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SHAKE TEST OF A PROPELLER TEST RIG IN THE 40- BY 80-FOOT WIND TUNNEL

Wayne Johnson

Ames Research Center
and
U.S. Army Air Mobility R&D Laboratory
Moffett Field, California, 94035

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16. Abstract

A shake test was conducted to determine the dynamic characteristics of a Propeller Test Rig in the Ames 40- by 80-Foot Wind Tunnel. The rotor-off hub transfer function (acceleration per unit force as a function of frequency) was measured in the longitudinal, lateral, and vertical directions for shaft angles of 0 and 90° corresponding to propeller and helicopter operation, respectively. The dynamic data are summarized for the configurations tested, giving the following properties for each mode identified: the natural frequency, the hub response at resonance, the damping coefficient, the damping ratio, and the modal mass. The complete transfer functions are presented, and the detailed test results are included.

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Ames Research Center and U.S. Army Air Mobility R&D Laboratory
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SUMMARY

A shake test was conducted to determine the dynamic characteristics of a Propeller Test Rig in the Ames 40- by 80-Foot Wind Tunnel. The rotor-off hub transfer function (acceleration per unit force as a function of frequency) was measured in the longitudinal, lateral, and vertical directions for shaft angles of 0 and 90° corresponding to propeller and helicopter operation, respectively. The dynamic data are summarized for the configurations tested, giving the following properties for each mode identified: the natural frequency, the hub response at resonance, the damping coefficient, the damping ratio, and the modal mass. The complete transfer functions are presented, and the detailed test results are included.

INTRODUCTION

A shake test was conducted to establish the dynamic characteristics of a Propeller Test Rig (PTR) in the Ames 40- by 80-Foot Wind Tunnel. Of interest were potential resonances at the 1/rev and N/rev frequencies of rotors likely to be tested on the PTR and potential proprotor/support instabilities.

The shake test was performed on the PTR module without a rotor, to determine the principal frequencies and damping of the structure. The rotor-off transfer function was measured in the longitudinal, lateral, and vertical directions, for shaft angles of 0 and 90°. The acceleration was measured in the direction of the applied force. The test procedures were described in detail in references 1 and 2.

SYSTEM AND TEST APPARATUS

The system tested consisted of the PTR module without a rotor, on the 15-ft struts and balance frame in the 40- by 80-ft wind tunnel. The module included a propeller nose case, and two 1500-HP electric motors installed. A hydraulic shaker was attached to the top of the module, just behind the nose case. The other end of the shaker was attached to a 5260 kg reaction

*Research Scientist

mass suspended from a crane. A load cell between the shaker and the module measured the applied force. An accelerometer at the point of excitation measured the response in the direction of the applied force.

The PTR module was mounted on the two main struts only. The yaw angle ψ as used here refers to the drive shaft of the module, not the strut system. At $\psi = 0$, the rotor was in axial flight; the strut system was yawed 90° to the right, with the main struts on the west side and the hub in the southwest corner of the test section. At $\psi = 90^\circ$ the rotor was in edgewise flight; the strut system was at zero yaw angle, with the struts forward and the rotor in the southeast corner of the test section. The direction of shaking (lateral or longitudinal) here is defined with respect to the PTR module, not the strut system and wind tunnel.

The PTR was also tested with the balance frame hydraulic snubbers engaged, giving the cantilever strut modes. This test was conducted at $\psi = 0$.

Finally, the PTR was tested with a gimballed proprotor nose case. The rotor was replaced by dummy weights attached to the hub. The exciting force was applied to the shaft, just forward of the gimbal. Results were obtained for lateral and vertical modes at $\psi = 0$ only. The major difference between this and the previous configuration was in the shaft bending modes.

TEST PROCEDURE AND ANALYSIS

The shake test procedures and data reduction techniques are described in detail in references 1 and 2. The applied force and resulting acceleration data were analyzed on-line to determine the dynamic characteristics of the system, using the Dynamic Analysis System. The DAS is basically a time series analyzer and computer, utilizing Fast Fourier Transform techniques and associated software, and programs specific to this shake test.

