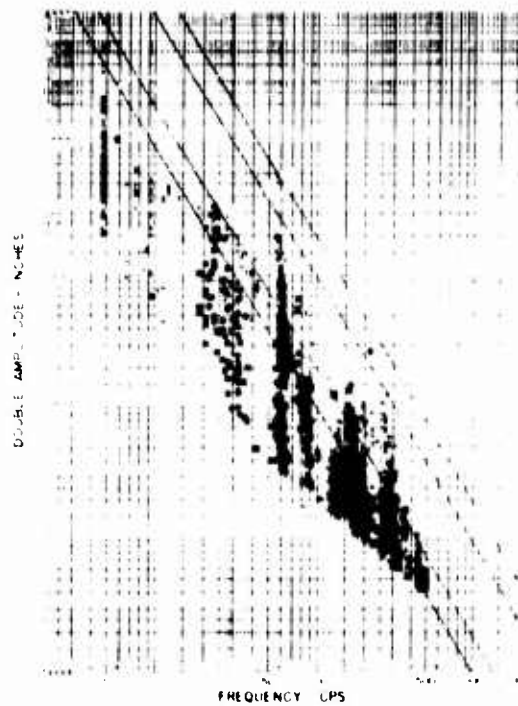


Figure 17. DIRECTION - VERTICAL, • F/A, • LATERAL
LOCATION ON CASE OF #5 HYDRAULIC PACK

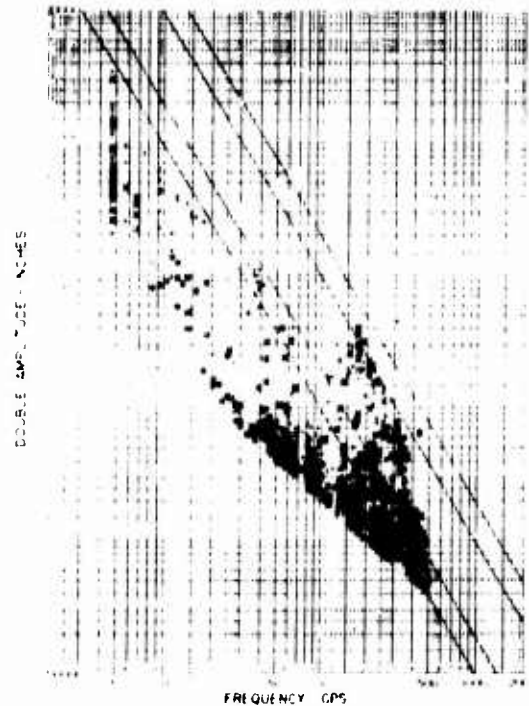


Figure 18. DIRECTION - VERTICAL, • F/A, • LATERAL
LOCATION WING STRUCTURE (TRAILING EDGE) AFT OF #2 FUEL BOOSTER PUMP

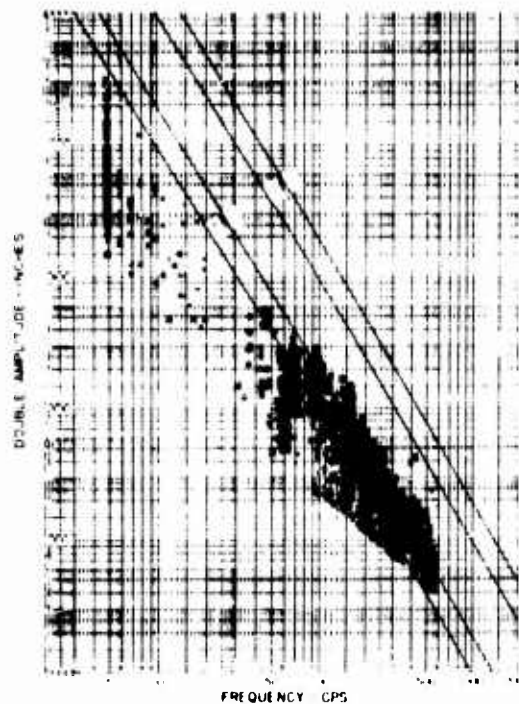


Figure 19. DIRECTION - VERTICAL, • F/A, • LATERAL
LOCATION FORWARD EDGE OF FORWARD COMPRESSOR SECTION ON #4 ENGINE

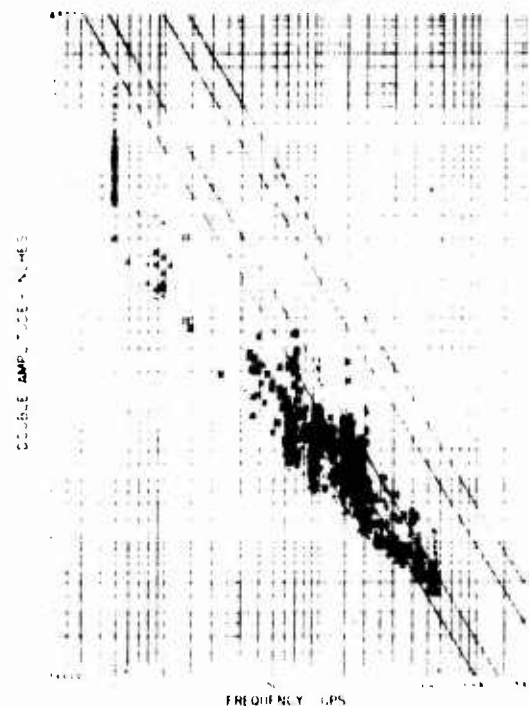


Figure 20. DIRECTION - VERTICAL, • F/A, • LATERAL
LOCATION ACCY SECTION OF #4 ENGINE FORWARD RIGHT SIDE

Figures 17 to 20. Summary Plots for Clusters of Two or Three Pickups

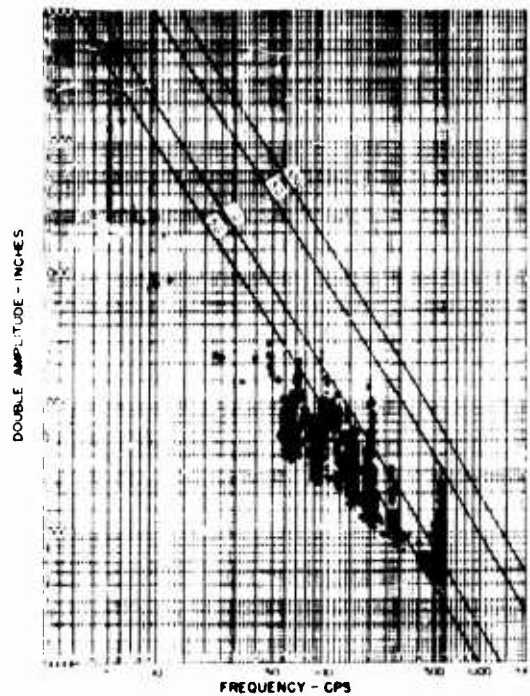


Figure 21. DIRECTION - VERTICAL, LATERAL
LOCATION - NUMBER 4 ENGINE IN PLANE
OF MAIN HANGARS

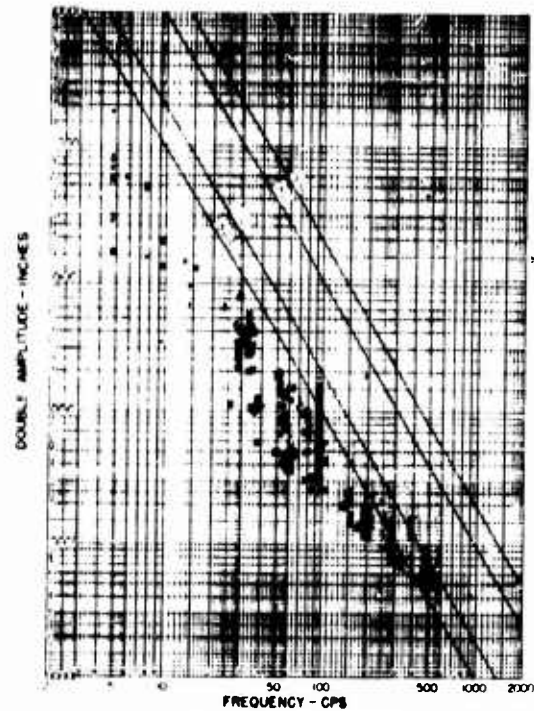


Figure 22. DIRECTION - VERTICAL, P/A, LATERAL
LOCATION - PILOT'S INSTRUMENT PANEL TOP CENTER STA. 115

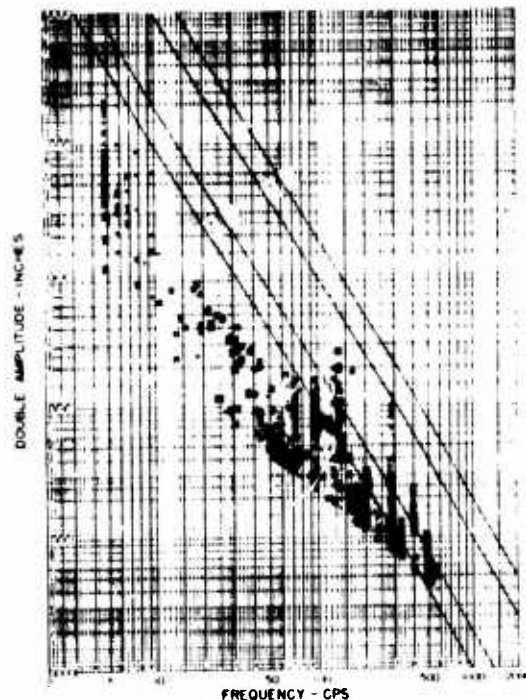


Figure 23. DIRECTION - VERTICAL, P/A, LATERAL
LOCATION - A/C STRUCTURE AT BASE OF PILOT'S SEAT
STA. 180

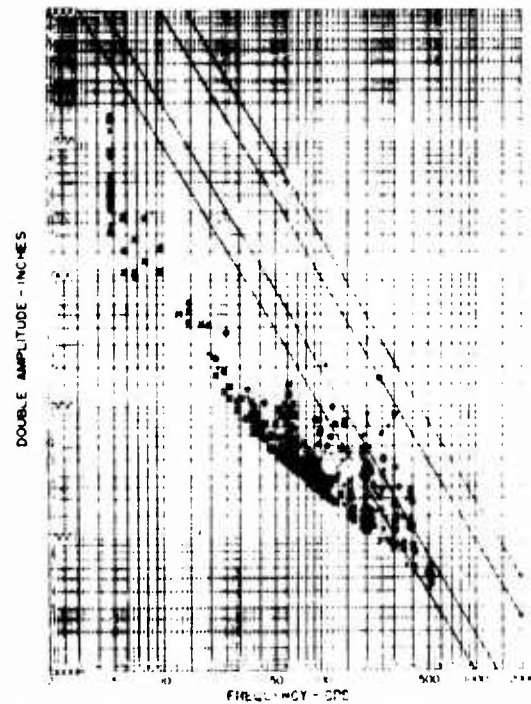


Figure 24. DIRECTION - VERTICAL, P/A, LATERAL
LOCATION - STRUCTURE OF RADIO EQUIPMENT RACK AFT
OF PILOT STA 302

Figures 21 to 24. Summary Plots for Clusters of Two or Three Pickups

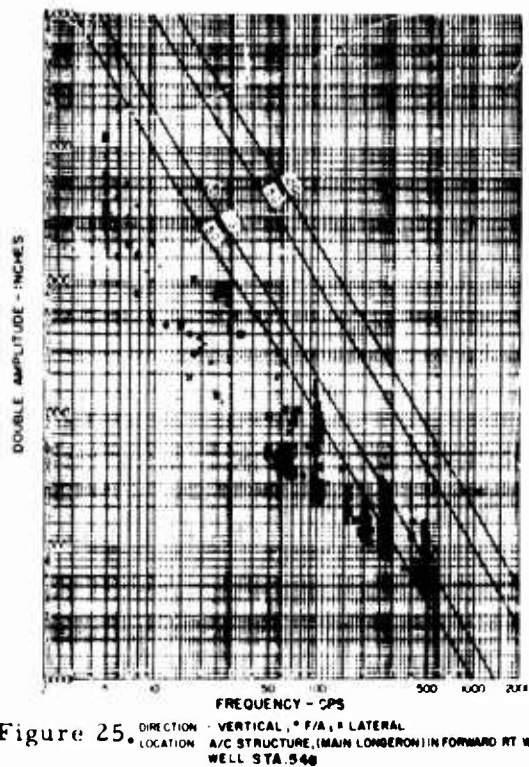


Figure 25. DIRECTION - VERTICAL, * F/A, * LATERAL
LOCATION - A/C STRUCTURE, MAIN LONGERON IN FORWARD RT WHEEL WELL STA 548

