19 MAR 1948

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WARTIME REPORT

ORIGINALLY ISSUED
August 1943 as
Memorandum Report

FLUTTER TESTS OF MODIFIED SB2U MODEL IN 16-FOOT TUNNEL

By Theodore Theodorsen, R. P. Coleman,
and N. H. Smith

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Langley Field, Va.

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IAL ADVISORY COMMITTEE FOR AERONAUTICS

MEMORANDUM REPORT

for the

Bureau of Aeronautics, Navy Department

FLUTTER TESTS OF MODIFIED SB2U MODEL IN 16-FOOT TUNNEL

By Theodore Theodorsen, R. P. Coleman,
and N. H. Smith

SUMMARY

These tests on the flutter characteristics of the SB2U model were conducted after the model had been modified so as to lower its flutter speed. This was done in order to insure the occurrence of normal flutter before anticipated skin failures. Such skin failure appeared imminent near top speed in the previous test series already reported. For this reason the wing torsion frequency was lowered from 1575 cycles per minute to 1330 cycles per minute. This latter value is closer to the originally intended model value and so also the flutter speed, predicted at about 125 miles per hour.

The model was tested to destruction. The value of the measured flutter speed, however, exceeded the expected value by more than 20 percent. It must be pointed out that in the upper range above the predicted flutter speed, or between 130 and 157 miles per hour, there appeared in all the vibration records a high frequency response of a remarkably constant frequency and amplitude, which response was

large enough to mask all other responses. The final flutter, however, occurred in the low frequency mode as expected.

INTRODUCTION

The tests reported herein are a continuation of those reported in reference 1. The flutter model of the SB2U-2 as first tested was found to have a higher wing torsional frequency and, consequently, a flutter speed higher than the intended design values. These were 1270 cycles per minute and 120 miles per hour, respectively, while the observed torsional frequency in the original model was 1575 cycles per minute. This original version of the model did not flutter in tunnel test at speeds below 140 miles per hour. The loosely attached metal skin showed a tendency to buckle at the higher speeds.

The following changes were incorporated in the second version of the model after consultation with the Bureau of Aeronautics:

1. The stiffness of the wing was lowered by drilling numerous evenly spaced holes in the main spar along the length of the outer panel of the wing.

2. The friction damping in the aileron system was lowered by a number of adjustments and small changes such as providing more freedom in the hinges and more clearance for the control cables.

3. A vibrator employing an arrangement of two oppositely rotating weights was installed in order to decrease the excessive magnitude of the nonsymmetric modes obtained in the original tests.

4. A "floating" support arrangement was used to simulate flight conditions in contrast to earlier tests in which the fuselage was rigidly attached to the tunnel base. Vertical cables were attached to the tail to maintain an approximately constant flight attitude of the plane.

5. Four new and more sensitive vibration pickup units were installed in the inboard positions in the wing.

The method of testing was similar to that previously used and described in reference 1.

PRELIMINARY DATA

Photographs of the setup and a diagram of pickup locations are given in figures 1 to 6.

Plots of wing flexibility in bending and torsion before and after modification are given in figures 7 and 8.

Plots of aileron damping are given in figure 9.

The frequencies of rolling and pitching of the whole model on the spring support were around 200 cycles per minute. Thus, as far as the flutter tests are concerned, the model could be considered as floating.

MAIN TESTS

Tests were conducted at air speeds of 0, 50, 75, 100, 110, 115, and 120 miles per hour for each of the conditions tested. The conditions included changes of aileron spring stiffness and aileron balance. Records of forced vibration were taken at each of the airspeeds. In a final run to determine the actual flutter speed the model wing was destroyed by violent flutter at 157 miles per hour.

As an important purpose of these tests was to study the forced responses below the flutter speed as an indication of the approach to the critical speed, it may be illuminating to present not only the final data but also the preliminary results and graphs as they were obtained and analyzed before the model was actually destroyed by flutter.

A summary of the test progress is given in chronological order.

7-6-43.- Ailerons balanced and with stiff springs (K = 52 lb/in.). Runs were made at airspeeds of 50, 75, 100, 0, and 110 miles per hour. The amplitude of pickup 11, left wing tip was measured on the record nearest 1330 cycles per minute (torsion frequency) and plotted as an indication of nearness of approach to flutter (fig. 10). If no further tests had been run, figure 10 might indicate a flutter speed of about 127 miles per hour.

7-8-43.- Part of the first run was repeated to check the sensitivity of the equipment and the speed was subsequently increased to 120 miles per hour. The amplitude of pickup 11 near 1330 cycles per minute is plotted in figure 11.

7-10-43.- With weaker aileron springs (K = 18 lb/in.) runs were made at 50, 75, 100, 0, 75, 100, 110, 115, and 120 miles per hour. The preliminary amplitude plot is shown in figure 12.

7-13-43.- With balance weights removed from ailerons and with the same springs (K = 18 lb/in.) runs were made at 50, 75, 100, 110, 115, 120, and 0 miles per hour. The amplifiers were behaving erratically during this run, so consistent data were not obtained; but no significant difference in behavior of the model was noted as compared with the previous run. No appreciable aileron motion was recorded.

7-13-43.- 3:00 p.m. With the balance weights restored in ailerons, runs were made at 0, 50, 75, 100, 110, 120, and 125 miles per hour. The skin on the inboard part of the wing began to pull up and buckle necessitating the use of some scotch tape for patching, and the tests were continued at 0, 124, 128, 130, 132, and 135 miles per hour. The trend of the torsion response peak is plotted in figure 13.

7-14-43.- Same conditions as previous test. Runs were made at 0 and 120 miles per hour, then a continuous oscillograph record was taken with the vibrator stopped and the airspeed increasing from 130 to 150 miles per hour; then forced vibration records were taken at 140 miles per hour. In this speed range above 130 miles per hour a new high frequency vibration appears in the records. This response is intense enough to mask all the lower responses almost completely. It exhibits a strikingly constant frequency at a rather constant amplitude. The lower responses seem to penetrate sporadically to displace the high frequency mode. Occasional bursts of vibration at about 1000 cycles per minute can be observed on the records. (See fig. 15.) The last run was made with the air flow accelerating from a speed of 140 miles per hour to the speed of continuous flutter (157 mph). At this point the wing was destroyed by violent flutter. Oscillograph records were successfully obtained for the entire run. Parts of the record are reproduced in figures 16 and 17.

DISCUSSION OF RESULTS

After the tests were completed, an extensive analysis was conducted. Amplitude and frequency were obtained from the

oscillograph records at several airspeeds and three-dimensional plots were made with amplitude as ordinate against frequency and airspeed. Such plots are shown in figures 18 to 36. These plots show clearly the emergence of a sharp peak for the torsional response in the higher speed range. At lower speeds this peak fades out and at zero airspeed it can be detected only with great difficulty. In fact this mode had to be established in preliminary tests by the method of using concentrated lead weights on the spar at each wing tip and observing the motion optically by the reflection of a light beam from a small mirror attached to the surface.

On the other hand, the bending response at 640 cycles per minute was easily obtained at zero airspeed but decreased rapidly with increase in airspeed. No bending response could be detected in the upper range.

No measurable changes in the response pattern resulted from the variations in aileron spring stiffness and mass balance coefficient. The large response peak at 130 miles per hour and 850 cycles per minute in figure 37 may have been due to the lower spring stiffness. This is not certain, however.

A curious damping effect at about 1300 cycles per minute was also apparent at low airspeeds for the weak spring. Similar "absorption bands" have been observed on other occasions.

It may also be remarked that the response picture obtained from the various pickups were substantially identical.

The most disconcerting product of the tests was the existence of the high frequency vibration (2570 cpm) in all records taken above 132 miles per hour. Through most of the upper speed range this high frequency vibration masked almost completely the low frequency response from the vibrator or the air stream. In the final run, however, as the airspeed was increased beyond 140 miles per hour this high frequency response did not increase in amplitude but actually decreased somewhat. The record of the actual flutter shows the higher frequency being displaced by a lower frequency (about 1000 cpm) which built up just before the wing broke. There is evidence, therefore, that the flutter did not result directly from the high frequency mode as this disappeared in advance. The observed flutter frequency of about 1000 cycles per minute evidently is the normal type involving the torsion mode at about 1330 cycles per minute and the low bending mode at 640 cycles per minute.

The mode of motion involved in the 2570 cycles per minute vibration was not established. A forced vibration test on the wing panels after the flutter tests indicated that 2570 was not an unreasonable value for panel vibration of the skin. A strong response existed at this point. It

should be noted that a similar phenomenon involving a high frequency type of surface disturbance had been observed earlier in tests (reference 2) on the P-47 tail unit in the 8-foot high-speed tunnel. The nature of this type of vibration is not fully known. Possibly a second torsion mode combined in the present case with the local response of the surface, the combination being excited in the air stream by effects of the boundary layer. It would be desirable to subject this problem of surface vibration to a systematic experimental study.

The final value of flutter speed (157 mph) was considerably higher than was predicted by calculations or by extrapolation of amplitude data below 120 miles per hour. With the reciprocal of torsional peak amplitude plotted against airspeed, as in figures 10 to 13, the extrapolation of these curves to zero reciprocal amplitude should normally be expected to give a plausible estimate of flutter speed. The extrapolated values are actually in good agreement with the predicted flutter speed, both being much lower than the observed value.

The results may suggest the existence of nonlinear wing damping. If the effective structural damping parameter g_α is considered to be increasing with amplitude, it follows that the vibration in the 2570-cycle-per-minute mode would increase the effective damping in the first torsion mode and thus increase the flutter speed.

Pictures taken after the model had been destroyed by flutter are shown in figures 37 to 40.

CONCLUSION

The second version of the SB2U model has been tested to destruction. The flutter speed was more than 20 percent in excess of the calculated value. Runs were made in the whole speed range below flutter and extrapolated response curves indicated a flutter speed in substantial agreement with the expected value. It is noted that all records taken in the upper 20 percent of the range show a very high frequency of such amplitude as to mask all lower responses. The assumption is made that this high frequency is due to a type of surface flutter and that this vibration possibly delayed the main flutter by increasing the effective damping. The final flutter occurred in the expected torsion-bending mode.

Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., August 18, 1943.

REFERENCES

1. Theodorsen, T., Coleman, R. P., and Smith, N. H.: Flutter Tests on SB2U Model in 16-Foot Tunnel. NACA MR, Feb. 17, 1943.