The following configurations were tested:

1) PTR at $\psi = 0$; lateral and longitudinal excitation (test 469)
2) PTR at $\psi = 90^\circ$; lateral, longitudinal, and vertical excitation (test 469)
3) Cantilever modes (test 469)
4) PTR at $\psi = 0$ with gimballed rotor nose case; lateral and vertical excitation (test 472)

RESULTS

The results of these tests are the dynamic characteristics of the Propeller Test Rig, specifically, the frequencies and response amplitudes of the principal modes identifiable in the hub transfer functions. Figures 1 through 8 present the transfer functions for the configurations tested. The abscissas in the figures are frequency, from 0 to 10 and 50 Hz for the low and high frequency ranges, respectively. The ordinates are the magnitude of the transfer function in g/1000 N.

Tables 1 through 4 summarize the dynamic characteristics of the PTR. The tables give the following quantities for each of the modes identified in the response at the point of excitation: the resonant frequency ω (Hz); the magnitude of the response H (g/1000 N and cm/1000 N); the damping coefficient C_s (N/m/sec); the damping ratio (percent critical damping); and the modal mass M (kg). The tables of Appendix A present in detail the shake test data for the configurations investigated.

TABLE 1.- SUMMARY OF DYNAMIC CHARACTERISTICS
PTR at ψ = 0 (test 469)

Mode	ω, Hz	H, g/1000 N	H, cm/1000 N	C_s, N/m/sec	ζ, % critical	M, kg
Lateral modes (EW)						
Bal. Lat.	1.73	0.200	1.650	2100	1.1	9000
Yaw	3.14	0.070	0.180	13500	1.2	29000
Strut Side	5.56	0.125	0.097	20000	1.3	30000
Module	12.3	0.115	0.019			
Module	17.2	0.145	0.012			
Module	33.3	0.293	0.007			
Longitudinal modes (NS)						
Bal. Long.	1.44	0.016	0.190	34000	3.3	59000
Strut Long.	3.54	0.110	0.220	20000	3.4	13600
Module	16.2	0.013	0.001			
Module	28.6	0.010	0.0003			

TABLE 2.- SUMMARY OF DYNAMIC CHARACTERISTICS
PTR at $\psi = 90^{\circ}$ (test 469)

Mode	ω, Hz	H, g/1000 N	H, cm/1000 N	C_s, N/m/sec	ζ, % critical	M, kg
Lateral modes (EW)						
Bal. Long.	1.29	0.045	0.640	6000	0.7	53300
Yaw	2.41	0.094	0.405	9000	1.9	15000
Strut Side	5.55	0.131	0.107	13000	0.5	36000
Module	11.7	0.083	0.015			
Module	15.9	0.160	0.015			
Module	33.1	0.290	0.007			
Longitudinal modes (EW)						
Bal. Lat.	2.30	0.059	0.272	20000	2.8	21200
Strut Long.	3.90	0.096	0.155	20000	2.1	19900
Module	16.8	0.009	0.001			
Module	28.8	0.009	0.0003			
Vertical Modes						
Balance	1.56	0.006	0.063	161000	4.4	187000
Balance	2.31	0.007	0.033	148000	1.6	313000
Balance	5.54	0.015	0.012	200000	1.0	278000
Balance	7.64	0.003	0.001			
Module	13.5	0.112	0.015			
Module	16.4	0.070	0.007			

TABLE 3.- SUMMARY OF DYNAMIC CHARACTERISTICS
PTR Cantilever Modes (test 469)

Mode	ω, Hz	H, g/1000 N	H, cm/1000 N	C_s, N/m/sec	ζ, % critical	M, kg
Lateral modes						
Strut Yaw	1.86	0.270	1.980	1160	0.4	15300
Strut Side	5.16	0.071	0.067	28000	1.8	24200
Longitudinal modes						
Strut. Long.	2.81	0.137	0.434	12000	3.2	10400

TABLE 4.- SUMMARY OF DYNAMIC CHARACTERISTICS
PTR with Gimballed Rotor Nose Case, ψ = 0 (test 472)