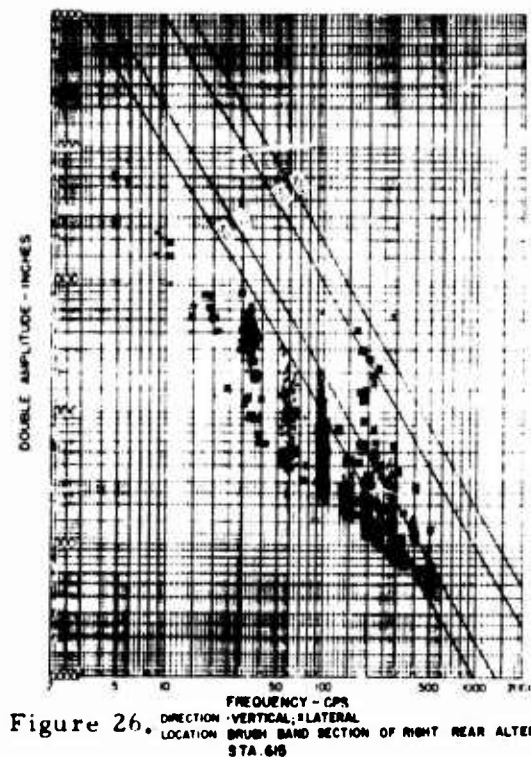


Figure 26. DIRECTION - VERTICAL, * F/A, * LATERAL
LOCATION - BRUSH BAND SECTION OF RIGHT REAR ALTERNATOR STA 615

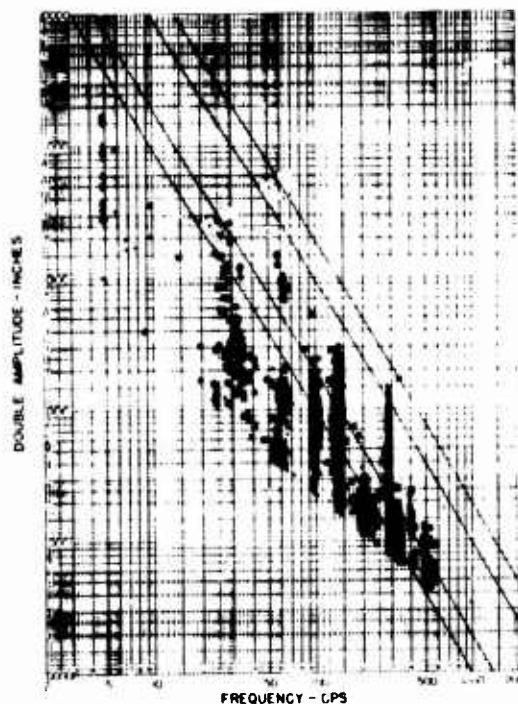


Figure 27. DIRECTION - VERTICAL, * F/A, * LATERAL
LOCATION - CASE OF RIGHT REAR ALTERNATOR DRIVE UP STA 637

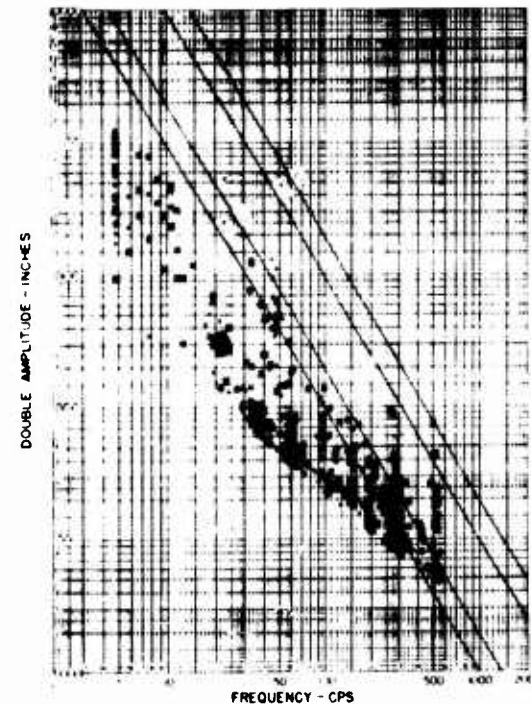


Figure 28. DIRECTION - VERTICAL, * F/A, * LATERAL
LOCATION - STRUCTURE OF FORWARD RIGHT END OF BOMB BAY STA 785

Figures 25 to 28. Summary Plots for Clusters of Two or Three Pickups

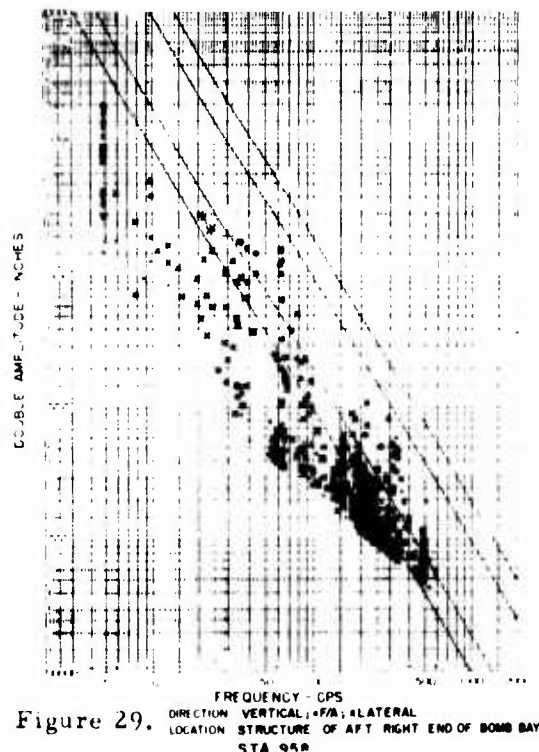


Figure 29.

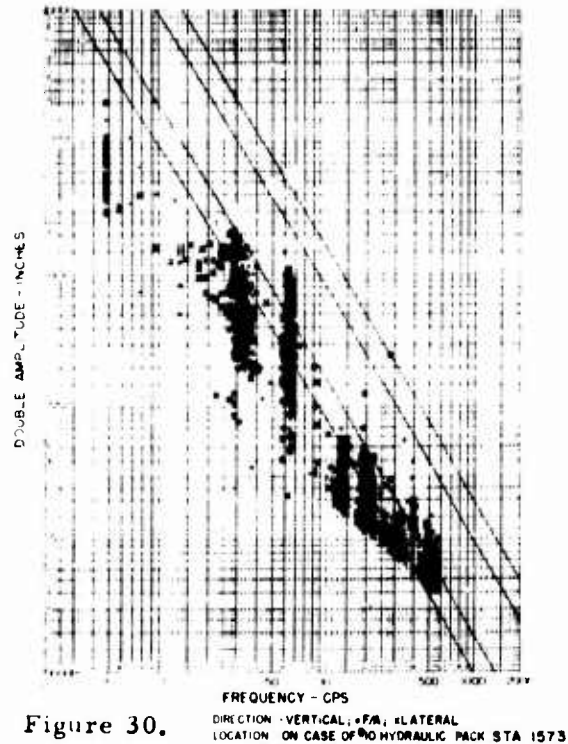


Figure 30.

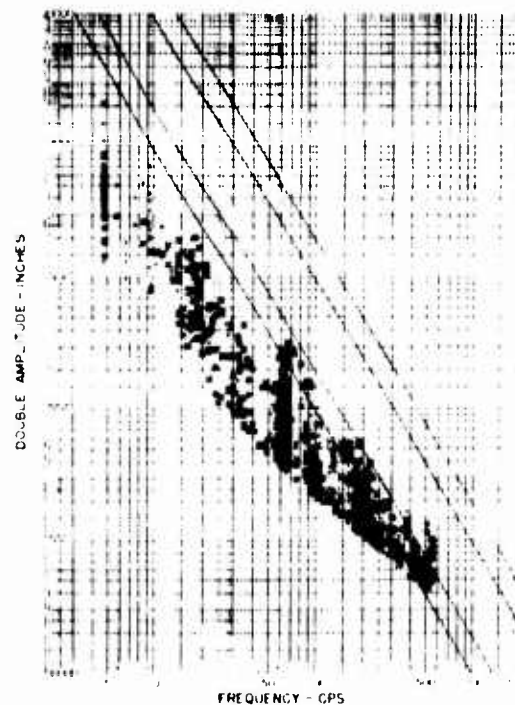


Figure 31.

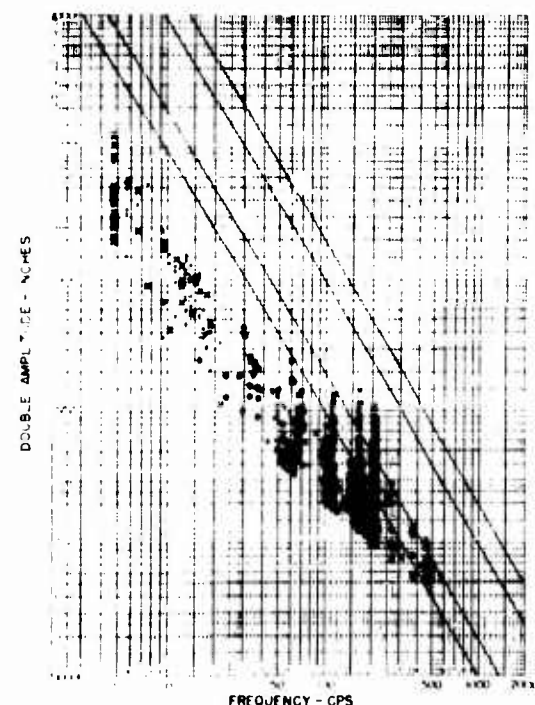


Figure 32.