2. Theodorsen, T.: Preliminary Vibration and Flutter Studies on P-47 Tail. NACA MR, Aug. 21, 1943.

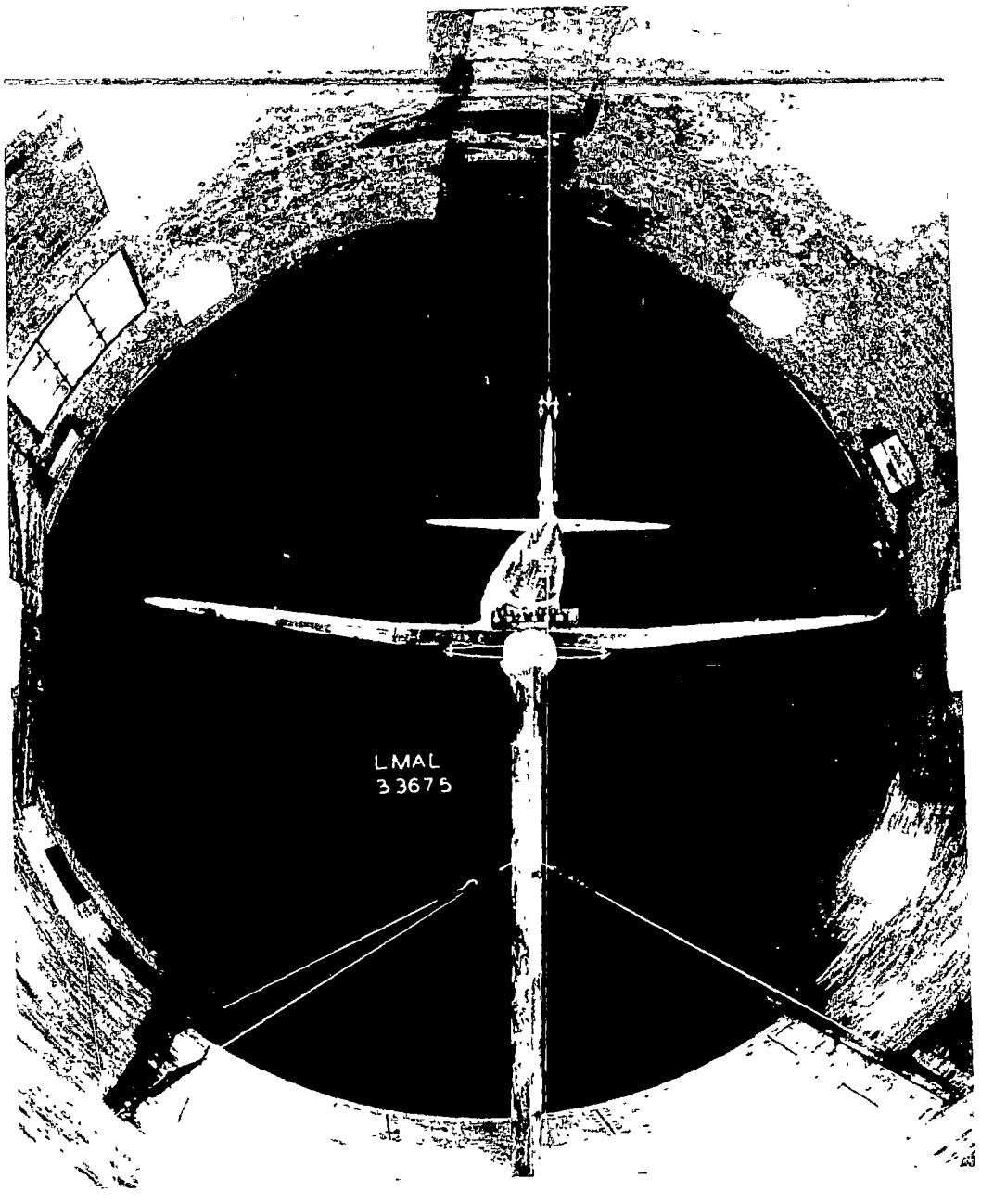


Figure 1.- Test setup.

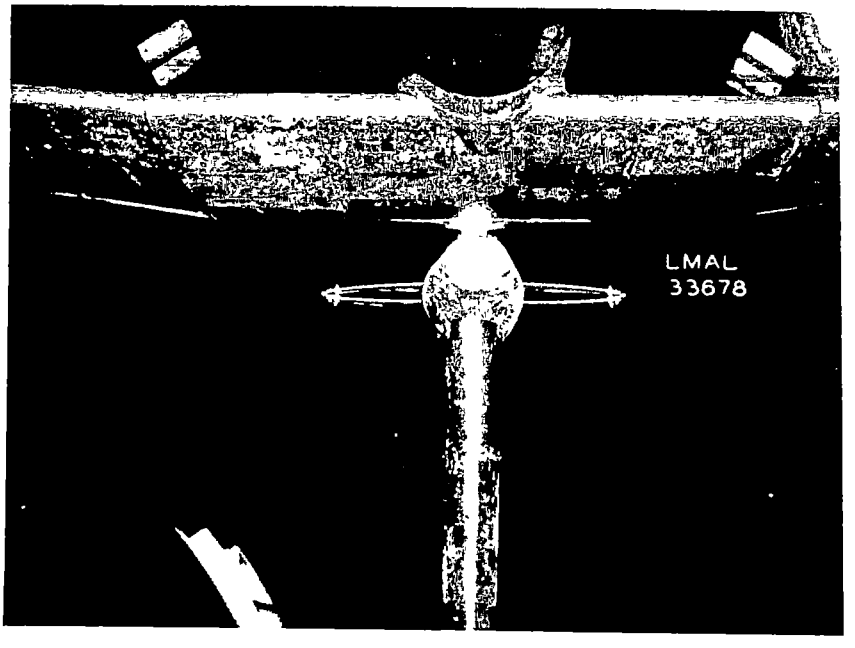


Figure 2.- Test setup.

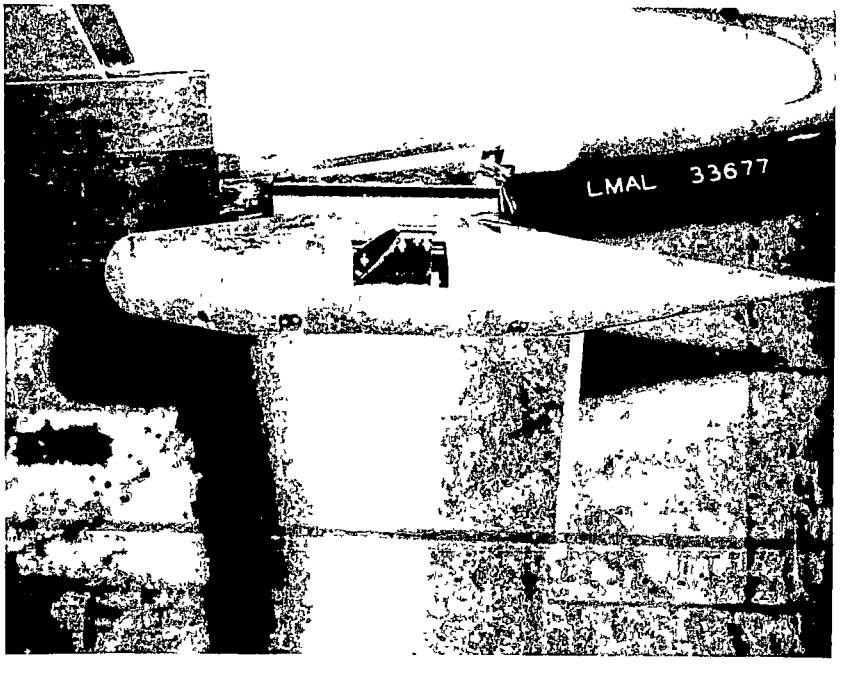


Figure 3.- Test setup.

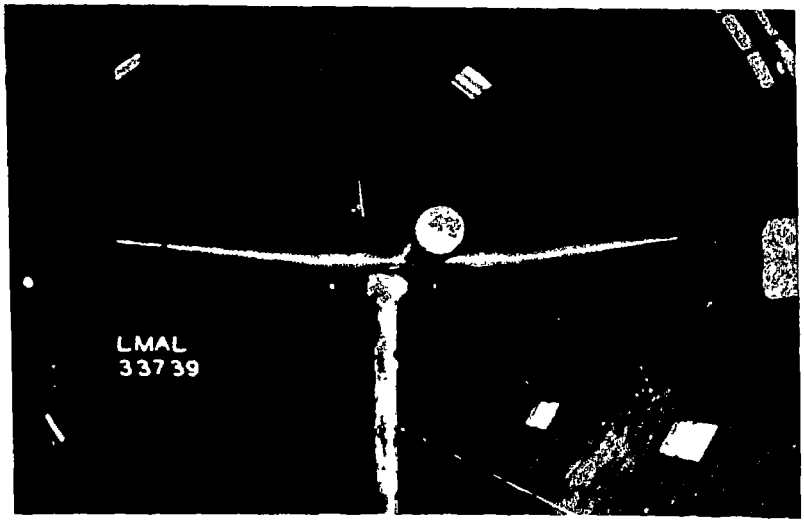


Figure 4.- Test setup.

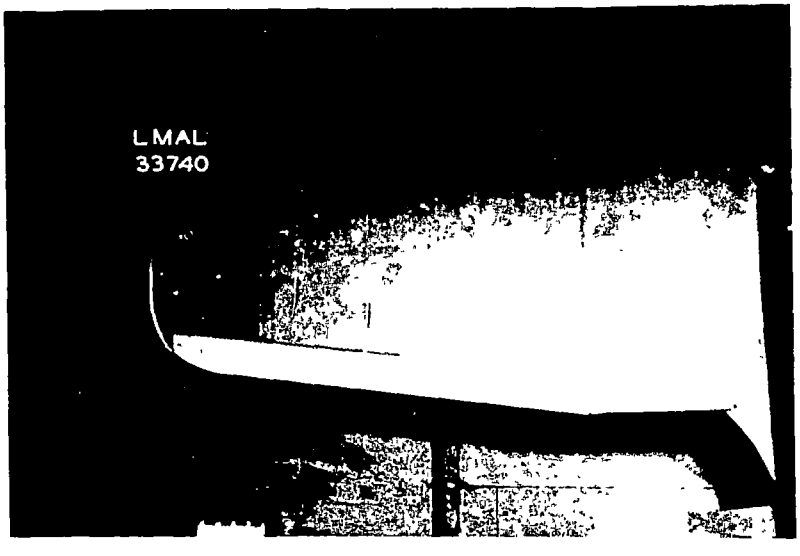
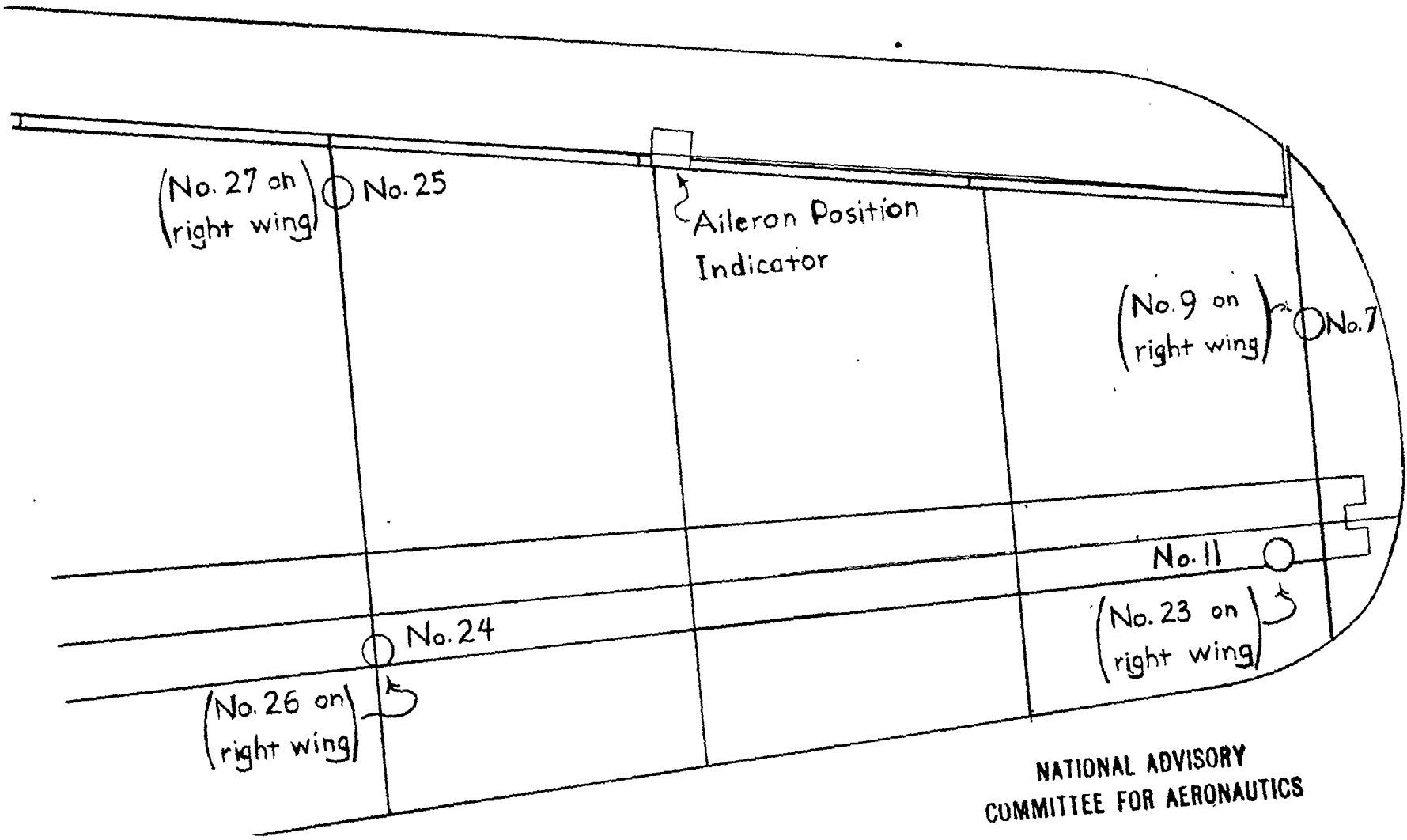


Figure 5.- Test setup.