Mode	ω, Hz	H, g/1000 N	H, cm/1000 N	C_s, N/m/sec	ζ, % critical	M, kg
Lateral modes (EW)						
Bal. Lat.	1.65	0.290	2.550	1300	0.9	8000
Yaw	3.26	0.049	0.114			
Strut Side	4.90	0.880	0.918	3600	2.7	2200
Mast	20.4	5.82	0.340	2250	3.3	280
Vertical modes						
Balance	7.34	0.541	0.248			
Module	11.0	1.210	0.258			
Module	14.7	0.410	0.047			
Mast	24.0	3.98	0.170	3800	4.3	300

APPENDIX A

Propeller Test Rig Shake Test Data

The tables of this appendix present the data for the resonant frequencies of the PTR transfer functions. The following configurations were tested:

Table A1: PTR at $\psi = 0$ (test 469)
Table A2: PTR at $\psi = 90^{o}$ (test 469)
Table A3: Cantilever modes of PTR (test 469)
Table A4: PTR with gimballed rotor nose case, $\psi = 0$ (test 472)

The following quantities are given in the tables: the resonant frequency ω (Hz); the amplitude of the response H (g/1000 N and cm/1000 N); the phase of the response <H (deg); the damping coefficient C_s (N/m/sec); the damping ratio ζ(percent critical damping); the modal mass M (kg); and the amplitude of the exciting force F at that frequency (n, with "D" indicating discrete frequency excitation).

TABLE A1.- PROPELLER TEST RIG AT ψ = 0 (test 469)

Run/ Pt	ω, Hz	H, g/1000 N	H, cm/1000 N	<H, deg	C_s, N/m/sec	ζ, % critical	M, kg	F, N D=discrete
Lateral modes (EW)								
1/1	1.73	0.215	1.725	-96	2200	1.2	8400	6.7
2	1.74	0.188	1.510		2050	0.9	10500	9.7
6	1.68	0.466	4.110	-33	1250			D 174
7	1.68	0.259	2.28	-21	1500			D 568
1/1	3.14	0.073	0.187	-29	13300			43
2	3.14	0.069	0.177	-30	13000	1.2	27800	48
1/1	5.56	0.118	0.093	-23	14500			42
2	5.55	0.130	0.106	-71	24000	1.5	23000	36
9	5.52	0.091	0.074	-30	18300			D 706
10	5.52	070	057	-19	16200			D 1300
11	5.44	069	058	-20	17500			D 1540
1/4	12.3	0.114	0.018	-58	60000	3.4	12000	62
5	12.3	0.115	0.019	-59	60000	3.4	12000	62
1/4	17.2	0.145	0.012	-43	54500	2.4	10600	63
5	17.3	0.146	0.012	-43	54700	2.4	10400	62
1/4	33.3	0.296	007	-59	63000	2.0	7630	29
5	33.3	0.291	007	-60	63000	2.0	7700	27

TABLE A1.- (CONCLUDED)

Run/ Pt	ω, Hz	H, g/1000 N	H, cm/1000 N	<H, deg	C_s, N/m/sec	ζ, % critical	M, kg	F, N D=discrete
Longitudinal modes (NS)								
2/1	1.41	0.015	0.175	-99	37400	3.6	59300	44
2	1.48	0.017	0.203	-154	32500	3.0	58300	107
2/1	3.55	0.120	0.240	-108	19400	3.3	13300	29
2	3.54	0.102	0.205	-70	21800	3.6	13800	56
7	3.44	0.105	0.221	-56	17340			D 542
2/3	16.2	0.013	0.001	-32	216000	0.5	223000	117
2/3	28.6	0.010	0.0003	-106	2250000	7.9	79140	88
2/5	3.52	0.088	0.176	-35	14700			D 596
6	3.52	0.068	0.136	-34	18800			D 1340
7	3.44	0.105	0.221	-56	17340			D 480
9	3.40	0.103	0.222	-79	20700			D 552
8	3.36	0.079	0.175	-106	26050			D 542

TABLE A2.- PROPELLER TEST RIG AT $\psi = 90^{o}$ (test 469)