Figures 29 to 32. Summary Plots for Clusters of Two or Three Pickups

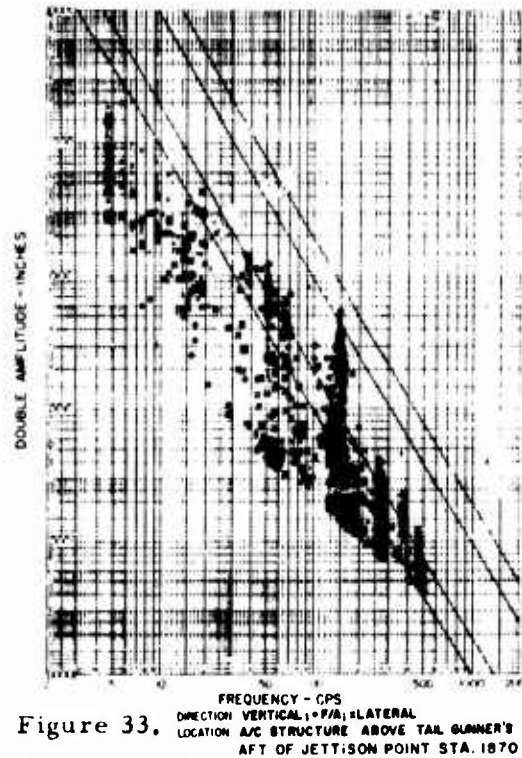


Figure 33. Summary Plot for Cluster of Two or Three Pickups

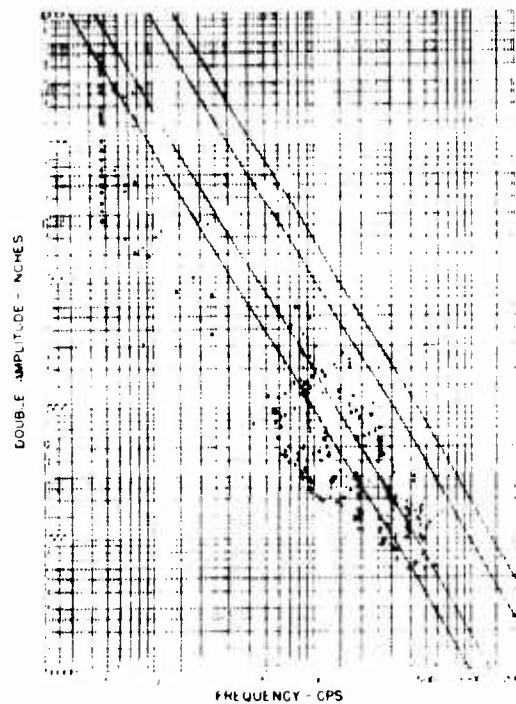


Figure 34. DIRECTION VERTICAL
LOCATION STRUCTURE OF LEFT WING TIP

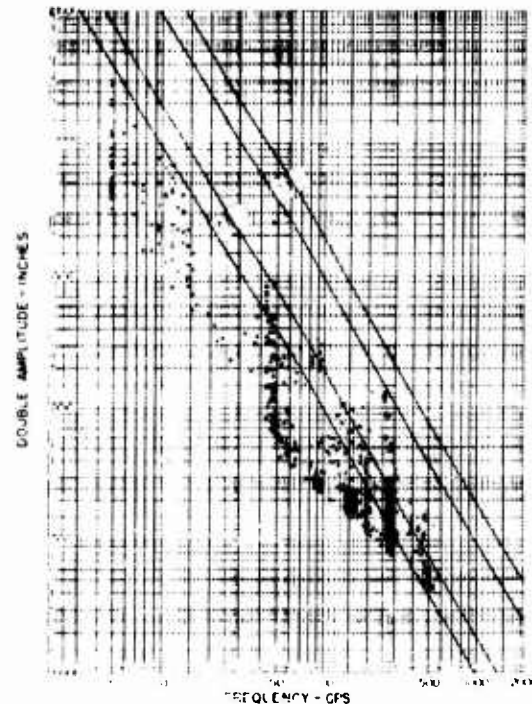


Figure 35. DIRECTION P/A
LOCATION STRUCTURE OF LEFT WING TIP

Figures 34 to 35. Summary Plots for Individual Vibration Pickups

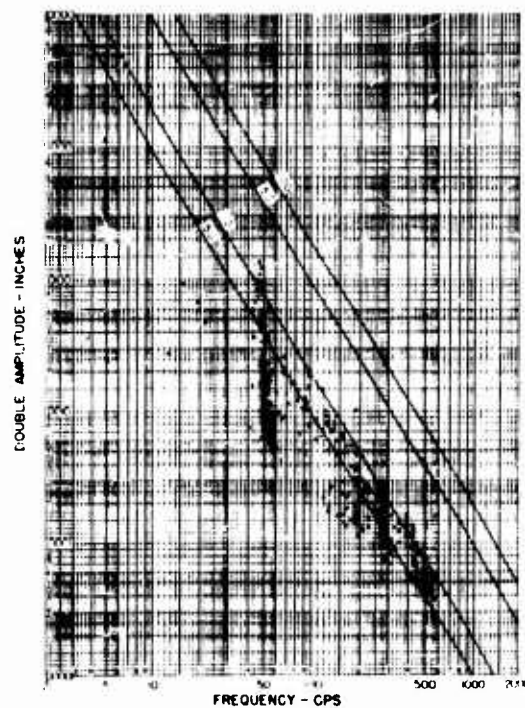


Figure 36. DIRECTION LATERAL
LOCATION STRUCTURE OF LEFT WING TIP

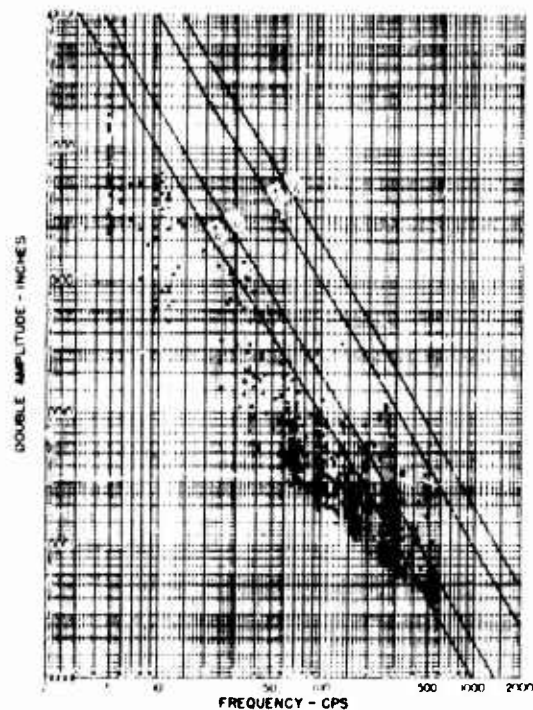


Figure 37. DIRECTION VERTICAL
LOCATION STRUCTURE OF LEFT OUTRIGGER WHEEL WELL

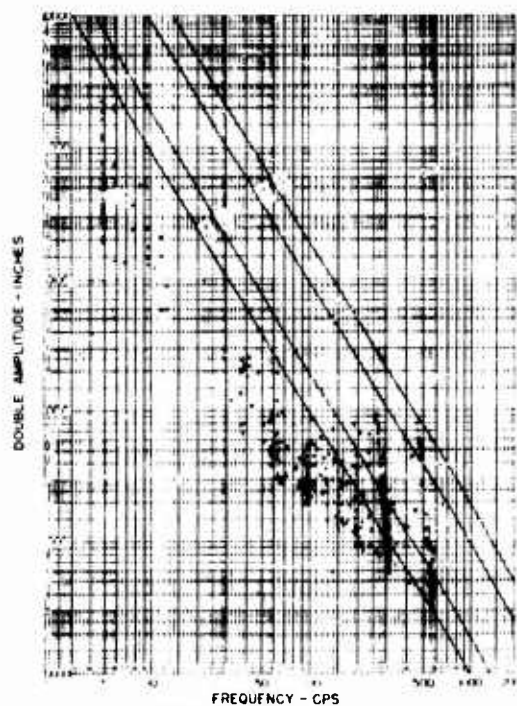


Figure 38. DIRECTION P/A
LOCATION STRUCTURE OF LEFT OUTRIGGER WHEEL WELL

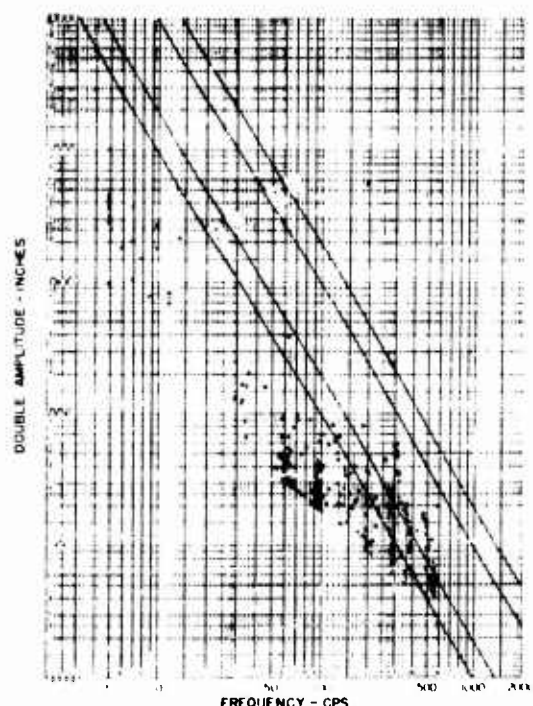


Figure 39. DIRECTION LATERAL
LOCATION STRUCTURE OF LEFT OUTRIGGER WHEEL WELL

Figures 36 to 39. Summary Plots for Individual Vibration Pickups

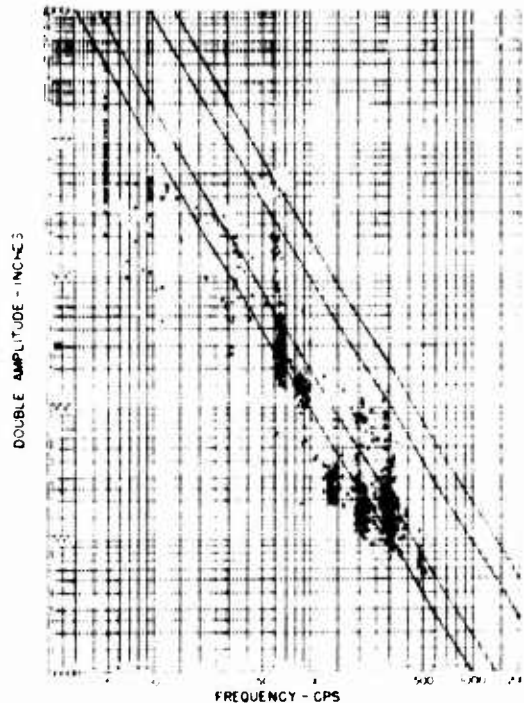


Figure 40.

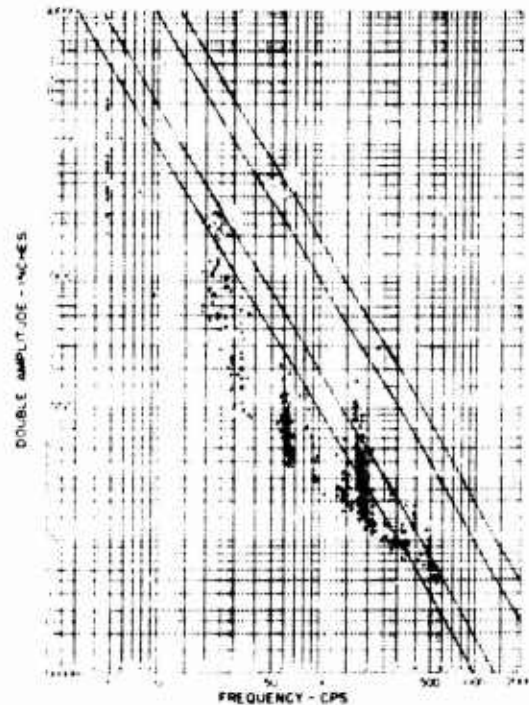


Figure 41.

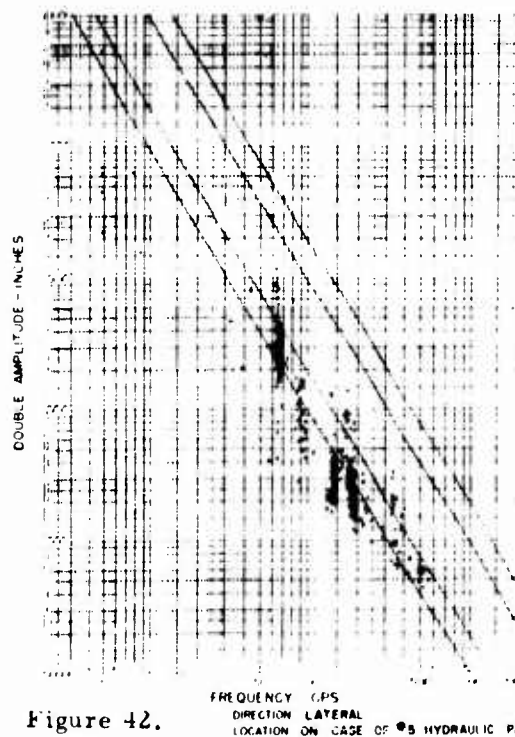


Figure 42.

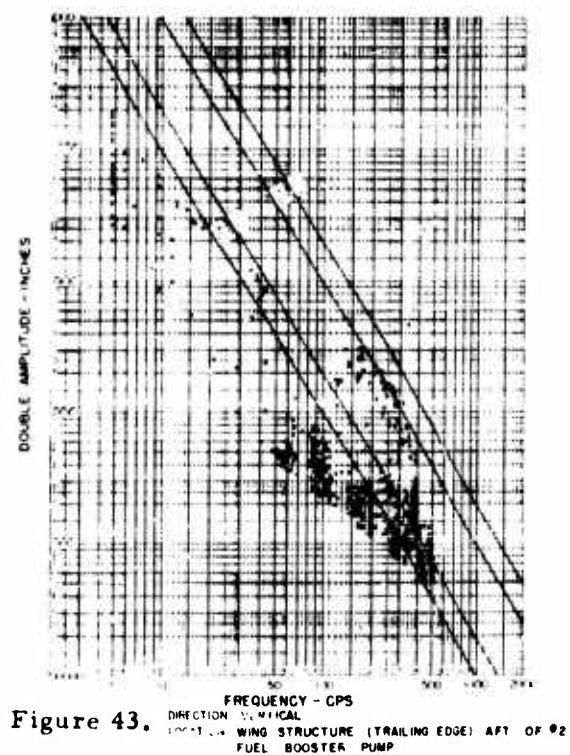


Figure 43.