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POSITIONS

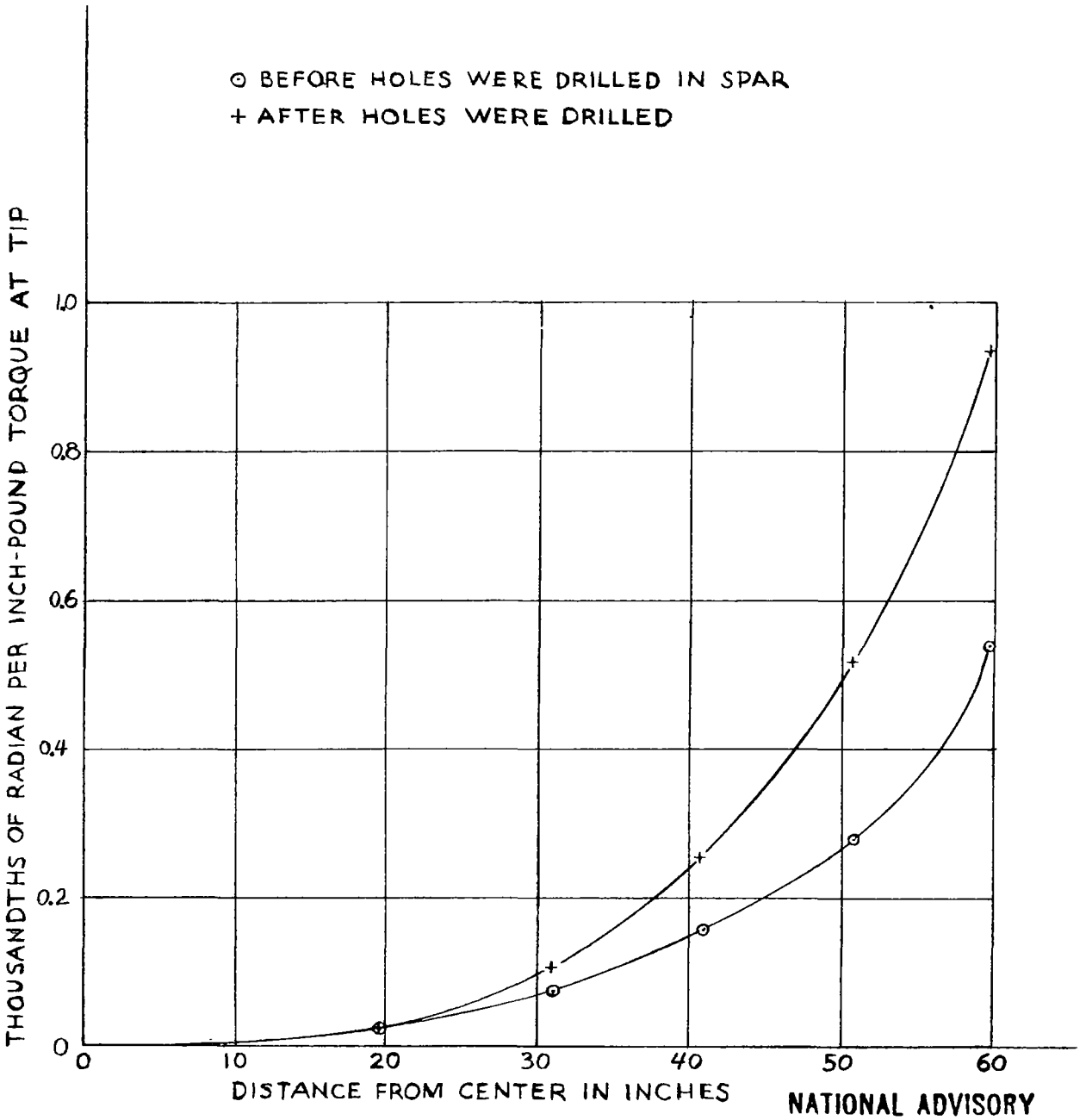

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Fig. 7, TORSIONAL FLEXIBILITY OF SPAR

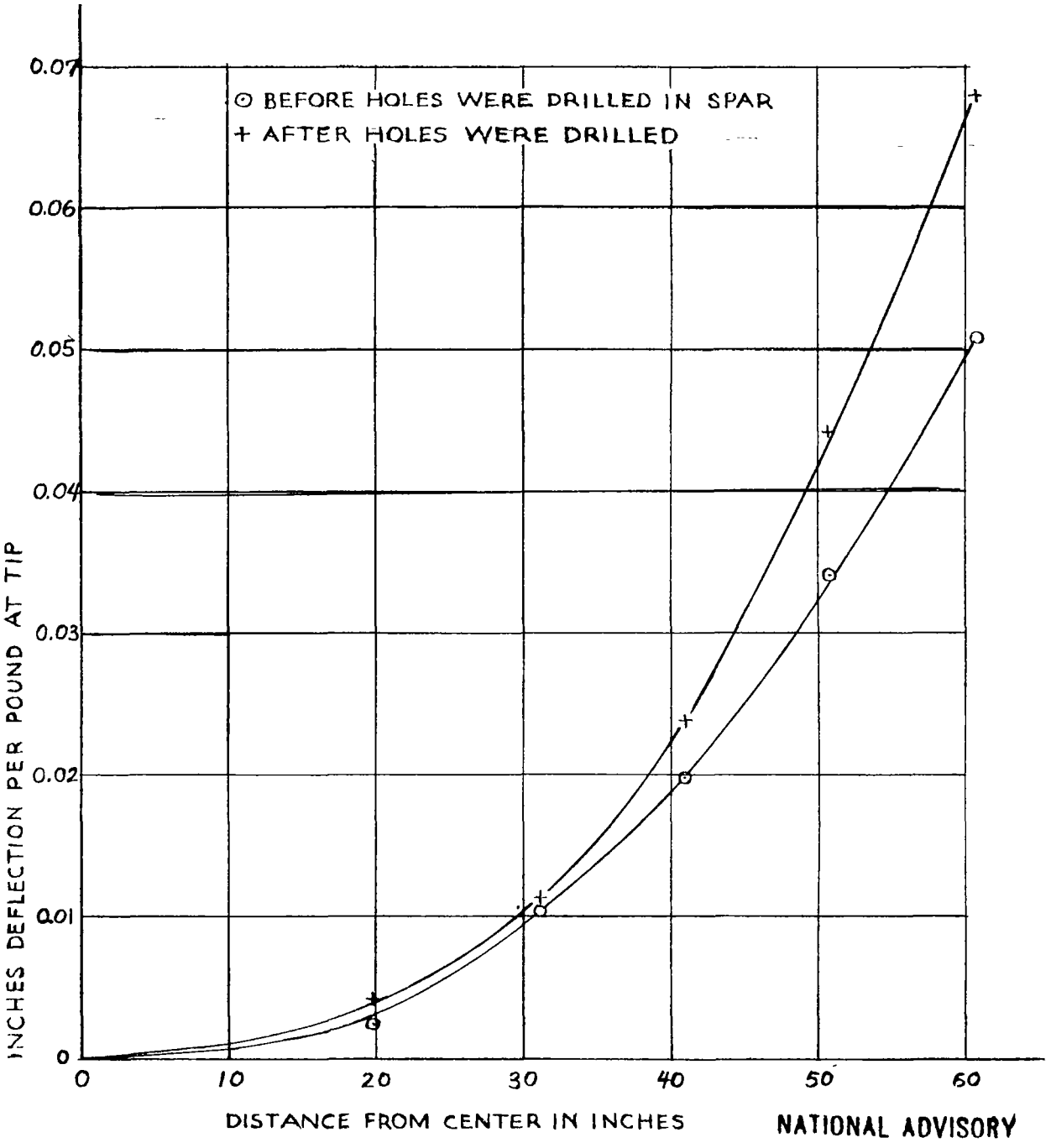

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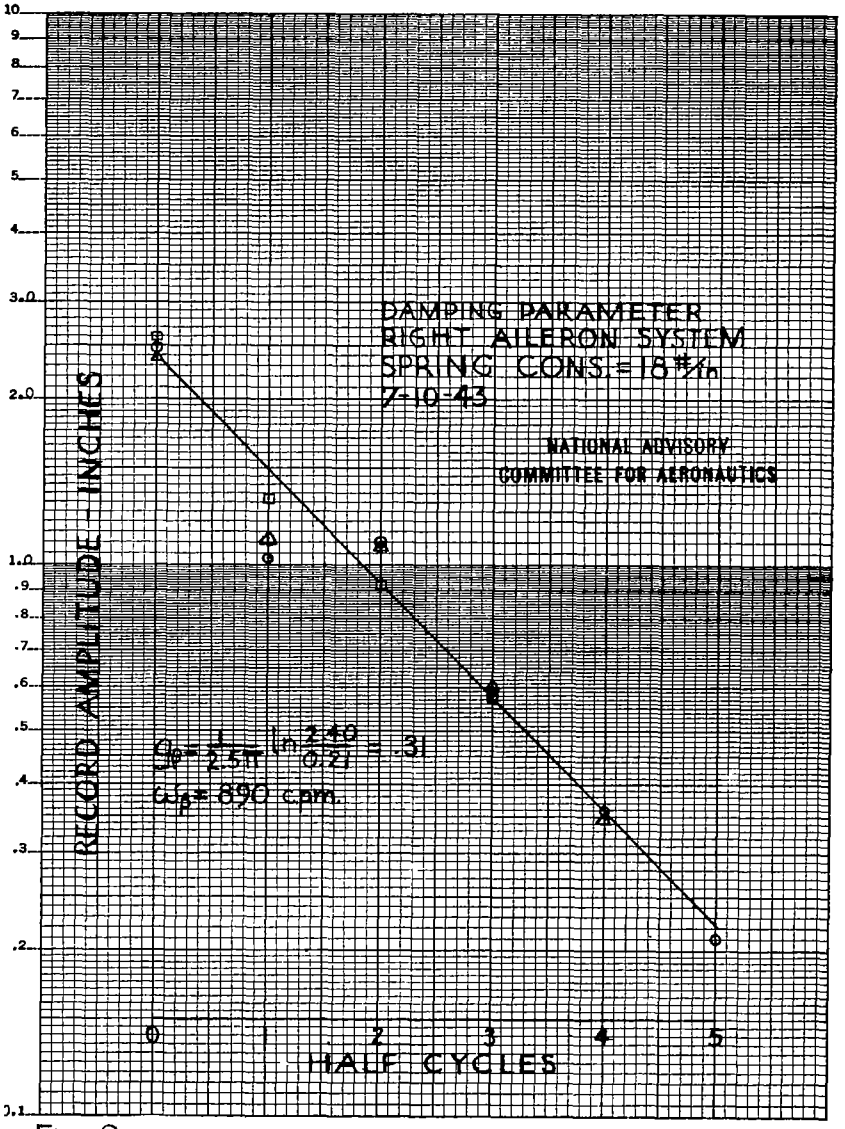
Fig. 8 BENDING FLEXIBILITY OF SPAR


DAMPING PARAMETER
RIGHT AILERON SYSTEM
SPRING CONS. = 18 #/in
7-10-43
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RECORD AMPLITUDE - INCHES
HALF CYCLES
$C_{\beta} = \frac{1}{2.5\pi} \ln \frac{2.40}{0.21} = .31$
$\omega_{\beta} = 890$ c.p.m.
10
9
8
7
6
5
4
3.0
2.0
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
0
1
2
3
4
5