Run/ Pt	ω, Hz	H, g/1000 N	H, cm/1000 N	<H, deg	C_s, N/m/sec	ζ, % critical	M, kg	F, N D=discrete
Lateral modes (NS)								
4/2	1.32	0.047	0.630	163				9
5/1	1.26	0.043	0.654	-169	6070	0.7	53400	20
4/1	2.43	0.113	0.487	-22	7300	1.6	15300	26
2	2.41	0.094	0.405	-26	9060	1.9	15700	23
5/1	2.38	0.093	0.402	-14	9000	2.5	12000	34
4/1	5.54	0.123	0.099	-18	12000	0.4	39000	51
2	5.56	0.132	0.108	-67	13000	0.5	36200	27
5/1	5.55	0.131	0.107	-68	14500	0.6	34100	39
4/3	11.7	0.086	0.016	-64	94800	3.3	19500	23
5/2	11.6	0.081	0.015	-48	94200	3.3	19500	53
4/3	16.1	0.146	0.014	-63	53000	2.7	9700	16
5/2	15.8	0.172	0.017	-45	48000	2.7	9200	41
4/3	33.2	0.290	0065	-63	74000	2.3	7700	9
5/2	33.1	0.291	0065	-51	70000	2.2	7600	20

TABLE A2.- (CONCLUDED)

Run/ Pt	ω, Hz	H, g/1000 N	H, cm/1000 N	<H, deg	C_s, N/m/sec	ζ, % critical	M, kg	F, N D=discrete
Longitudinal modes (EW)								
3/1	2.30	0.059	0.272	-63	17000	2.8	21000	36
3/1	3.90	0.096	0.155	-51	20000	2.1	20000	46
3/2	16.8	0.009	0.001	-17				99
3/2	28.8	0.009	0.0003	-83				58
Vertical modes								
6/1	1.56	0.006	0.063	57	161000	4.4	187000	116
6/1	2.31	0.007	0.033	157	148000	1.6	313000	117
6/1	5.54	0.015	0.012	86	200000	1.0	278000	80
6/1	7.64	0.0033	0.0014	141				70
6/1	13.5	0.112	0.015	-32				135
6/1	16.4	0.070	0.0065	71				136

TABLE A3.- PROPELLER TEST RIG CANTILEVER MODES (TEST 469)

Run/ Pt	ω, Hz	H, g/1000 N	H, cm/1000 N	<H, deg	C_s, N/m/sec	ζ, % critical	M, kg	F, N D=discrete
Lateral modes								
1/12	1.86	0.270	1.98	-6	1160	0.4	15300	7
1/12	5.16	0.071	0.067	-50	28000	1.8	24000	64
Longitudinal modes								
2/4	2.81	0.137	0.434	-65	11500	3.2	10400	35

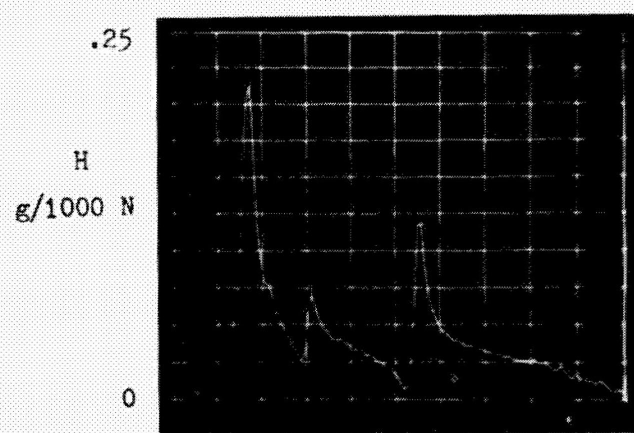
TABLE A4.- PROPELLER TEST RIG WITH GIMBALLED PROPROTOR NOSE CASE
= 0 (TEST 472)

Run/ Pt	ω, Hz	H, g/1000 N	H, cm/1000 N	<H, deg	C_s, N/m/sec	ζ, % critical	M, kg	F, N D=discrete
Lateral modes (EW)								
1/1	1.52	0.298	3.20	-172	970	0.5	12000	6
2	1.65	0.289	2.55	-18	1300	0.9	7300	9
1/2	3.26	0.049	0.114	-50	37000	4.7	19300	87
1/2	4.90	0.880	0.918	-109	3600	2.7	2200	15
1/4	20.7	5.664	0.338	-56	2000	2.7	288	7
5	20.4	5.824	0.348	-96	2200	3.3	268	4
Longitudinal modes (NS)								
2/2	7.34	0.541	0.248	-109	3800	0.5	8720	21
1	7.35	0.54						
2/3	11.0	1.419	0.302	-164				15
4	11.0	1.210	0.258	178	2800	1.1	1875	12
2/3	14.7	0.452	0.051	-134				20
4	14.8	0.371	0.042	-110				20
2/3	24.1	3.722	0.161	-99	4100	4.5	300	8
4	24.0	4.232	0.182	-115	3700	4.1	296	7