Figures 40 to 43. Summary Plots for Individual Vibration Pickups

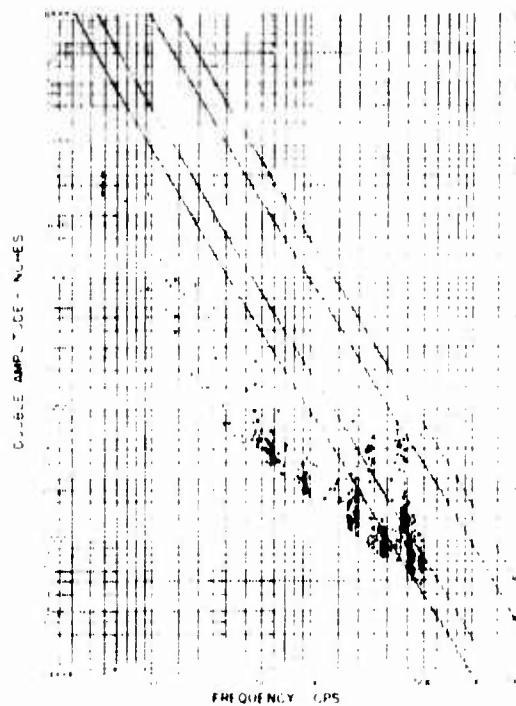


Figure 44. DIRECTION: PA
LOCATION: WING STRUCTURE (TRAILING EDGE) AFT OF #2 FUEL BOOSTER PUMP

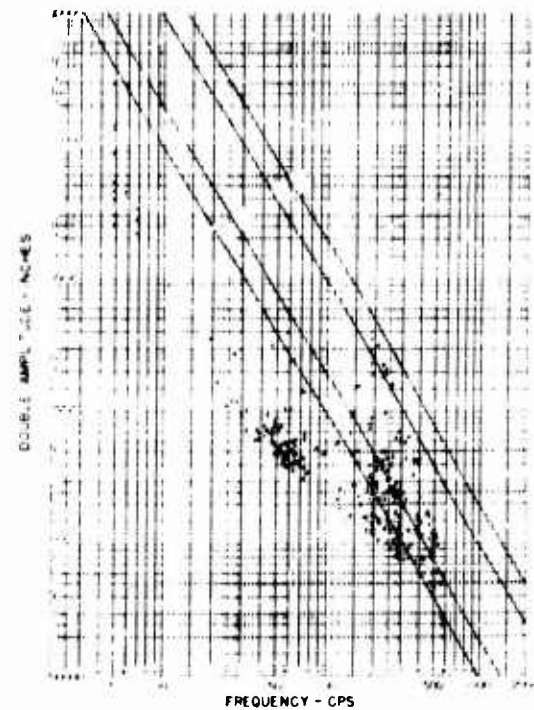


Figure 45. DIRECTION: LATERAL
LOCATION: WING STRUCTURE (TRAILING EDGE) AFT OF #2 FUEL BOOSTER PUMP

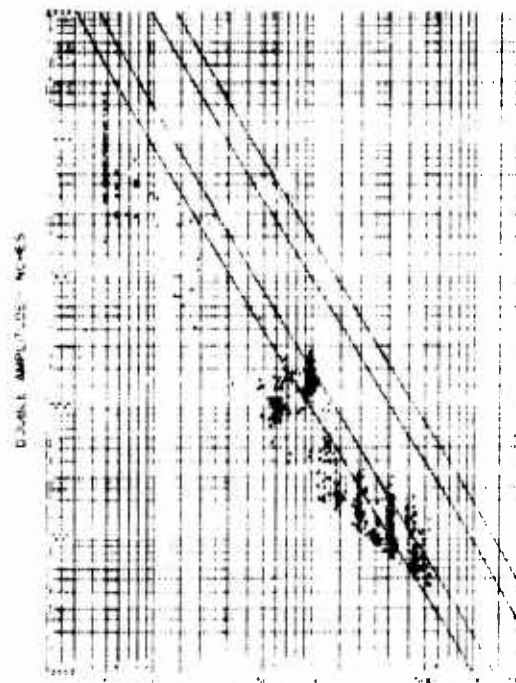


Figure 46. DIRECTION: VERTICAL
LOCATION: FORWARD EDGE OF FORWARD COMPRESSOR SECTION ON #4 ENGINE

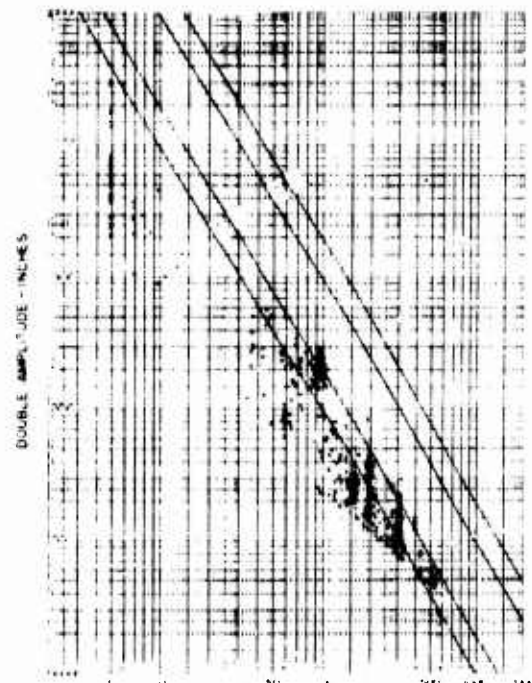


Figure 47. DIRECTION: LATERAL
LOCATION: FORWARD EDGE OF FORWARD COMPRESSOR SECTION ON #4 ENGINE

Figures 44 to 47. Summary Plots for Individual Vibration Pickups

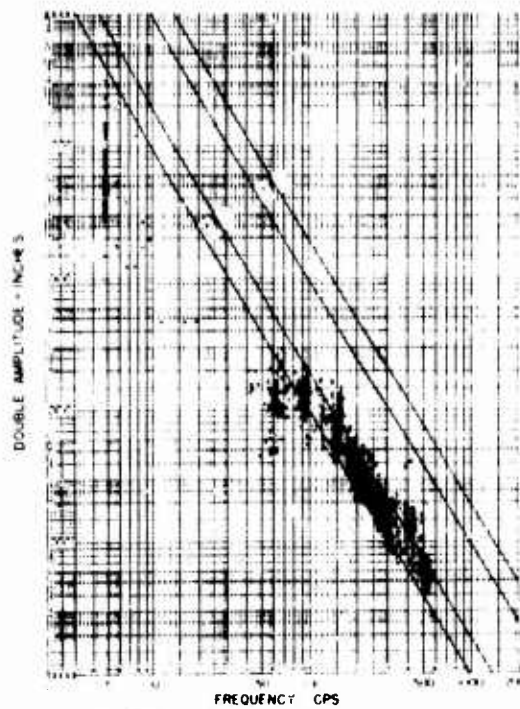


Figure 48. DIRECTION VERTICAL
LOCATION #4 ENGINE FORWARD RIGHT SIDE

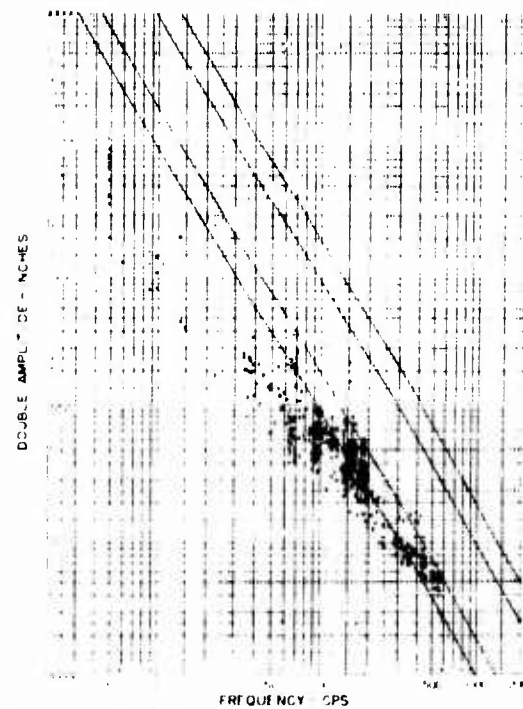


Figure 49. DIRECTION LATERAL
LOCATION #4 ENGINE FORWARD RIGHT SIDE

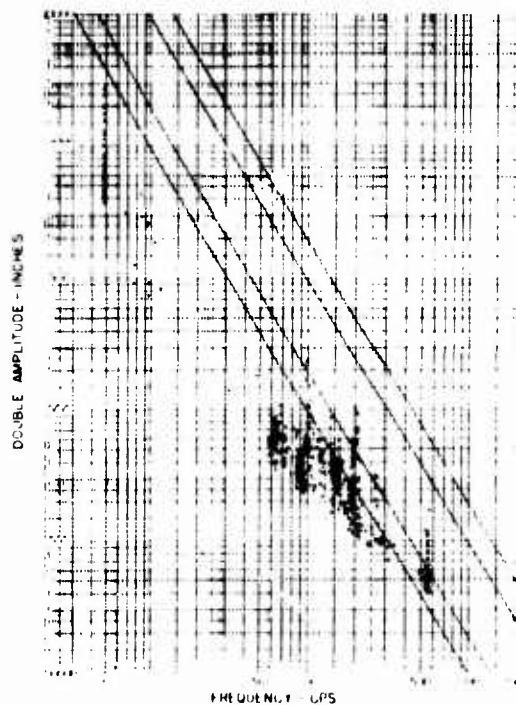


Figure 50. DIRECTION VERTICAL
LOCATION #4 ENGINE IN PLANE OF MAIN HANGAR

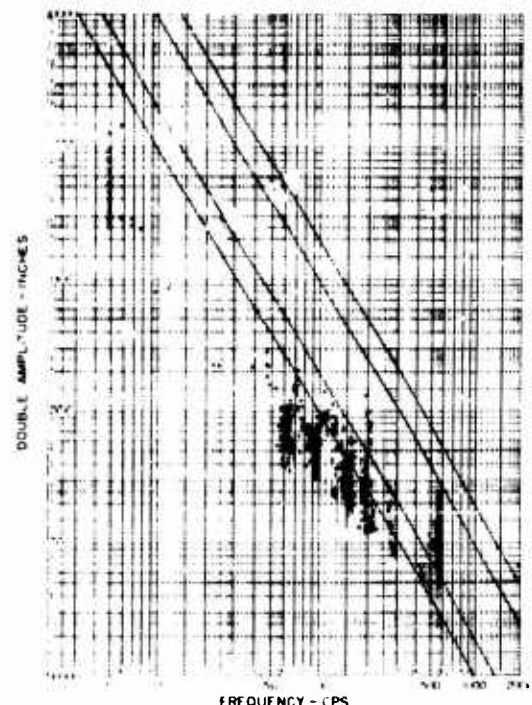


Figure 51. DIRECTION LATERAL
LOCATION #4 ENGINE IN PLANE OF MAIN HANGAR

Figures 48 to 51. Summary Plots for Individual Vibration Pickups

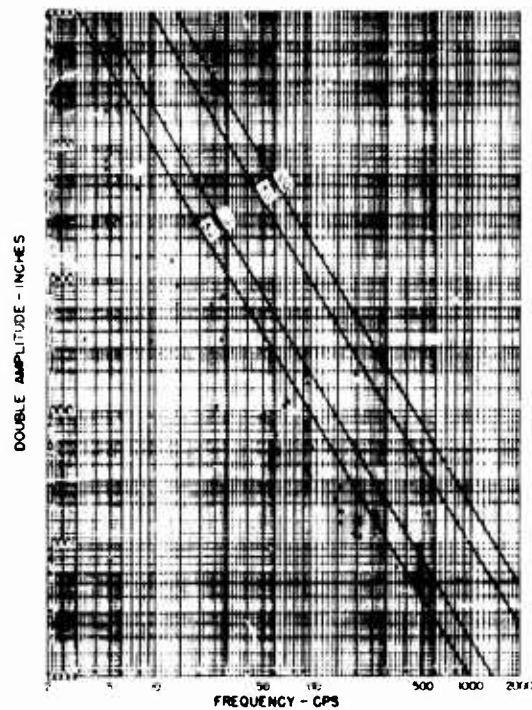


Figure 52. DIRECTION VERTICAL
LOCATION PILOT'S INSTRUMENT PANEL TOP CENTER STA 115

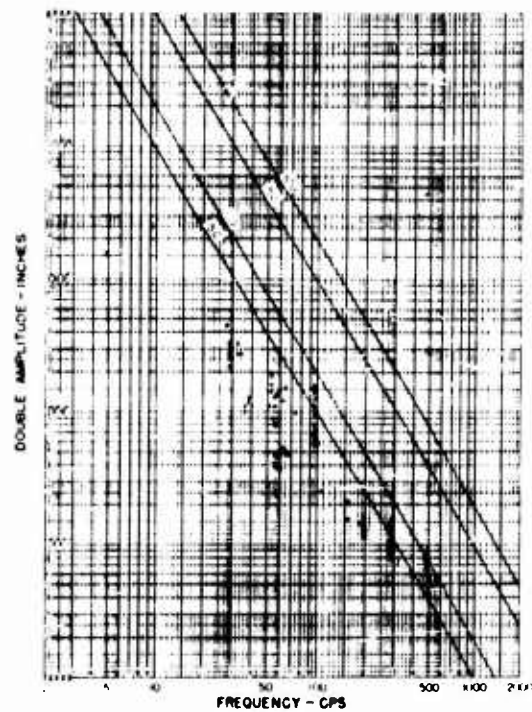


Figure 53. DIRECTION PA
LOCATION PILOT'S INSTRUMENT PANEL TOP CENTER STA 115

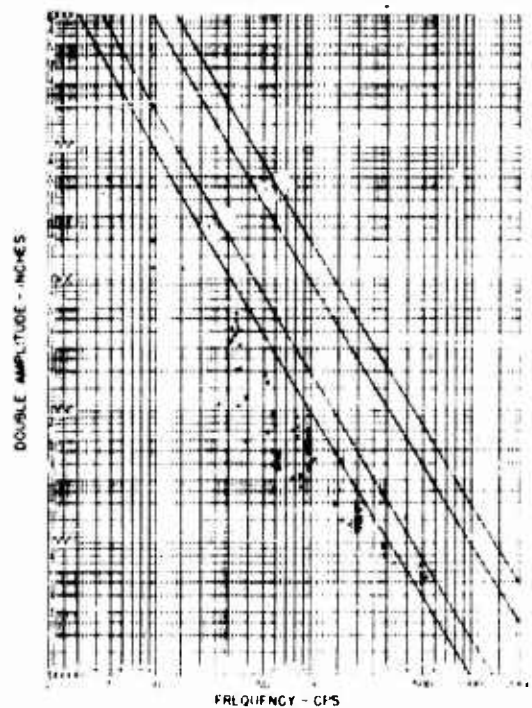


Figure 54. DIRECTION LATERAL
LOCATION PILOT'S INSTRUMENT PANEL TOP CENTER STA 115

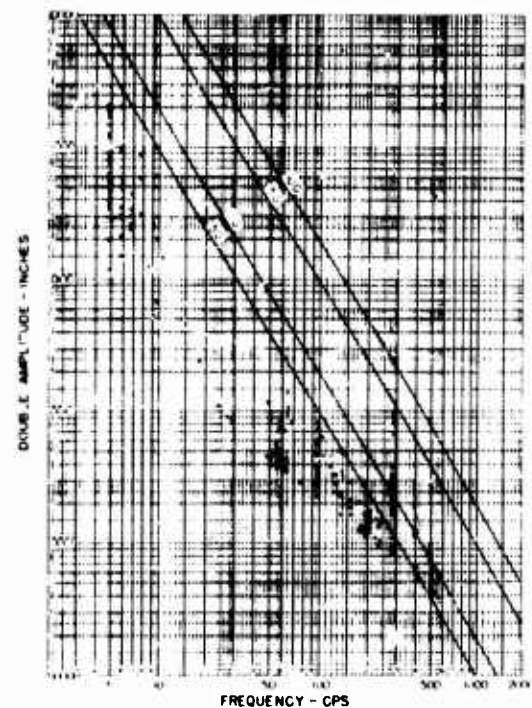


Figure 55. DIRECTION VERTICAL