Fig. 9

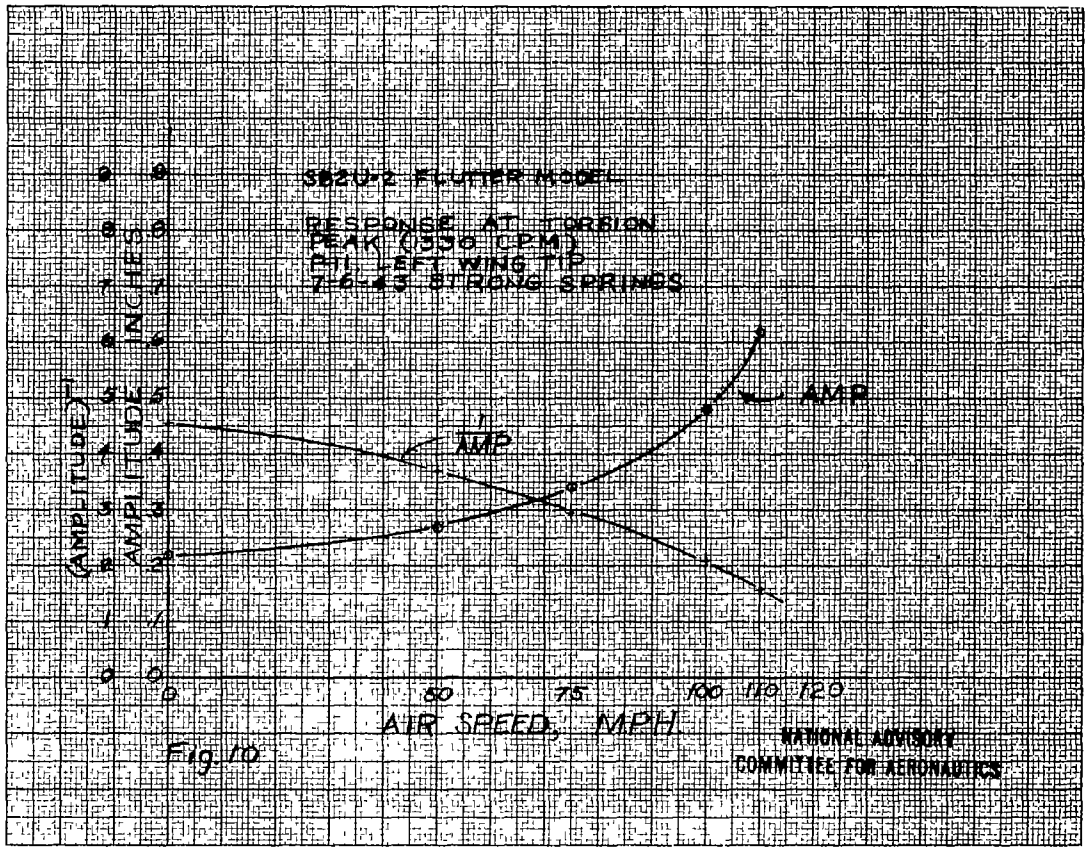

Fig. 10

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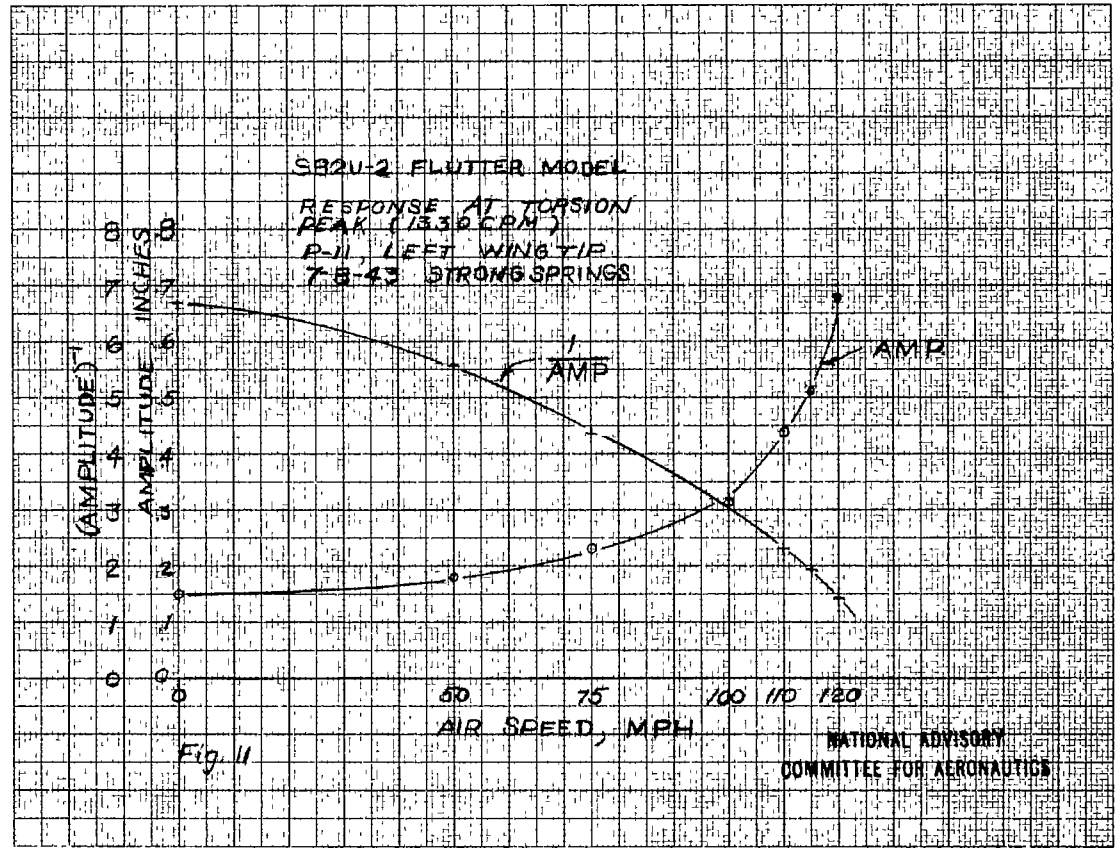

Fig. 11

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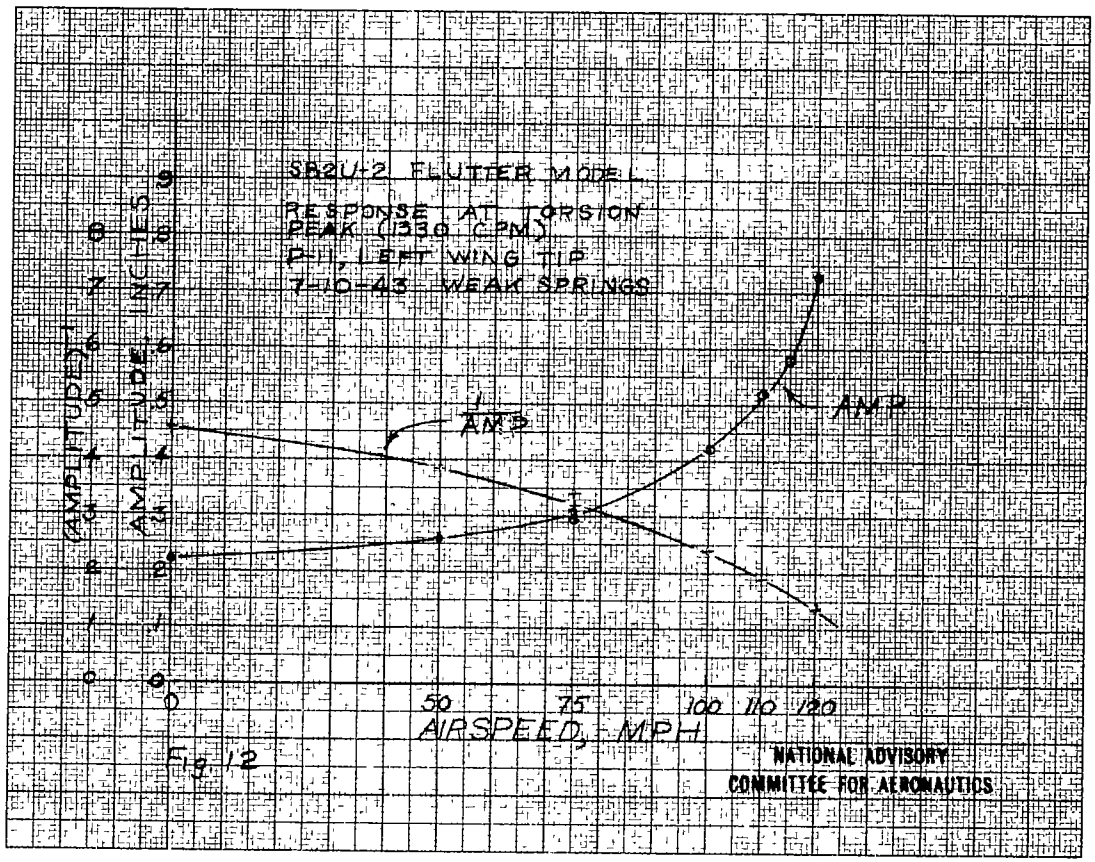

Fig. 12

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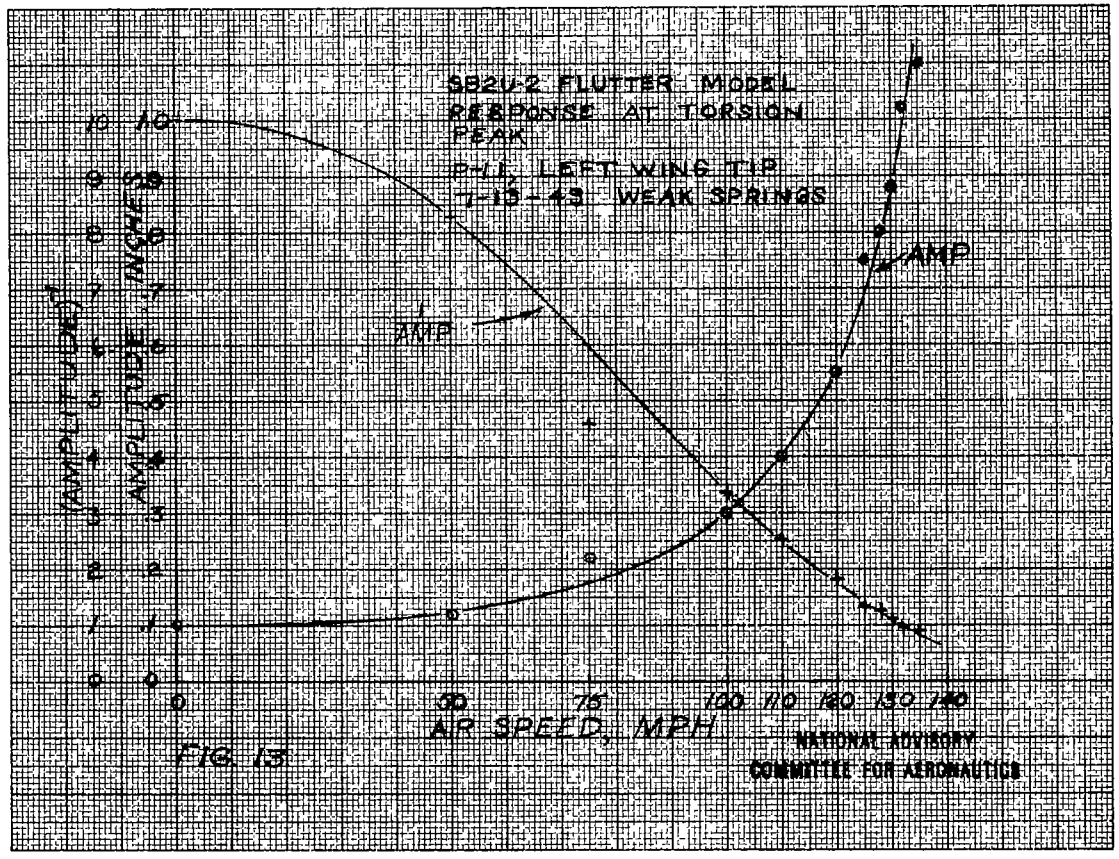
SB2U-2 FLUTTER MODEL
RESPONSE AT TORSION
PEAK
P-11, LEFT WING TIP
7-13-43 WEAK SPRINGS
AMP
AMP
AMPLITUDE, INCHES
AMPLITUDE, INCHES
AIR SPEED, MPH
50
75
100
110
120
130
140
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FIG. 13