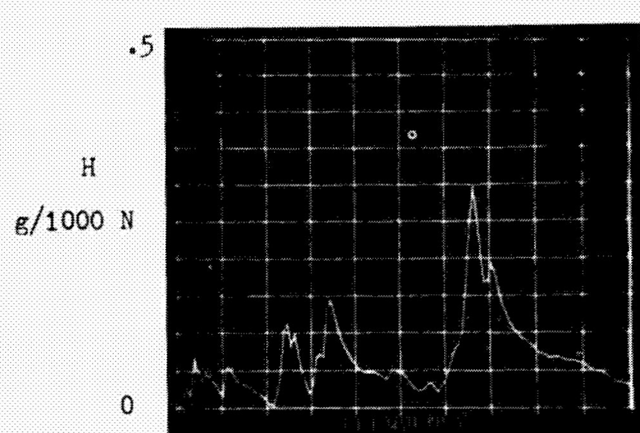
REFERENCES

1. Johnson, Wayne; and Biggers, James C.: Shake Test of Rotor Test Apparatus with Balance Dampers in the 40- by 80-Foot Wind Tunnel. NASA TM X-62,470, 1975.

2. Johnson, Wayne; and Biggers, James C.: Shake Test of Rotor Test Apparatus in the 40- by 80-Foot Wind Tunnel. NASA TM X-62,418, 1975.

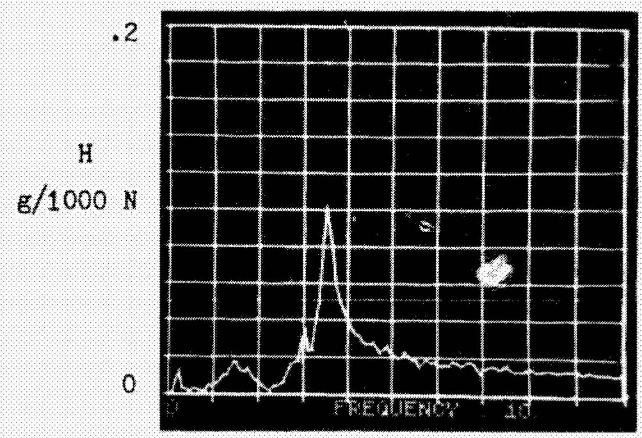


.5-9 Hz broadband excitation
(test 469, run 1, point 1)



.5-40 Hz broadband excitation
(test 469, run 1, point 4)

Figure 1. Propeller Test Rig at ψ = 0, lateral modes (EW)



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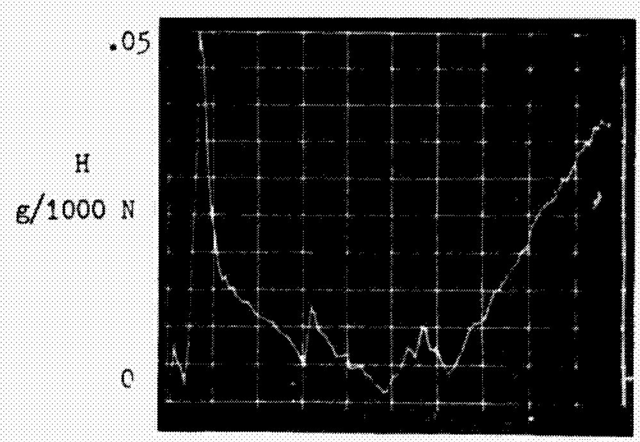