LOCATION AT STRUCTURE AT BASE OF PILOT'S SEAT
STA 180

Figures 52 to 55. Summary Plots for Individual Vibration Pickups

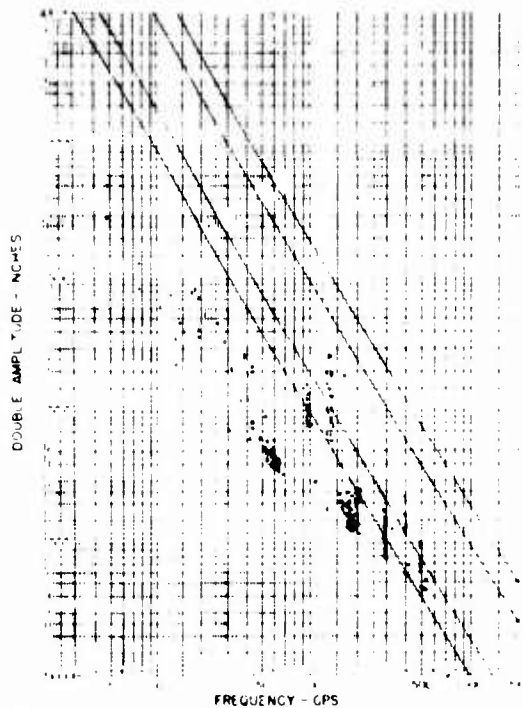


Figure 56. A/C STRUCTURE AT BASE OF PILOT'S SEAT STA 180

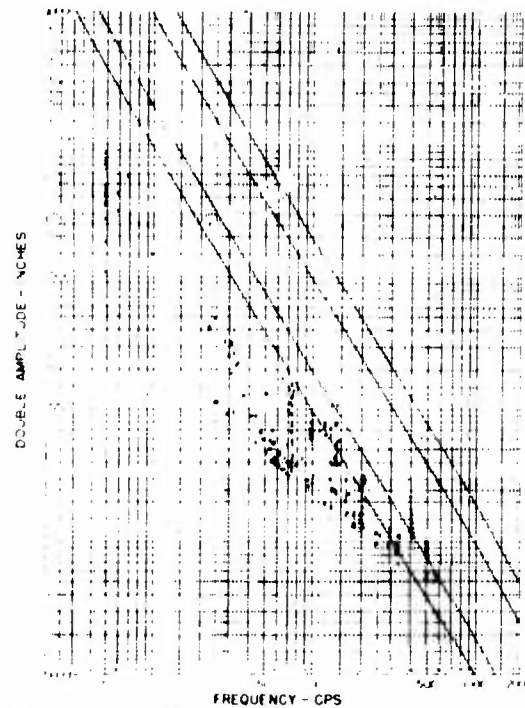


Figure 57. LATERAL A/C STRUCTURE AT BASE OF PILOT'S SEAT STA 180

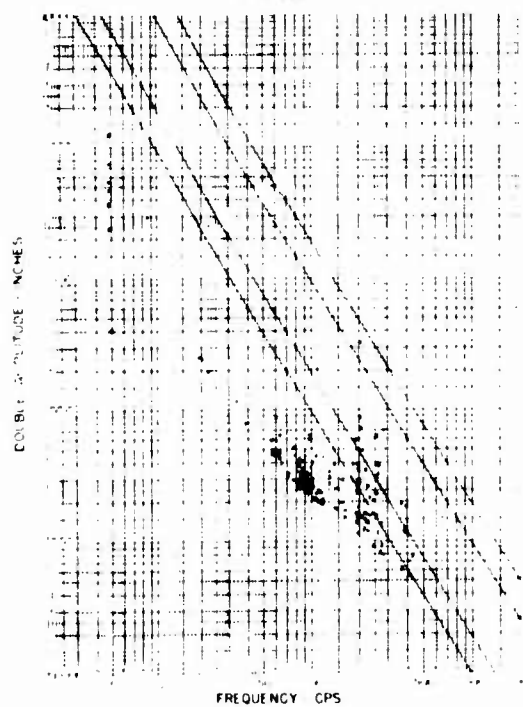


Figure 58. VERTICAL STRUCTURE OF RADIO EQUIPMENT RACK AFT OF PILOT STA 302

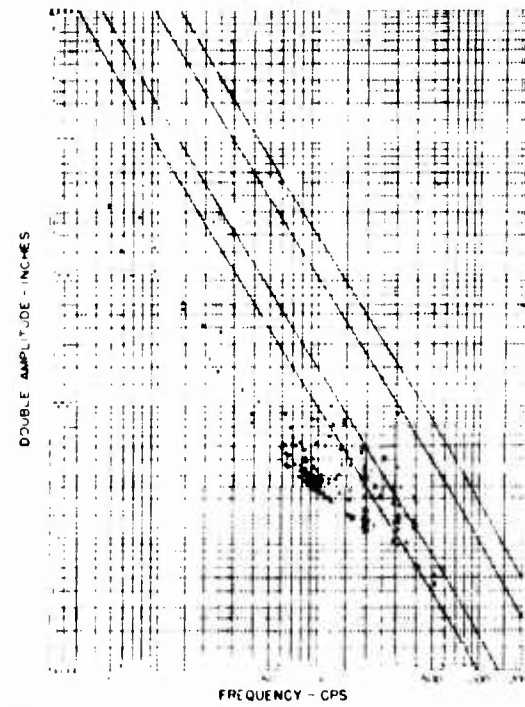


Figure 59. F/A STRUCTURE OF RADIO EQUIPMENT RACK AFT OF PILOT STA 302

Figures 56 to 59. Summary Plots for Individual Vibration Pickups

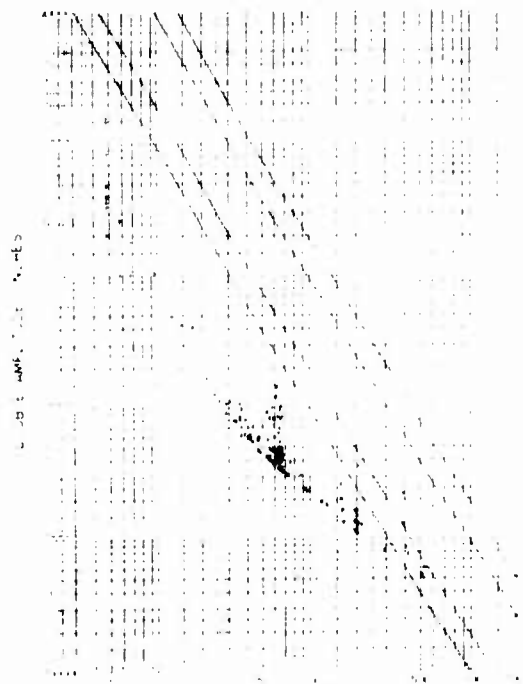


Figure 60. DIRECTION: LATERAL
LOCATION: STRUCTURE OF RADIO EQUIPMENT RACK AFT OF PILOT, STA 502

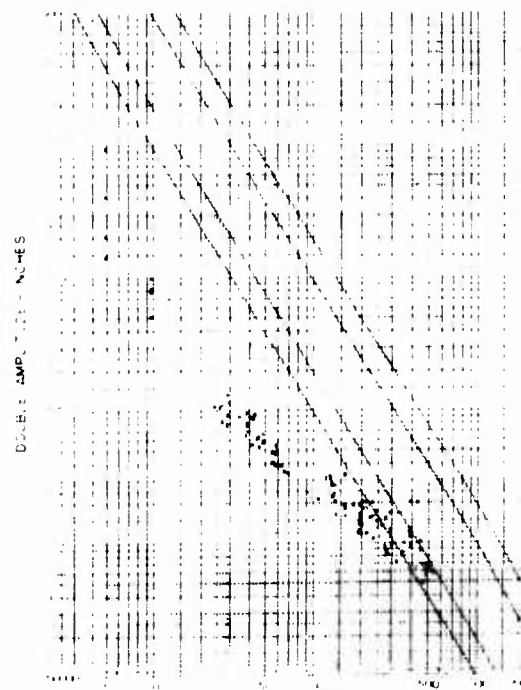


Figure 61. DIRECTION: LATERAL
LOCATION: A/C FUSELAGE RIGHT SIDE STA 316

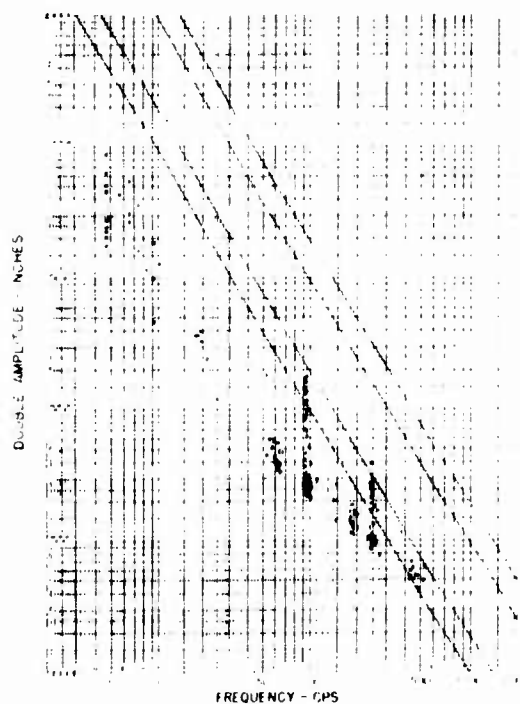


Figure 62. DIRECTION: VERTICAL
LOCATION: A/C STRUCTURE (MAIN LONGERON) IN FORWARD RT WHEEL WELL STA 548

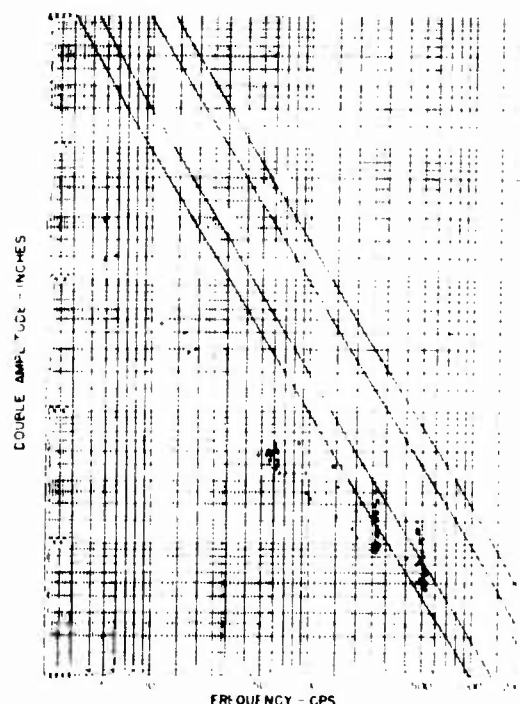


Figure 63. DIRECTION: VERTICAL
LOCATION: A/C STRUCTURE (MAIN LONGERON) IN FORWARD RT WHEEL WELL STA 548

Figures 60 to 63. Summary Plots for Individual Vibration Pickups

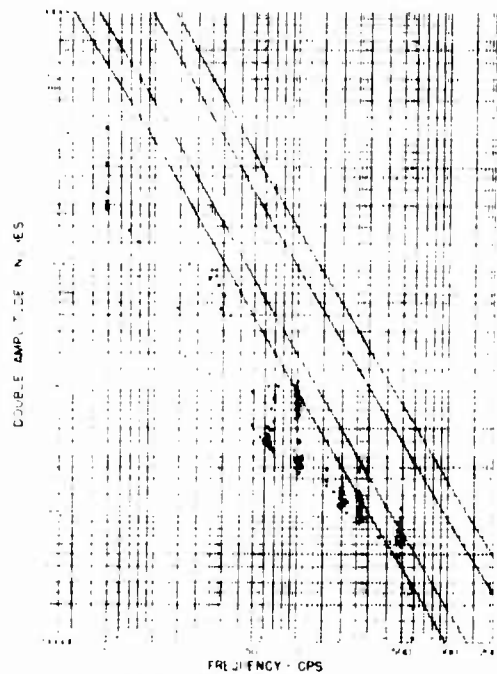


Figure 64. DIRECTION: LATERAL
LOCATION: A/C STRUCTURE, (MAIN LONGERON) IN FORWARD RT WHEEL
WELL STA 548

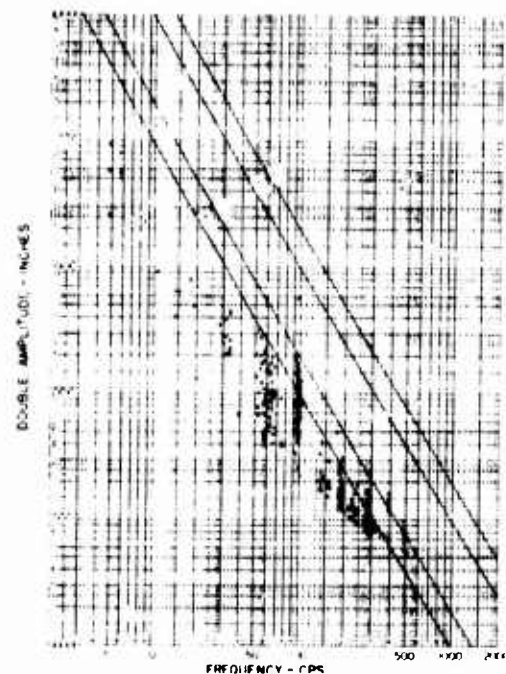


Figure 65. DIRECTION: VERTICAL
LOCATION: BRUSH BAND SECTION OF RIGHT REAR ALTERNATOR
STA 615

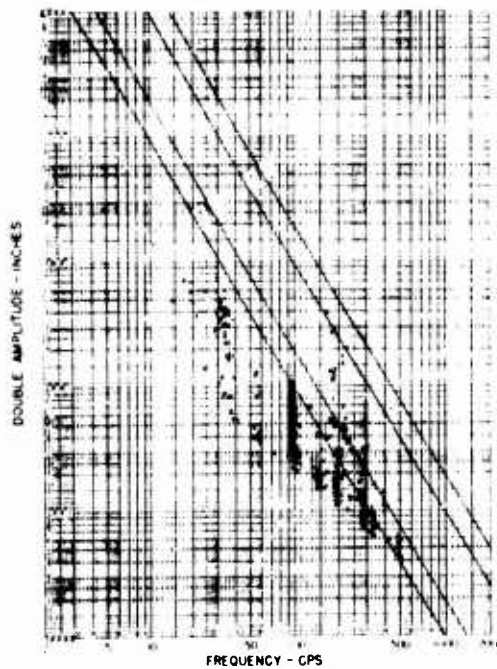


Figure 66. DIRECTION: LATERAL
LOCATION: BRUSH BAND SECTION OF RIGHT REAR ALTERNATOR