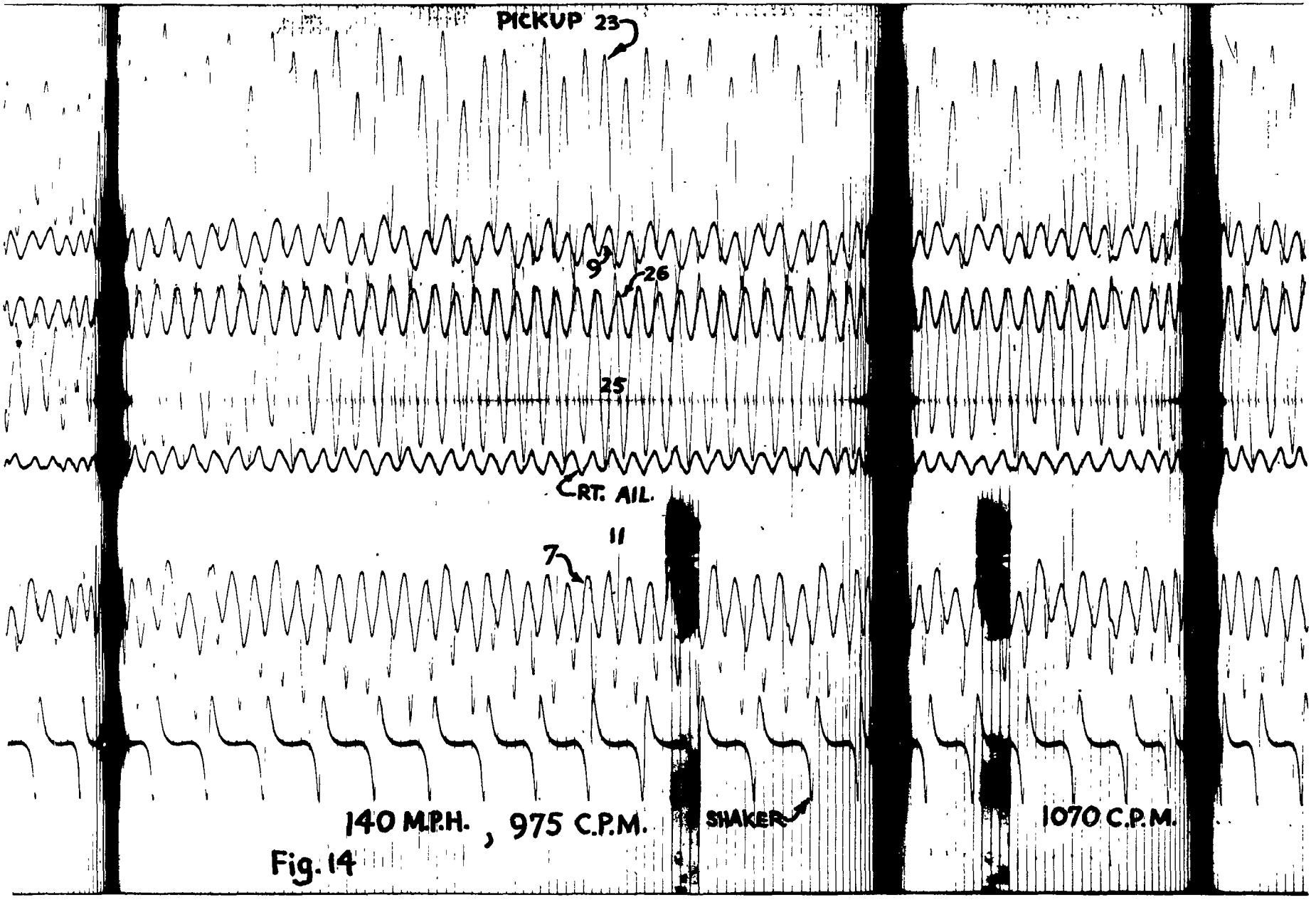


Fig. 14

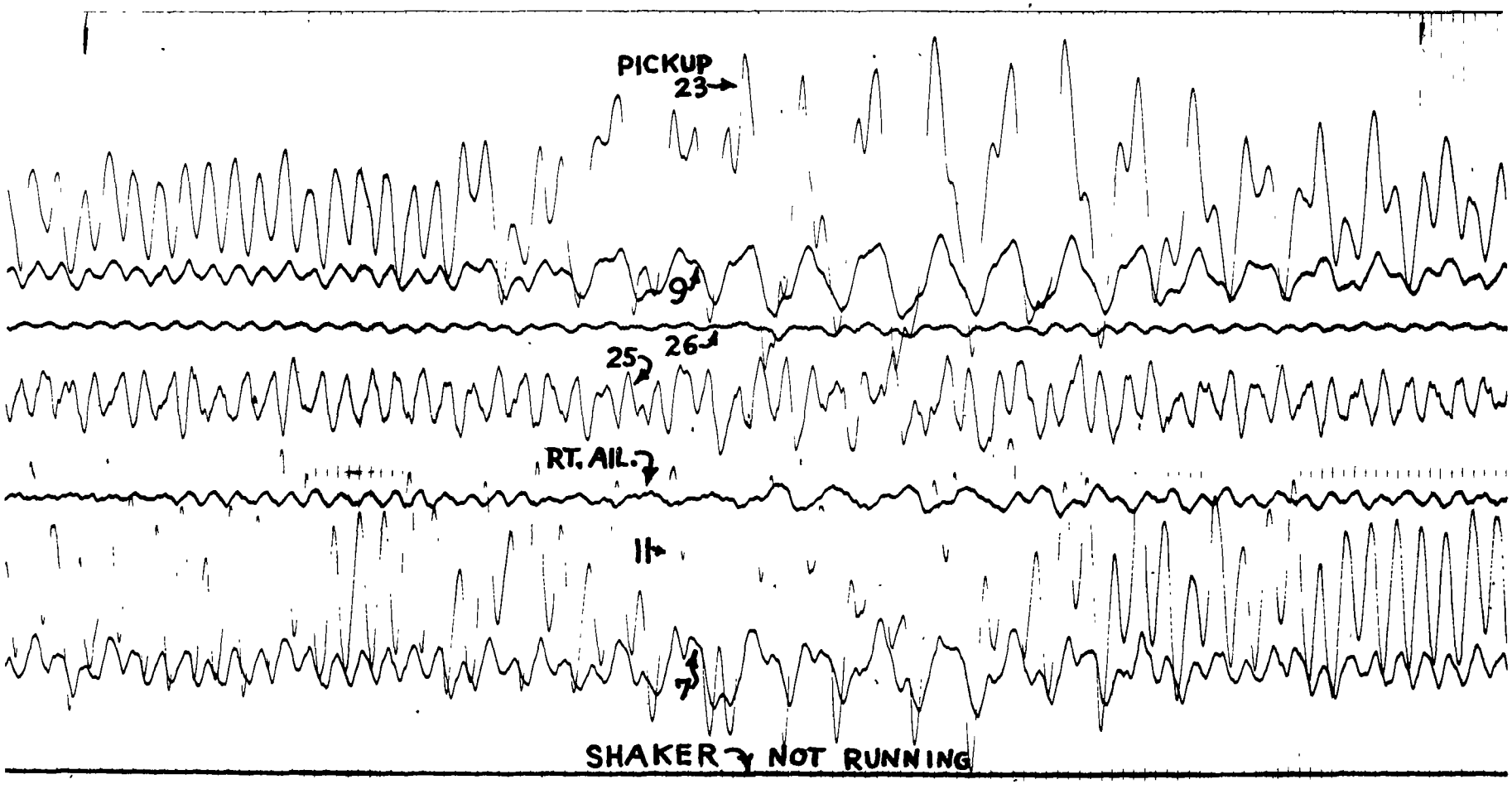
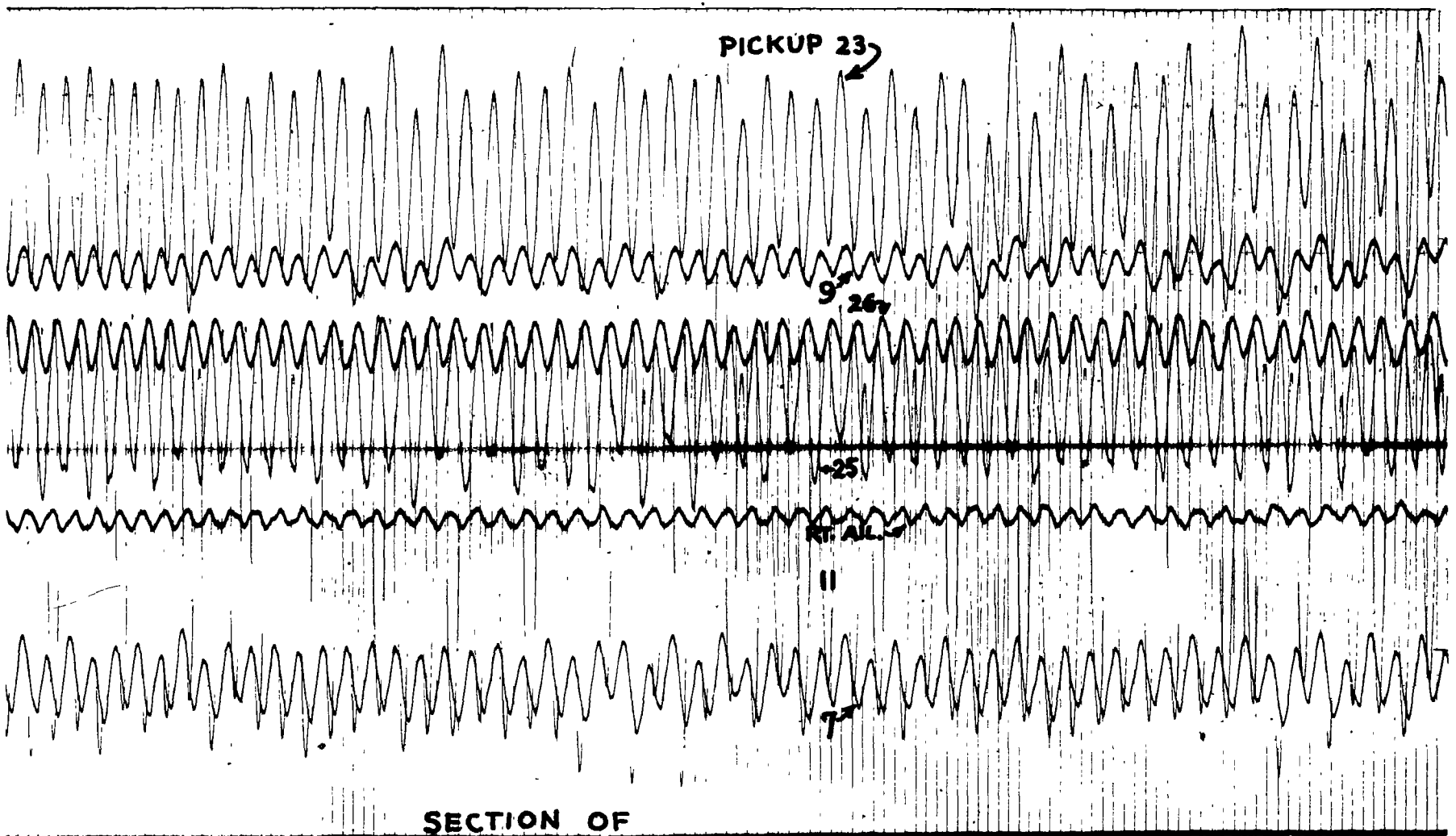


Fig. 15 ACCELERATED RUN, 130 TO 150 M.P.H
BURST AT ABOUT 1000 C.P.M.