.5-40 Hz broadband excitation

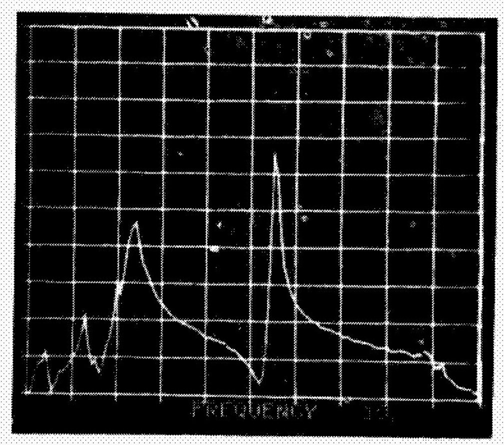
(test 469, run 2, point 3)

Figure 2. Propeller Test Rig at $\Psi = 0$, longitudinal modes (NS)

.2

H
g/1000 N

0



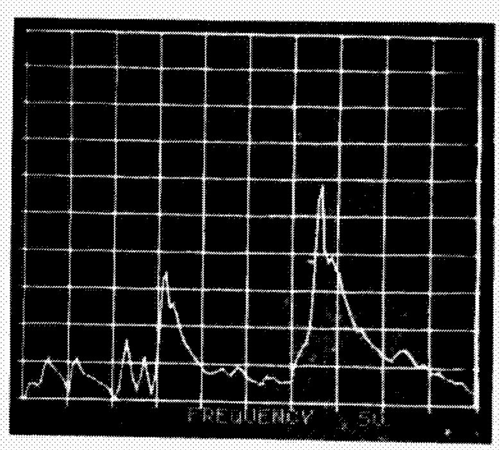
.5-9 Hz broadband excitation

(test 469, run 5, point 1)

.5

H
g/1000 N

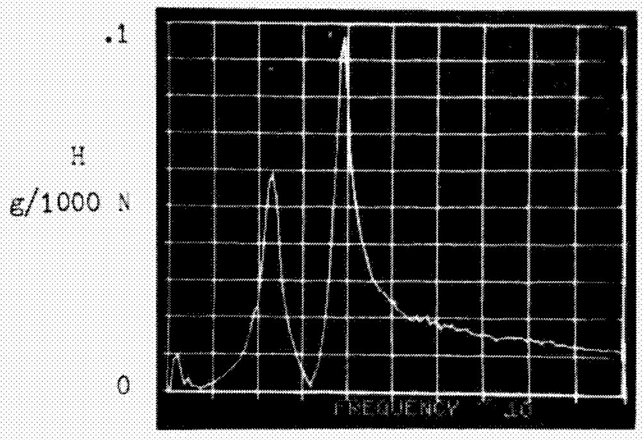
0



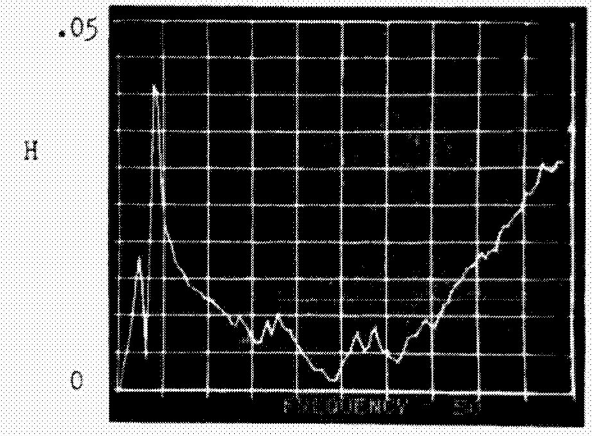
.5-40 Hz broadband excitation

(test 469, run 5, point 2)

Figure 3. Propeller Test Rig at $\Psi = 90^{o}$, lateral modes (NS)