STA 615

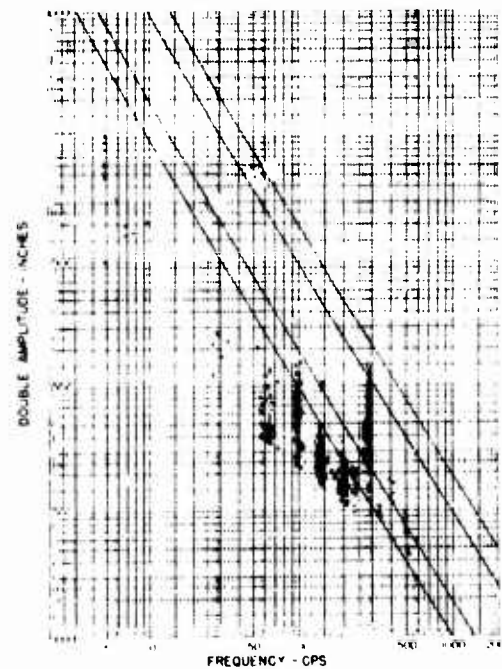


Figure 67. DIRECTION: VERTICAL
LOCATION: CASE OF RIGHT REAR ALTERNATOR DRIVE UNIT
STA 637

Figures 64 to 67. Summary Plots for Individual Vibration Pickups

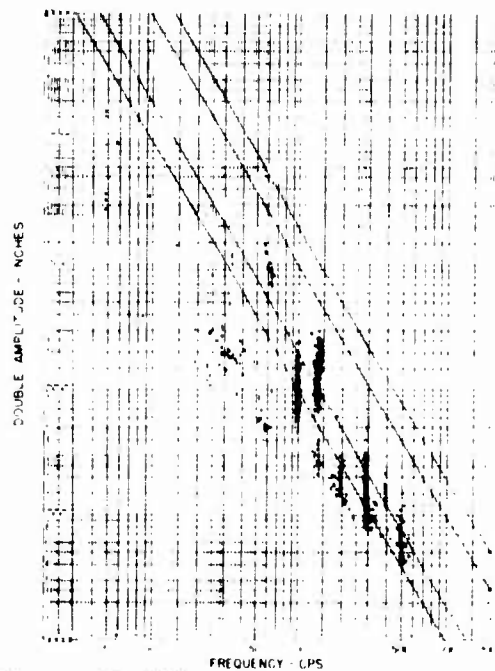


Figure 68. DIRECTION: P/A
LOCATION: CASE OF RIGHT REAR ALTERNATOR DRIVE UNIT
STA 637

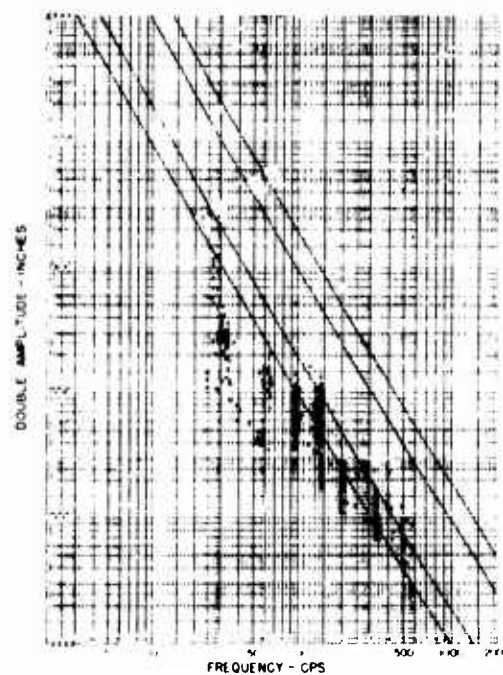


Figure 69. DIRECTION: LATERAL
LOCATION: CASE OF RIGHT REAR ALTERNATOR DRIVE UNIT
STA 637

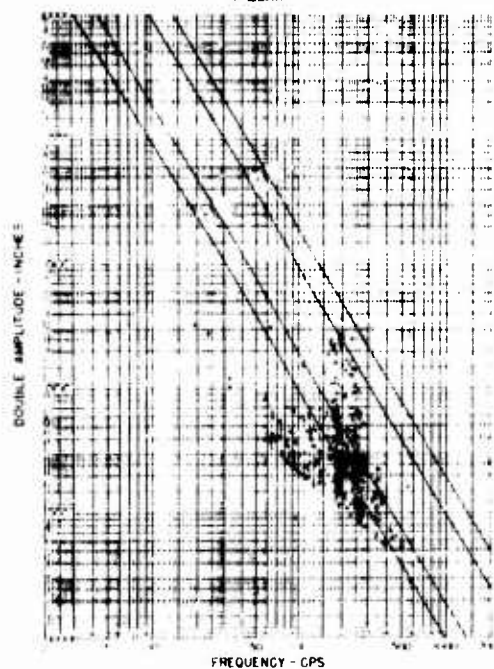


Figure 70. DIRECTION: LATERAL
LOCATION: A/C FUSELAGE, RIGHT SIDE STA 705

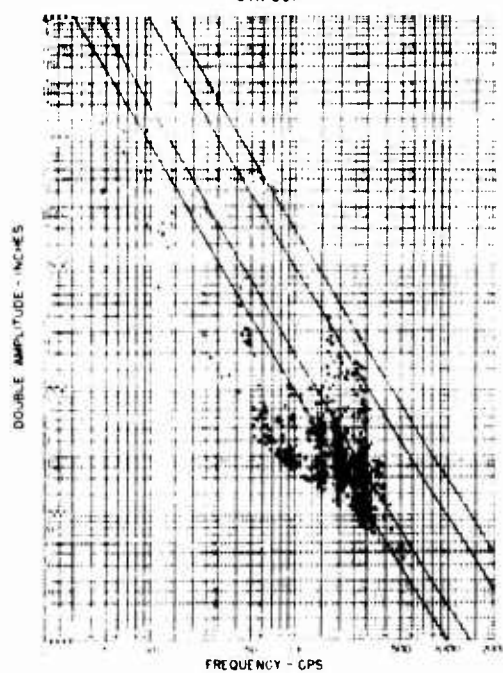


Figure 71. DIRECTION: LATERAL
LOCATION: A/C FUSELAGE, RIGHT SIDE STA 715

Figures 68 to 71. Summary Plots for Individual Vibration Pickups

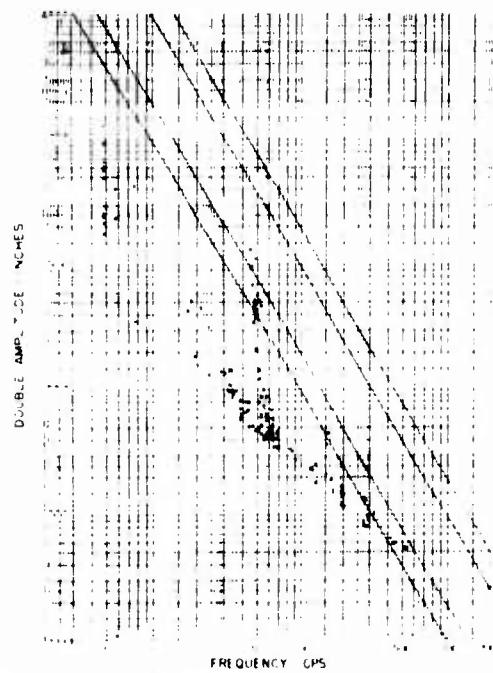


Figure 72. DIRECTION: VERTICAL
LOCATION: STRUCTURE OF FORWARD RIGHT END OF BOMB BAY
STA 784

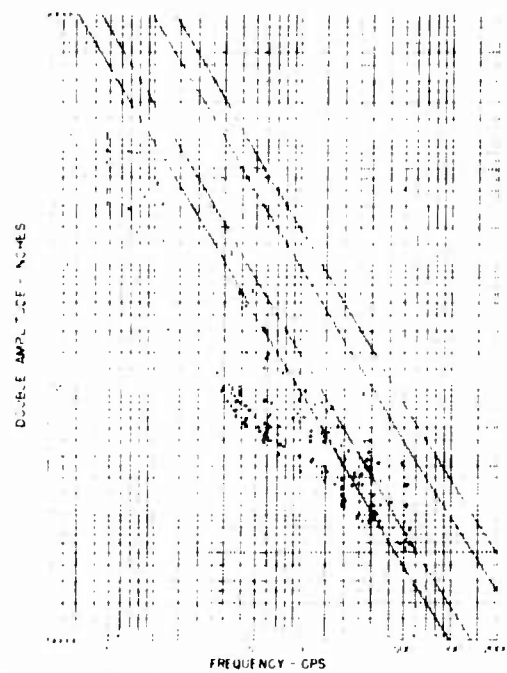


Figure 73. DIRECTION: VERTICAL
LOCATION: STRUCTURE OF FORWARD RIGHT END OF BOMB BAY
STA 784

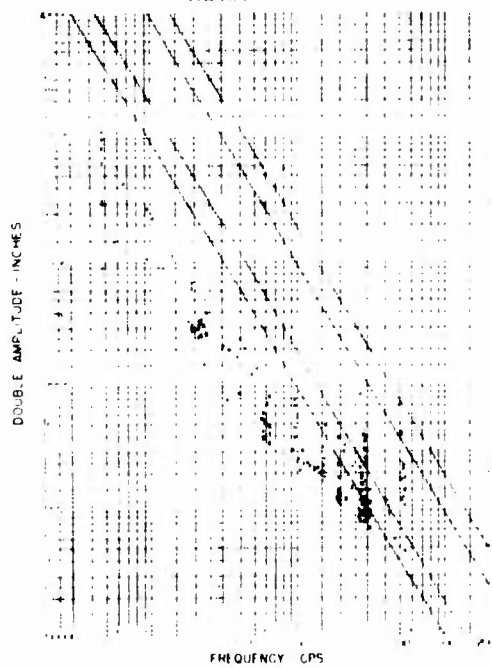


Figure 74. DIRECTION: LATERAL
LOCATION: STRUCTURE OF FORWARD RIGHT END OF BOMB BAY
STA 785

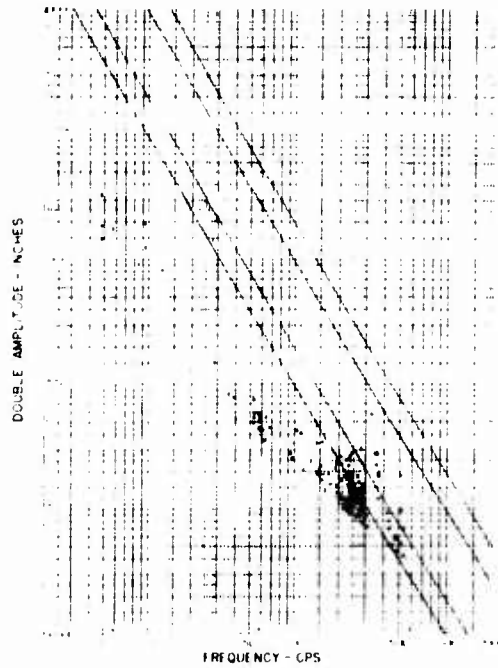


Figure 75. DIRECTION: VERTICAL
LOCATION: STRUCTURE OF AFT RIGHT END OF BOMB BAY
STA 908

Figures 72 to 75. Summary Plots for Individual Vibration Pickups

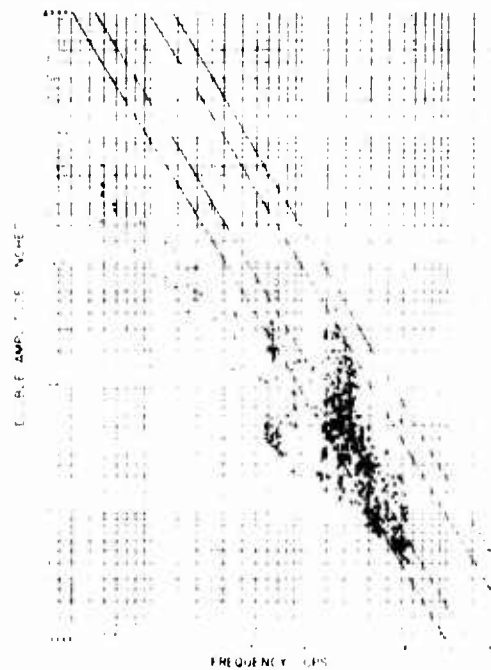


Figure 76. Direction: Lateral
Location: Structure of Aft Right End of Bomb Bay
STA 955

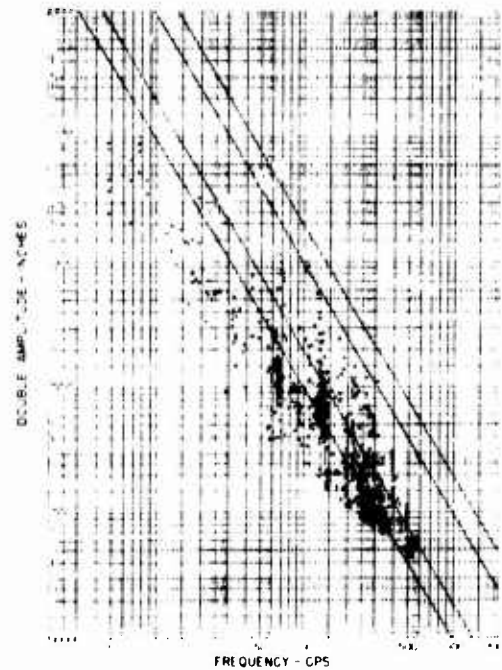


Figure 77. Direction: Lateral
Location: Structure of Aft Right End of Bomb Bay
STA 958