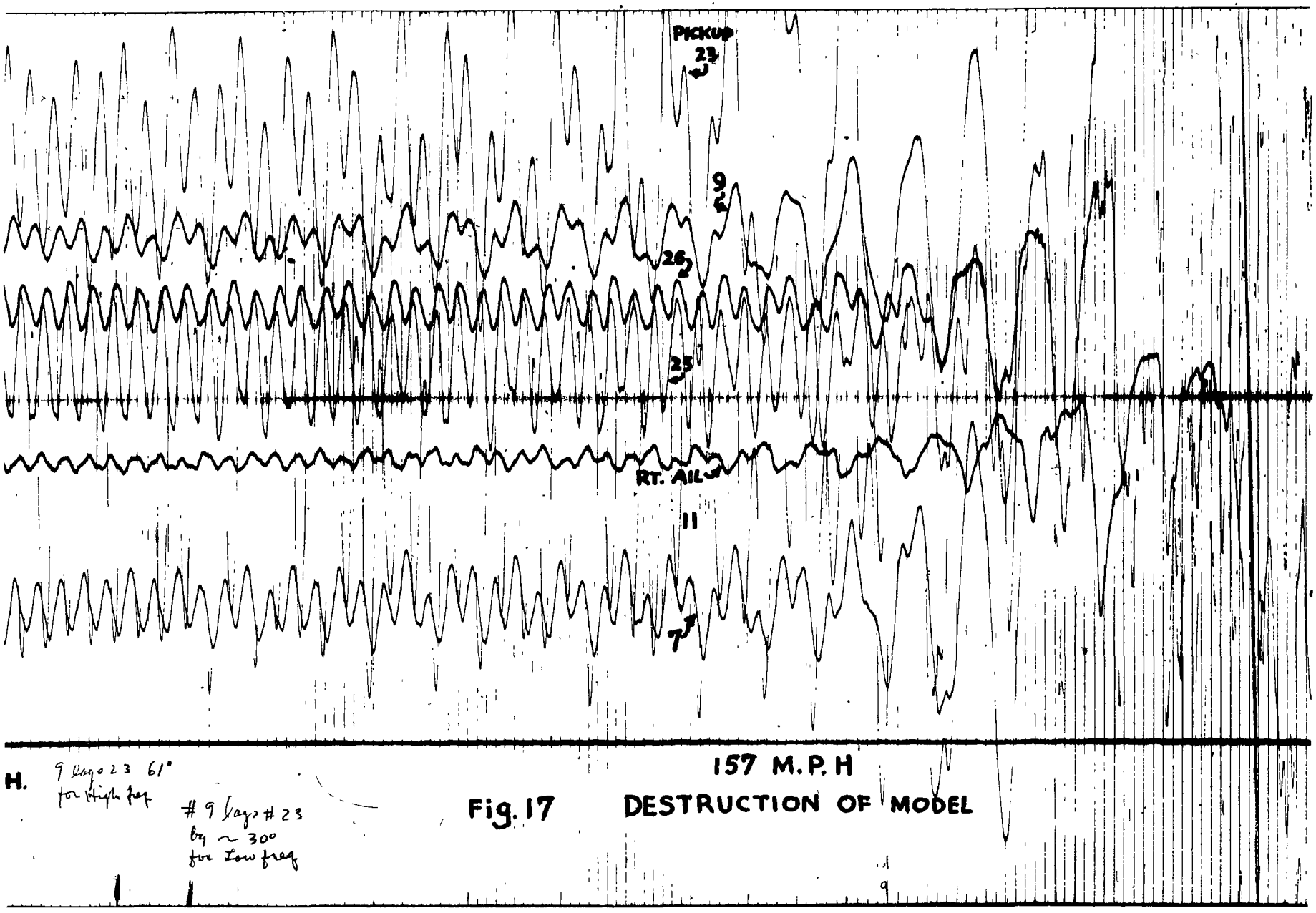
SECTION OF
ACCELERATION-TO-DESTRUCTION RECORD
VELOCITY INCREASED FROM 140 TO 157 M.P.H.
DURING RUN

Fig. 16

lags 23, 70°

9 lags 23 61° for high freq

#9 lags #23 by ~ 30° for low freq



H. 9 lags 23 61°
for High freq

9 lags # 23
by ~ 300
for Low freq

157 M.P.H

Fig. 17 DESTRUCTION OF MODEL

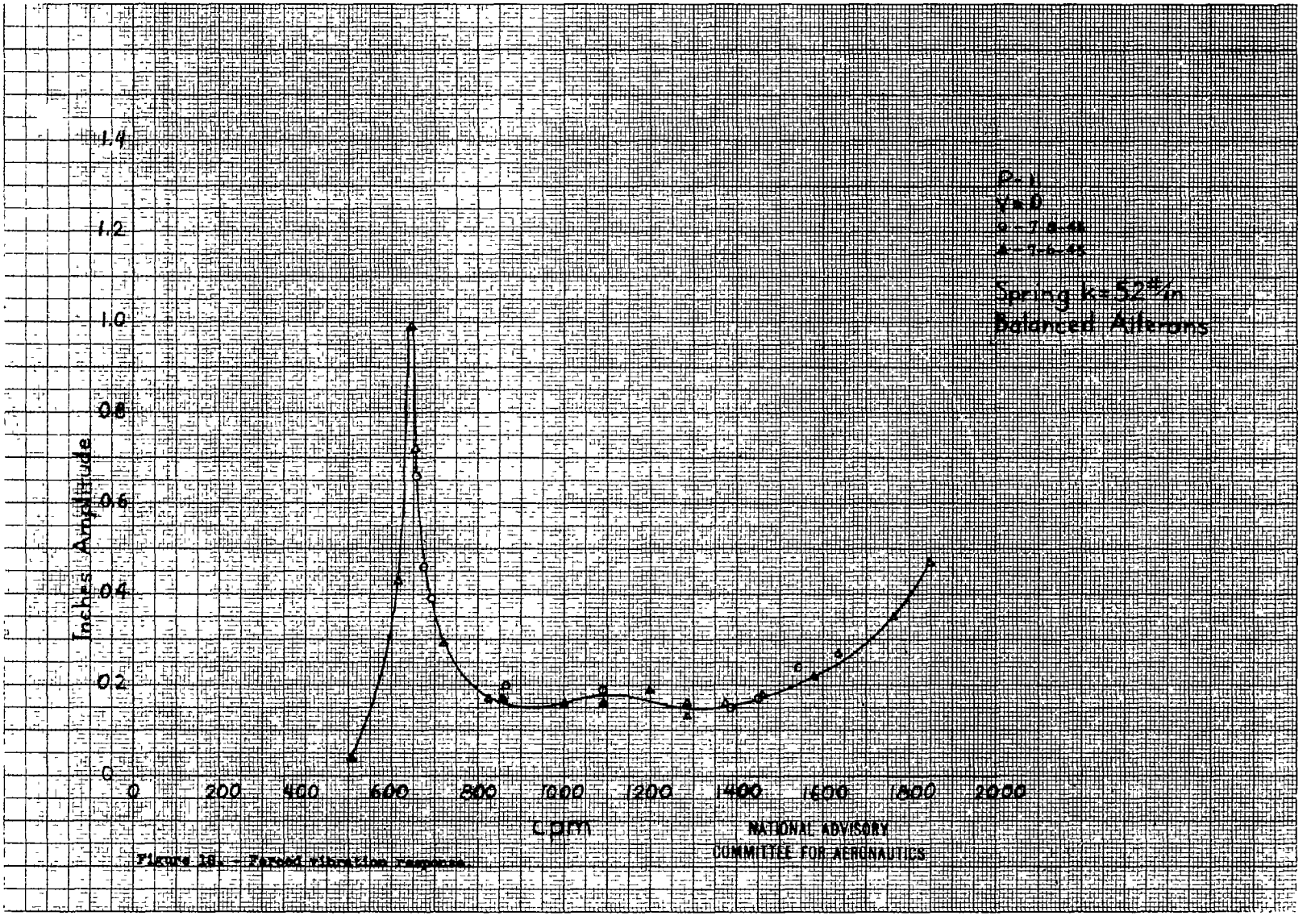


Figure 18. - Forced vibration response.

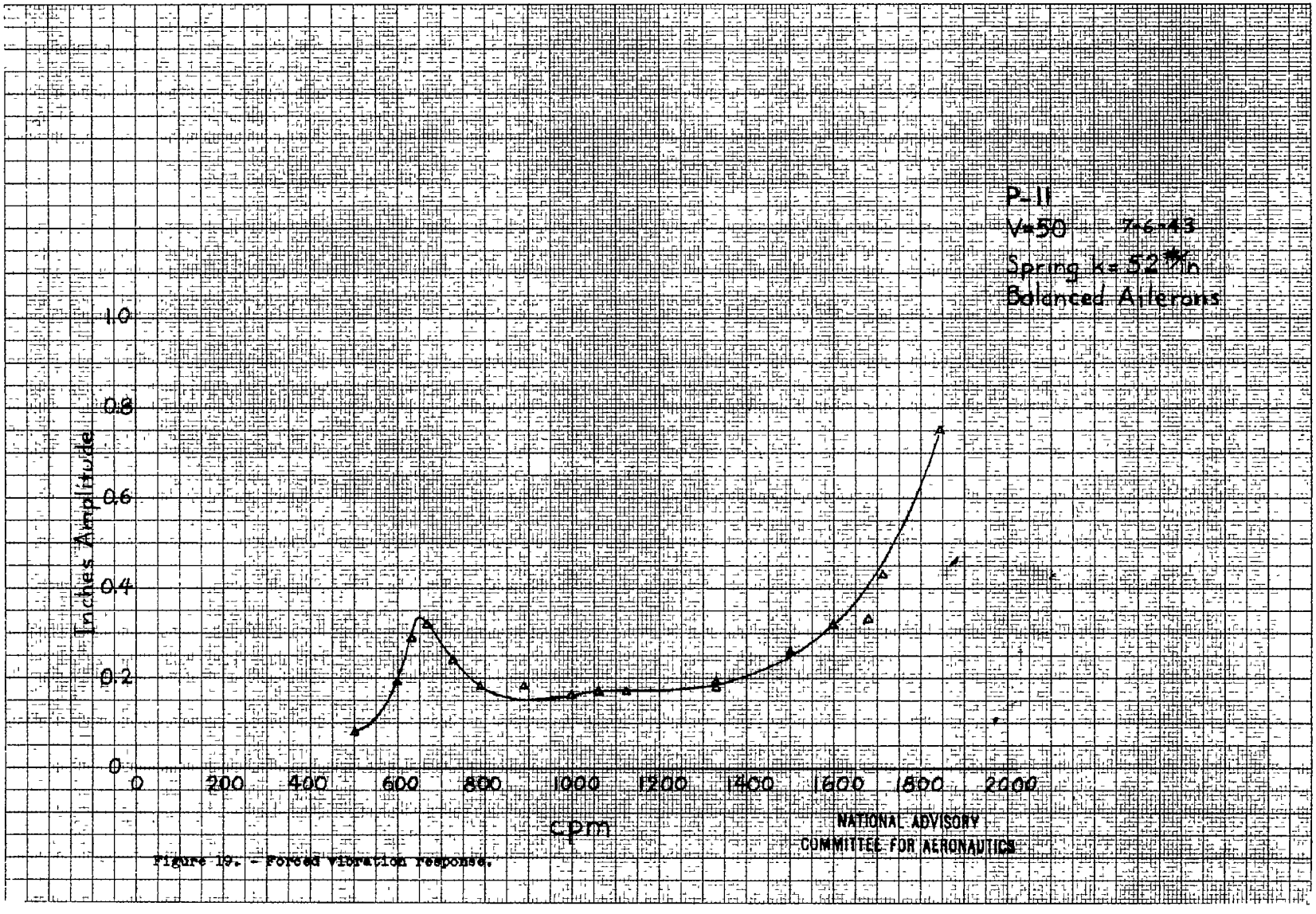


Figure 19. - Forced vibration response.

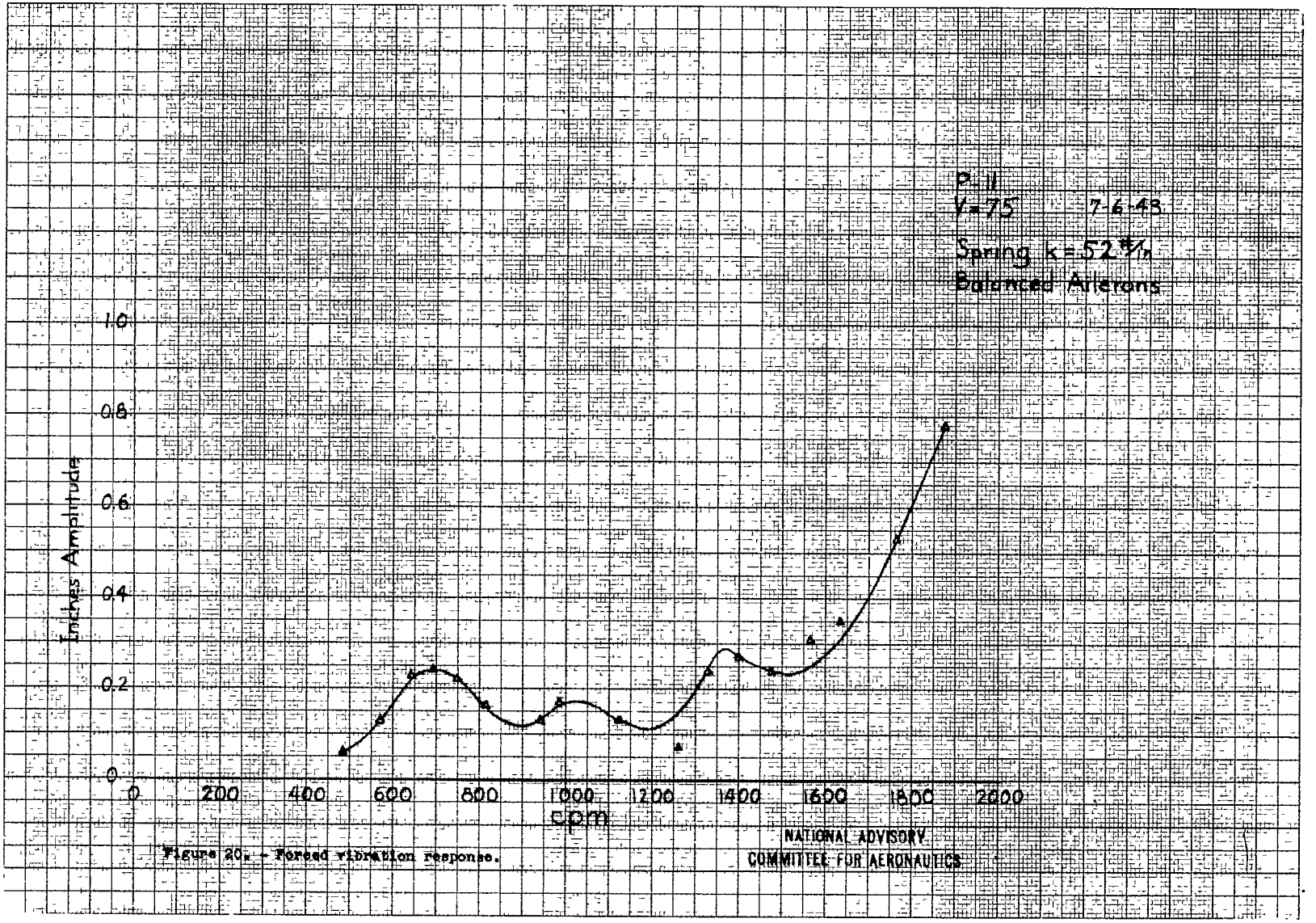


Figure 20. - Forced vibration response.