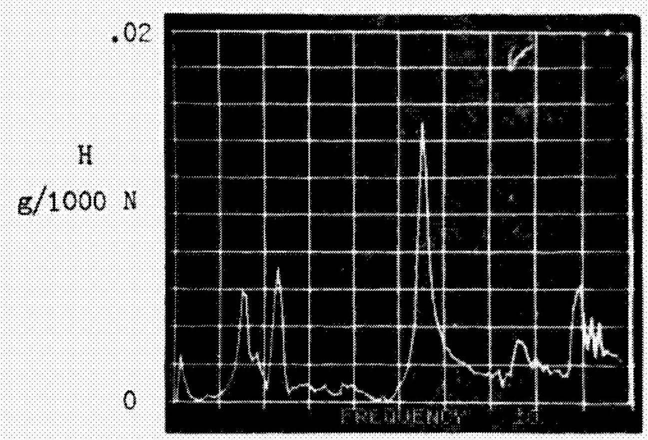


.5-9 Hz broadband excitation
(test 469, run 3, point 1)



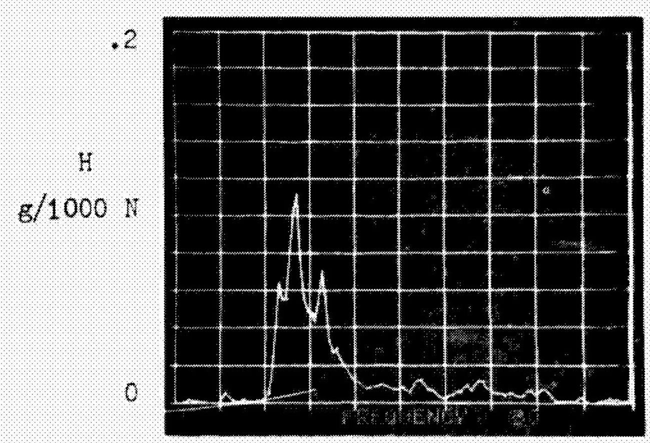
.5-40 Hz broadband excitation
(test 469, run 3, point 2)

Figure 4. Propeller Test Rig at $\psi = 90°$, longitudinal modes (EW)



.5-9 Hz broadband excitation

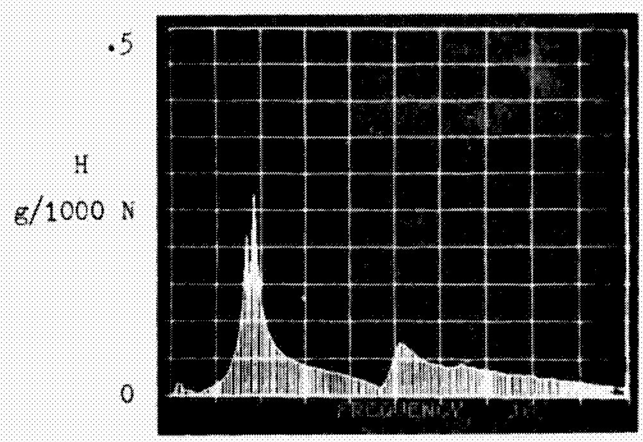
(test 469, run 6, point 1)



.5-40 Hz broadband excitation

(test 469, run 6, point 2)

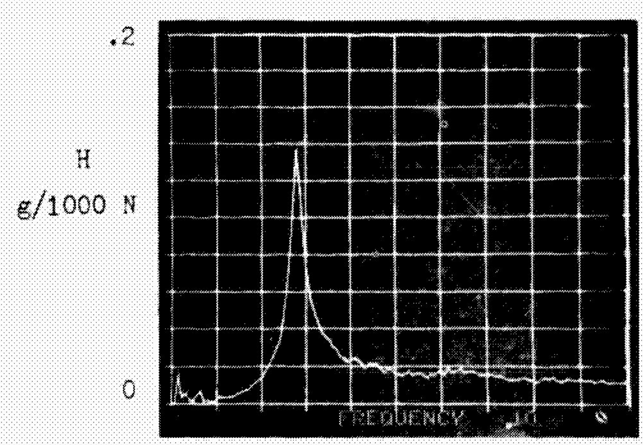
Figure 5. Propeller Test Rig at $\Psi = 90^{\circ}$, vertical modes



lateral modes

.5-9 Hz broadband excitation

(test 469, run 1, point 12)