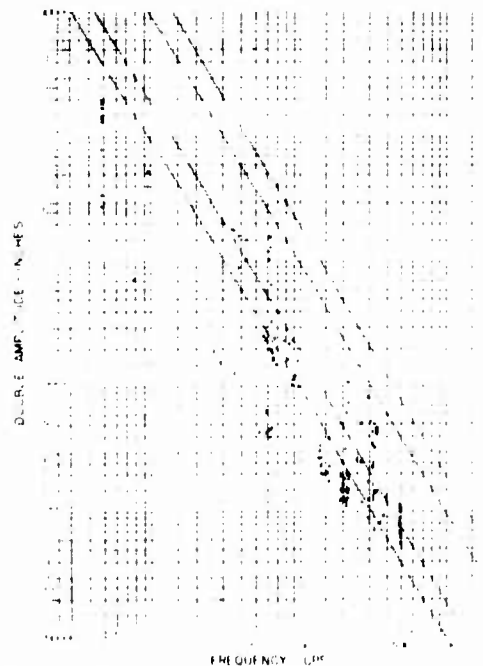


Figure 78. Direction: Lateral
Location: A/C Fuselage, Right Side STA 1009

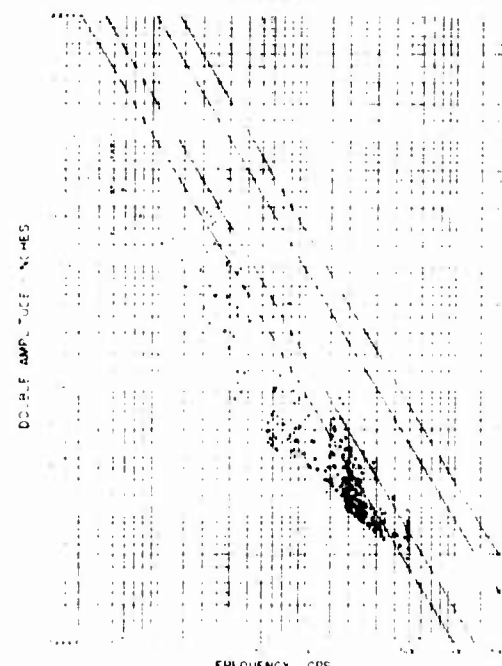


Figure 79. Direction: Lateral
Location: A/C Fuselage, Right Side STA 1277

Figures 76 to 79. Summary Plots for Individual Vibration Pickups

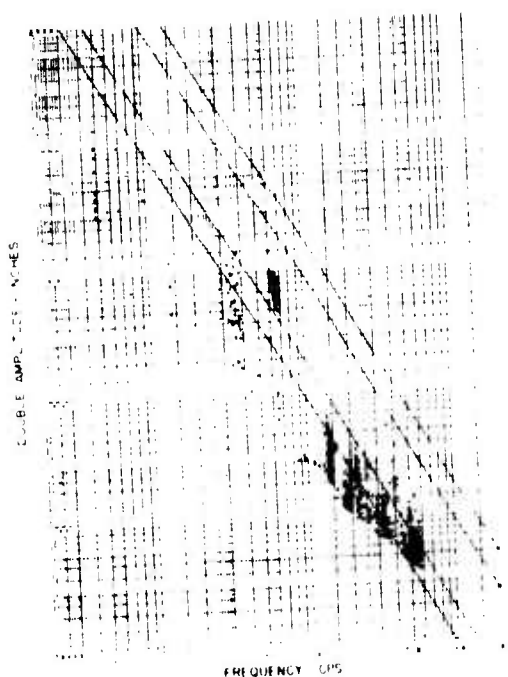


Figure 80. VIBRATION VERTICAL
ON CASE OF HYDRAULIC PACK STA 1573

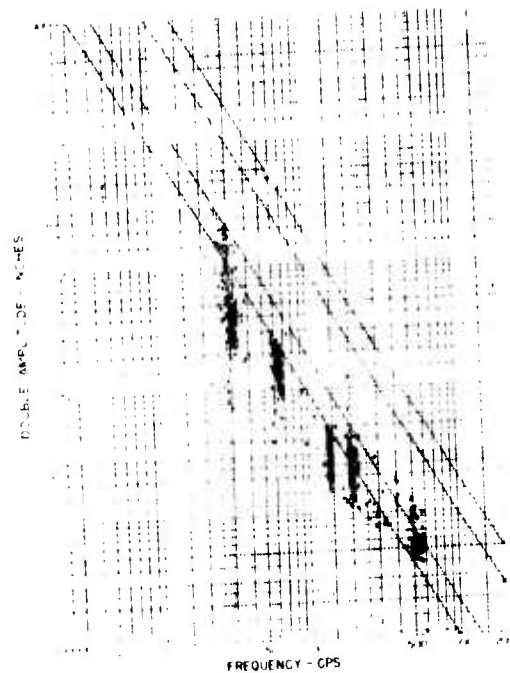


Figure 81. VIBRATION VERTICAL
ON CASE OF HYDRAULIC PACK STA 1573

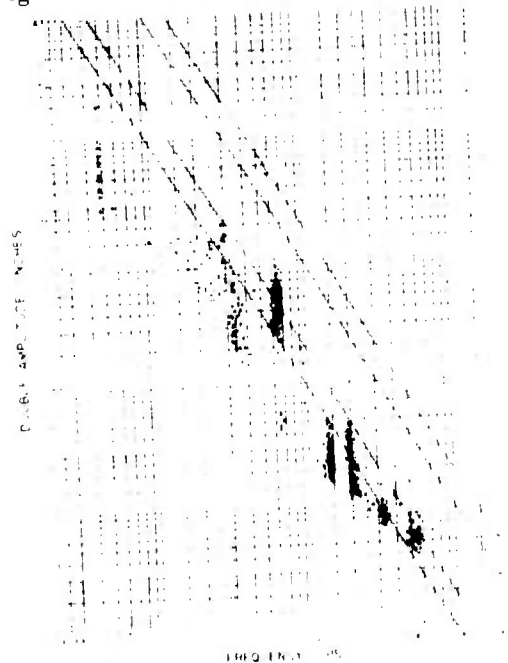


Figure 82. VIBRATION LATERAL
ON CASE OF HYDRAULIC PACK STA 1573

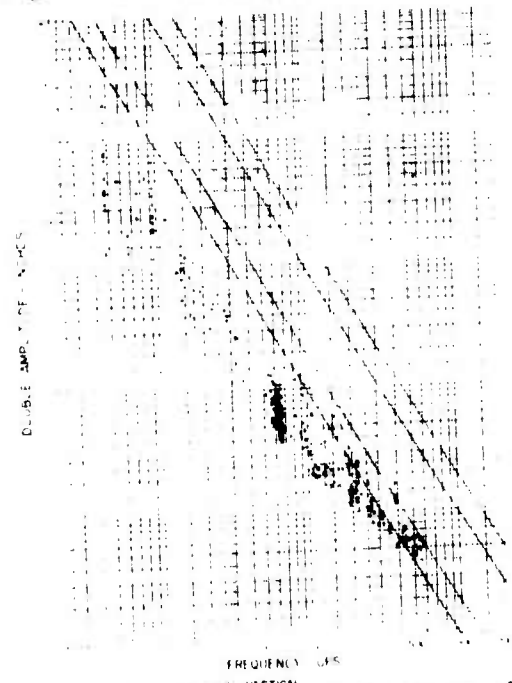


Figure 83. VIBRATION VERTICAL
ON CASE OF HYDRAULIC PACK STA 1540

Figures 80 to 83. Summary Plots for Individual Vibration Pickups

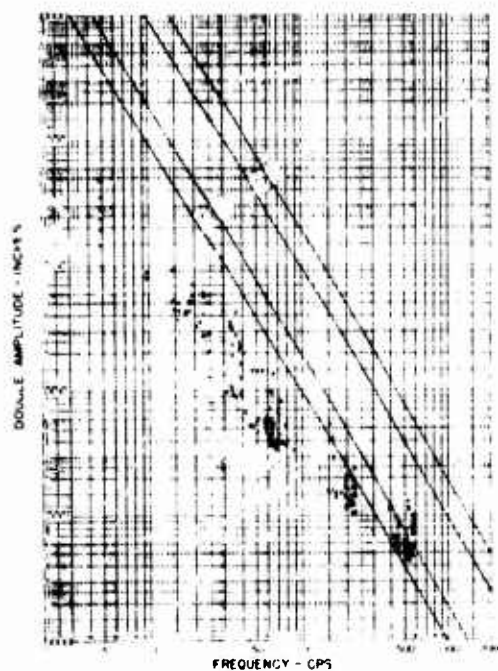


Figure 84. LOCATION: A/C STRUCTURE (MAIN LONGERON) BELOW *10
HYDRAULIC PACK STA 1540

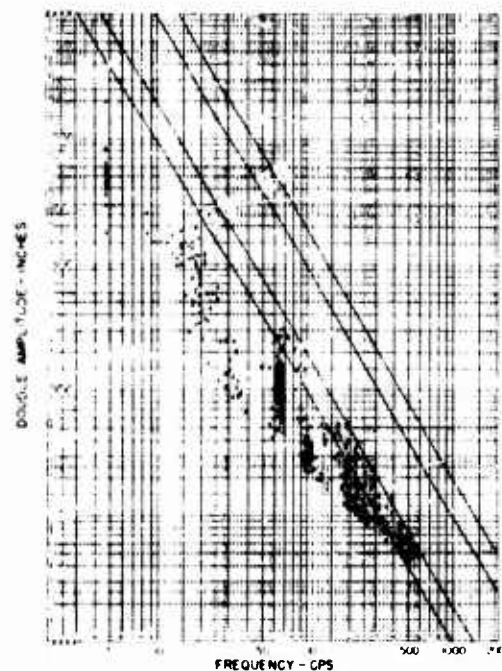


Figure 85. LOCATION: A/C STRUCTURE (MAIN LONGERON) BELOW *10
HYDRAULIC PACK STA 1540

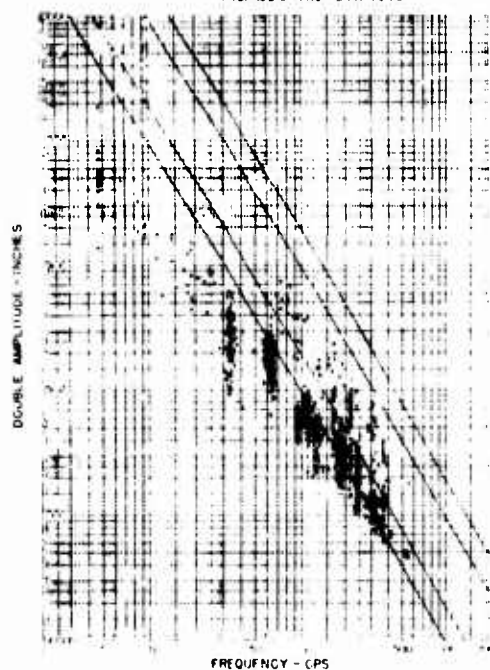


Figure 86. LOCATION: A/C FUSELAGE RIGHT SIDE STA 1540

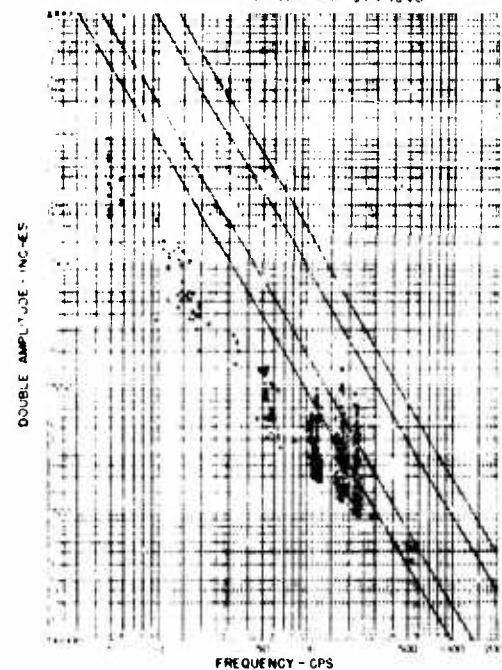