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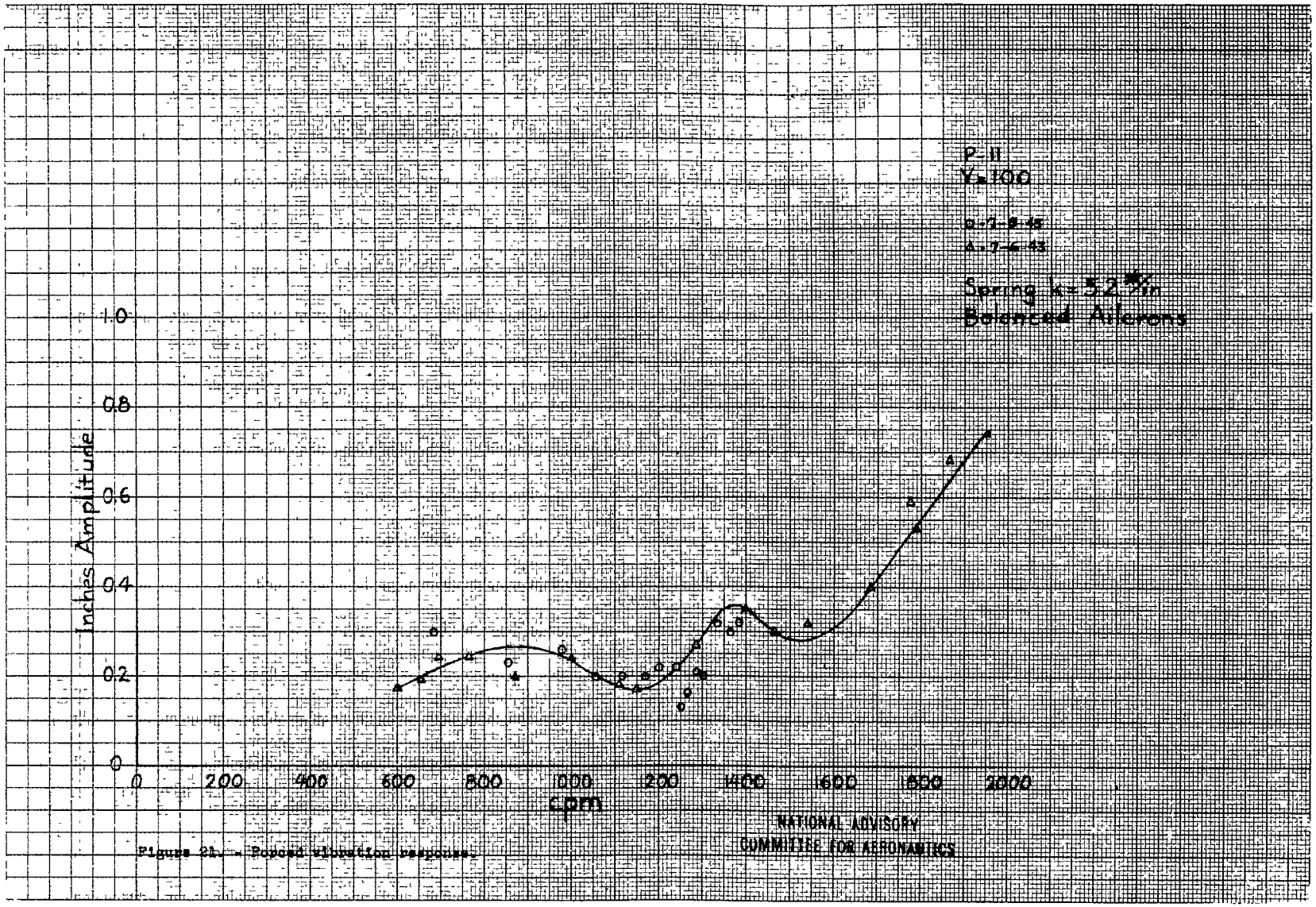

Figure 21. - Forced vibration response.

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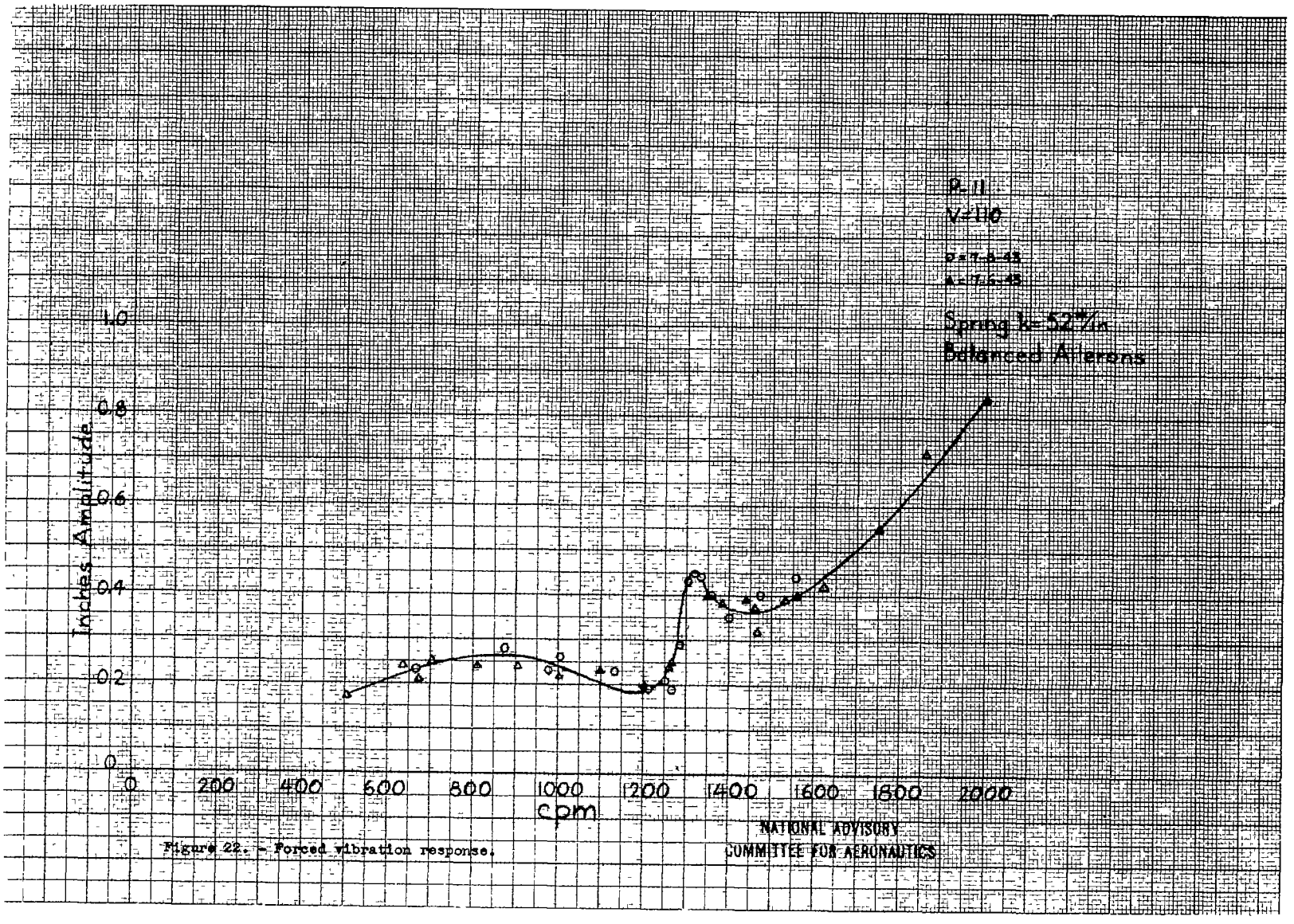

Figure 22. - Forced vibration response.

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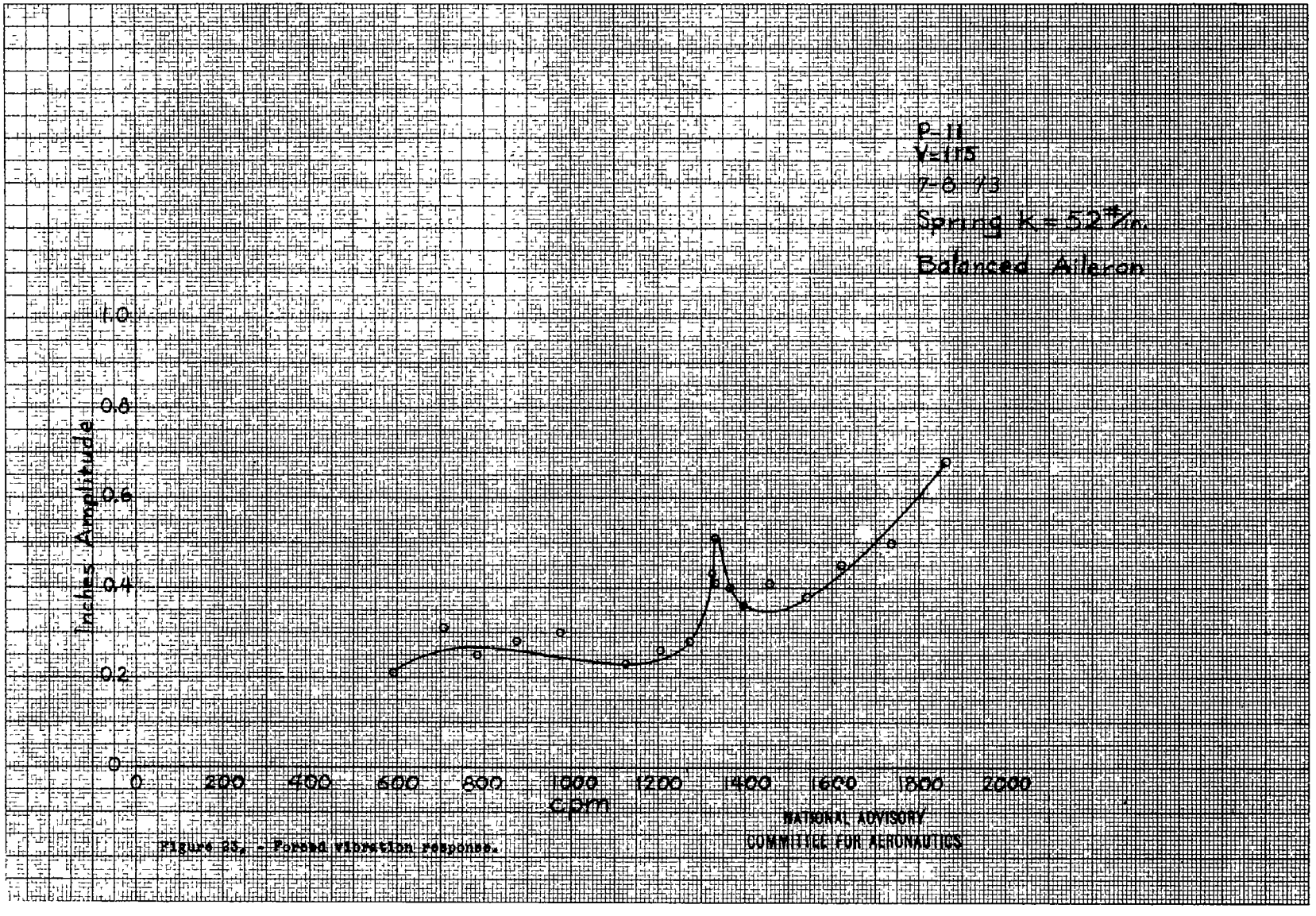

Figure 25. - Forced vibration response.