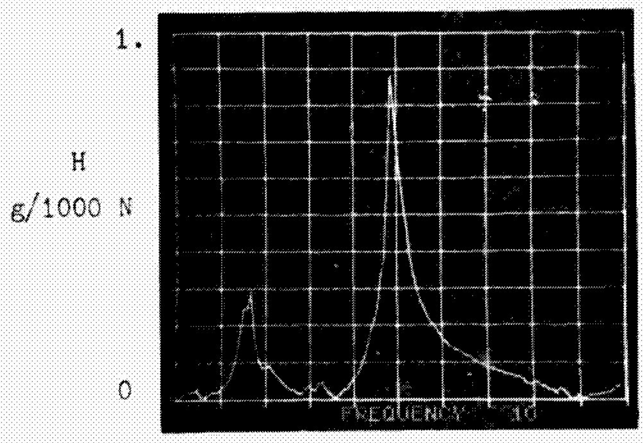


longitudinal modes

.5-9 Hz broadband excitation

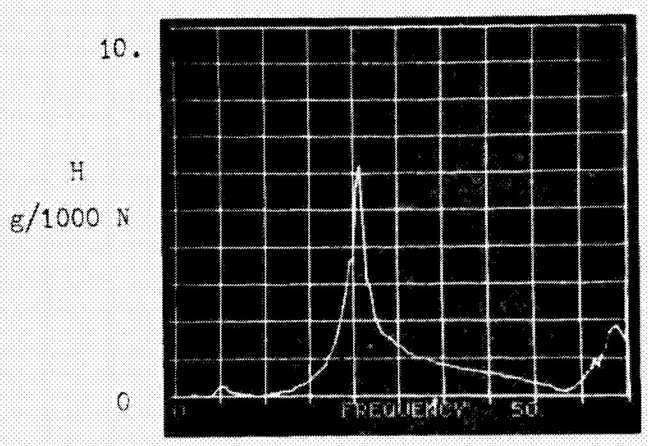
(test 469, run 2, point 4)

Figure 6. Propeller Test Rig cantilever modes



.5-9 Hz broadband excitation

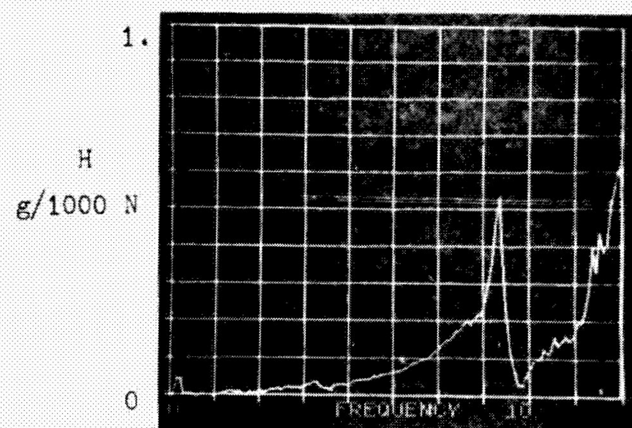
(test 472, run 1, point 2)



.5-40 Hz broadband excitation

(test 472, run 1, point 4)

Figure 7. Propeller Test Rig with gimballed proprotor nose case, $\Psi = 0$, lateral modes (EW)



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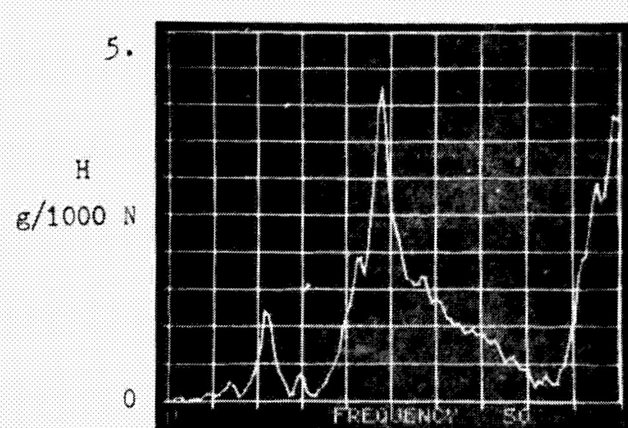
(test 472, run 2, point 1)



.5-40 Hz broadband excitation
(test 472, run 2, point 4)

Figure 8. Propeller Test Rig with gimballed proprotor nose case, $\Psi = 0$, vertical modes