Figure 87. LOCATION: A/C STRUCTURE IN AFT SECTION BELOW COLLINS
EQUIPMENT STA 1719

Figures 84 to 87. Summary Plots for Individual Vibration Pickups

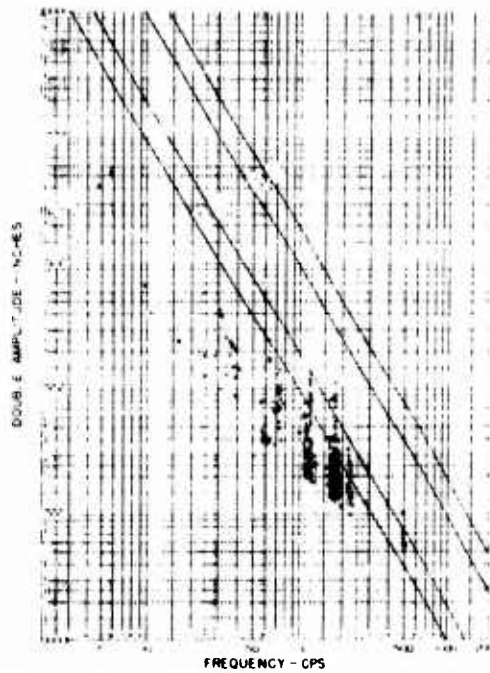


Figure 88. DIRECTION: P/A
LOCATION: A/C STRUCTURE IN AFT SECTION BELOW COLLINS
RADIO EQUIPMENT STA 1719

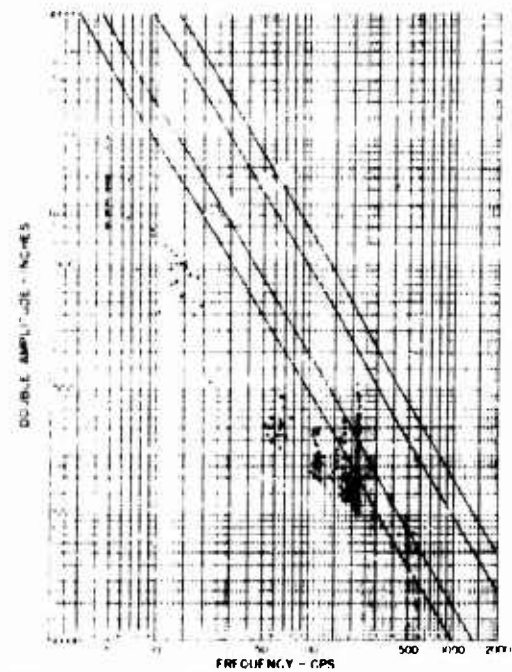


Figure 89. DIRECTION: LATERAL
LOCATION: A/C STRUCTURE IN AFT SECTION BELOW COLLINS
RADIO EQUIPMENT STA 1719

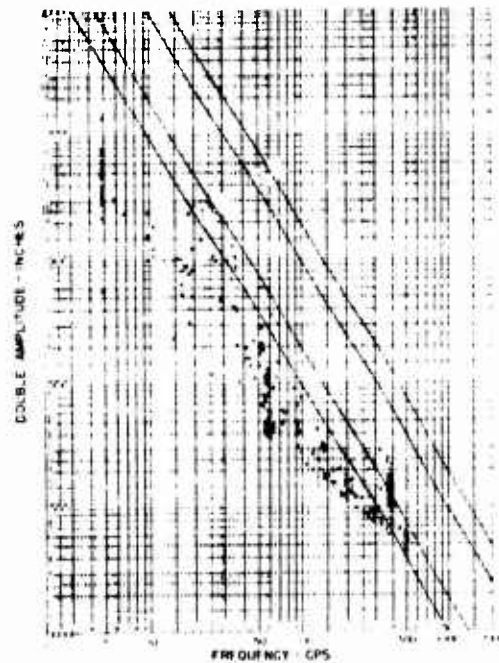


Figure 90. DIRECTION: LATERAL
LOCATION: A/C FUSELAGE, LEFT SIDE STA 1810

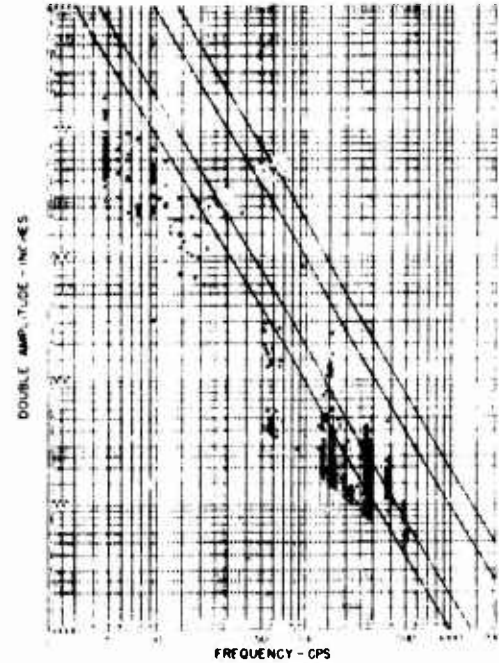


Figure 91. DIRECTION: VERTICAL
LOCATION: A/C STRUCTURE ABOVE TAIL GUNNER'S POSITION,
AFT OF JETTISON POINT STA 1870

Figures 88 to 91. Summary Plots for Individual Vibration Pickups

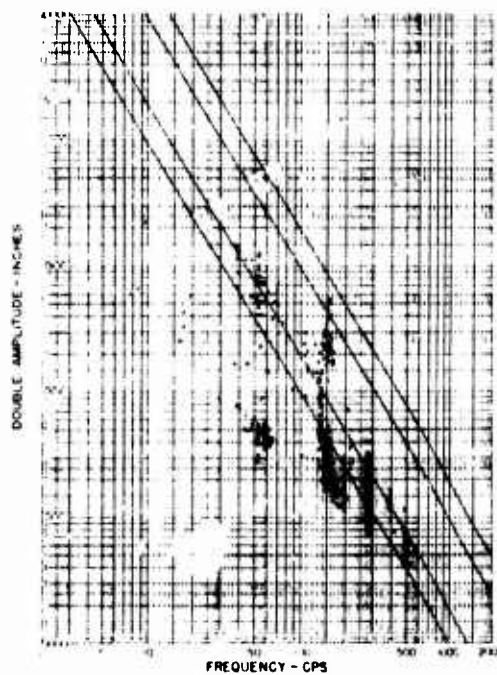


Figure 92. DIRECTION P/A
LOCATION A/C STRUCTURE ABOVE TAIL GUNNER'S POSITION,
AFT OF JETTISON POINT STA. 1870

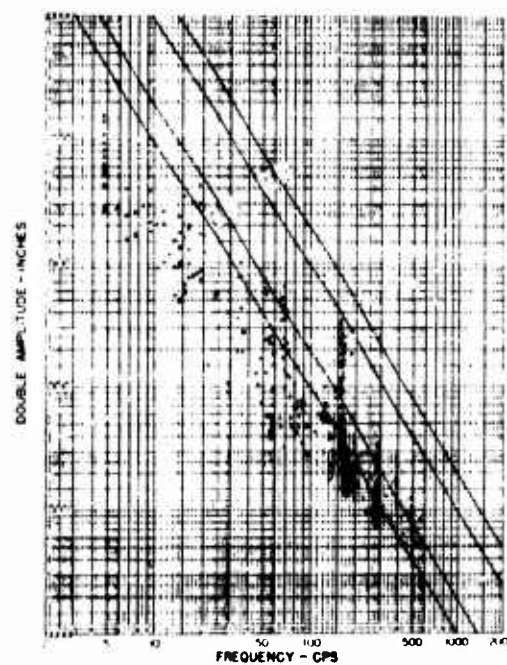


Figure 93. DIRECTION LATERAL
LOCATION A/C STRUCTURE ABOVE TAIL GUNNER'S POSITION
AFT OF JETTISON POINT STA. 1870

Figures 92 to 93. Summary Plots for Individual Vibration Pickups