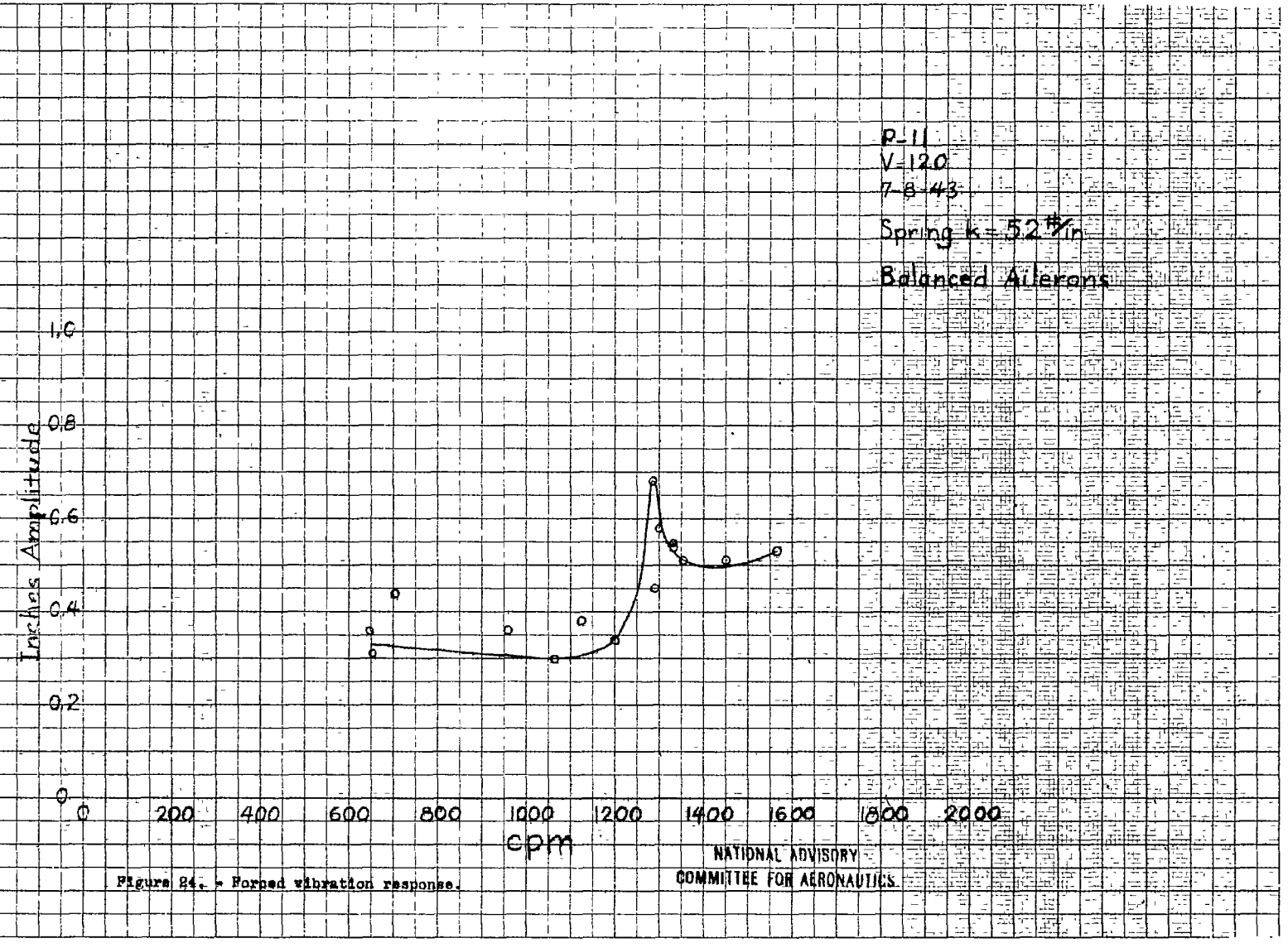

Figure 24. - Forced vibration response.

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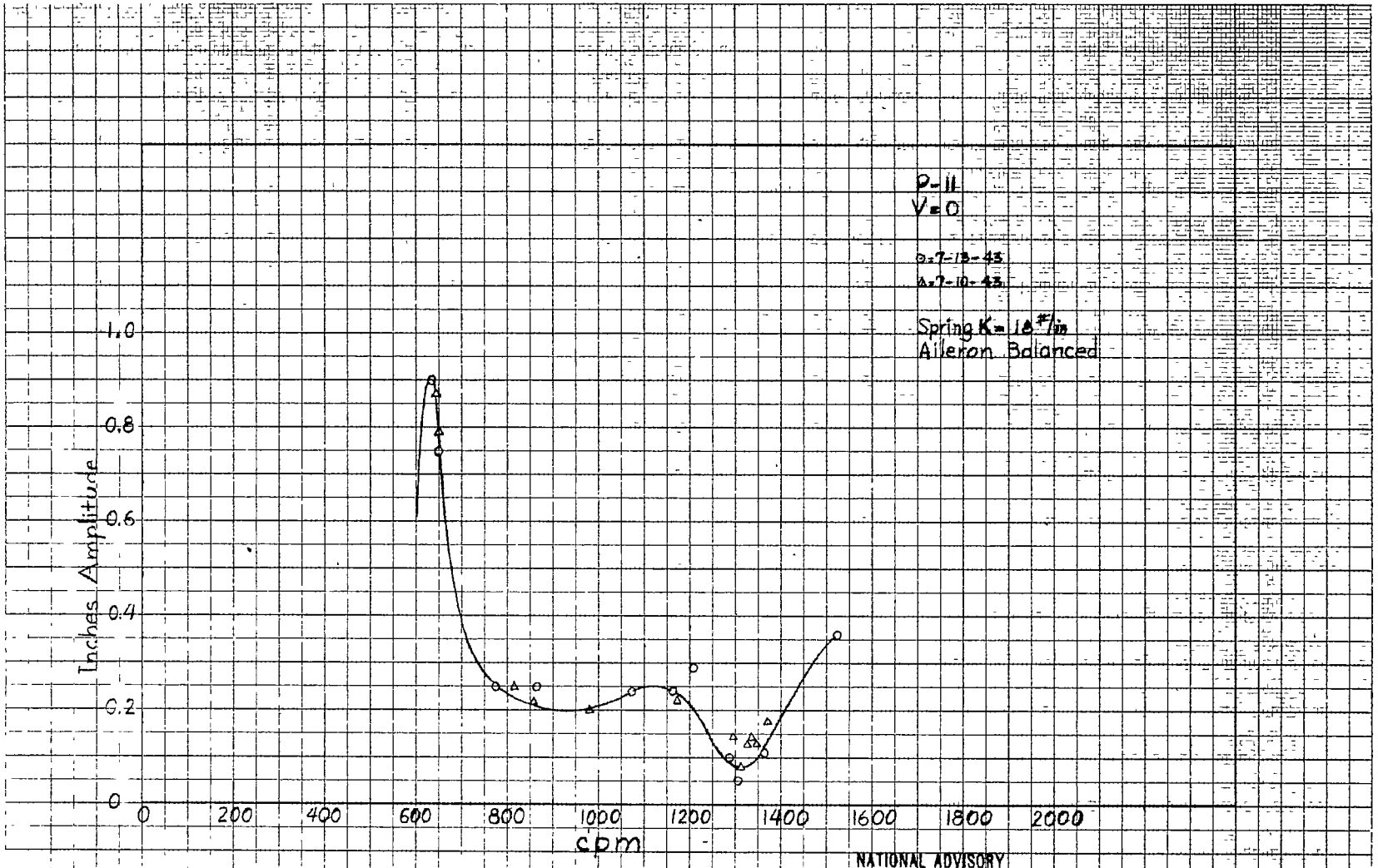

Figure 25. - Forced vibration response.

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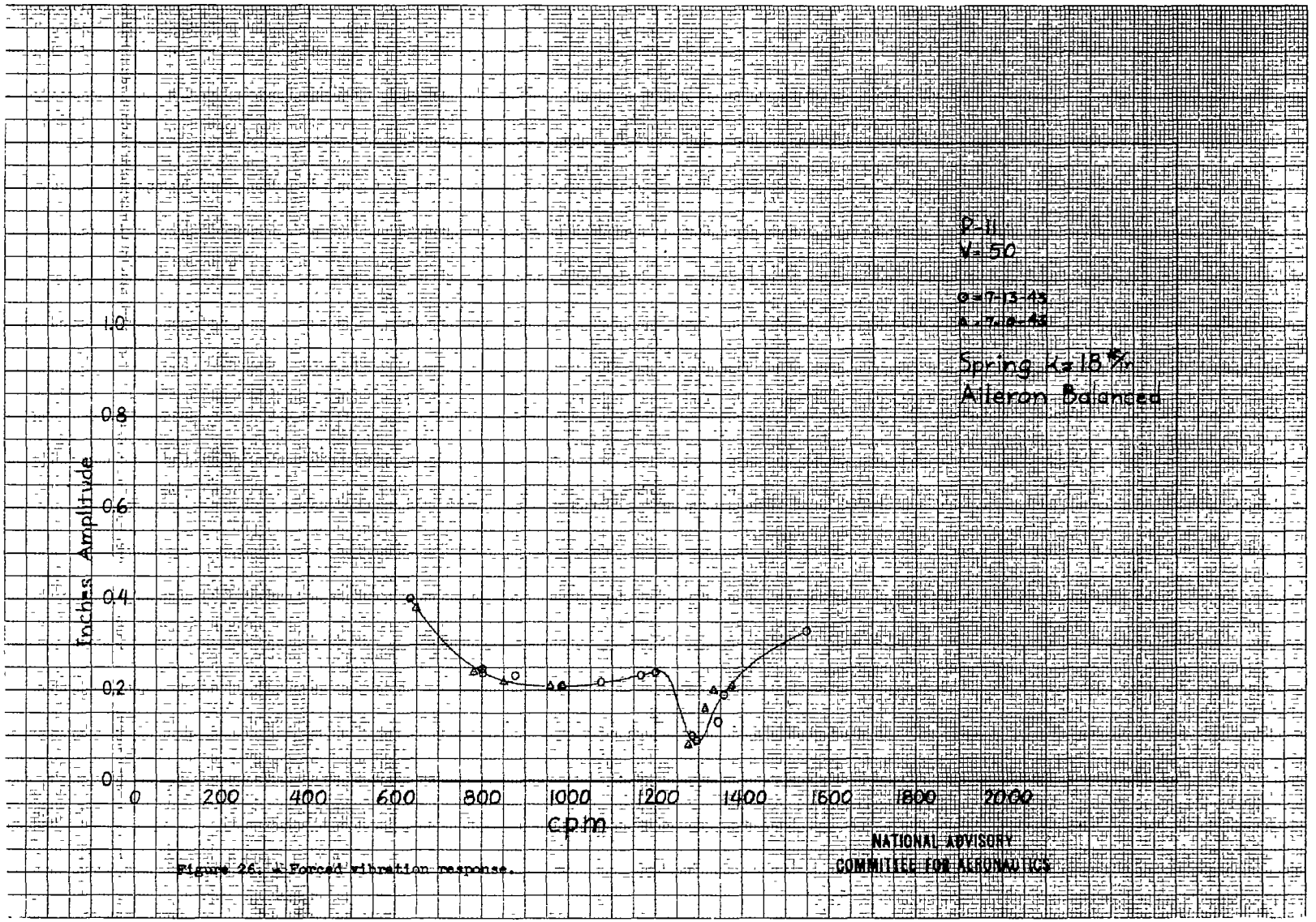

Figure 26. - Forced vibration response.

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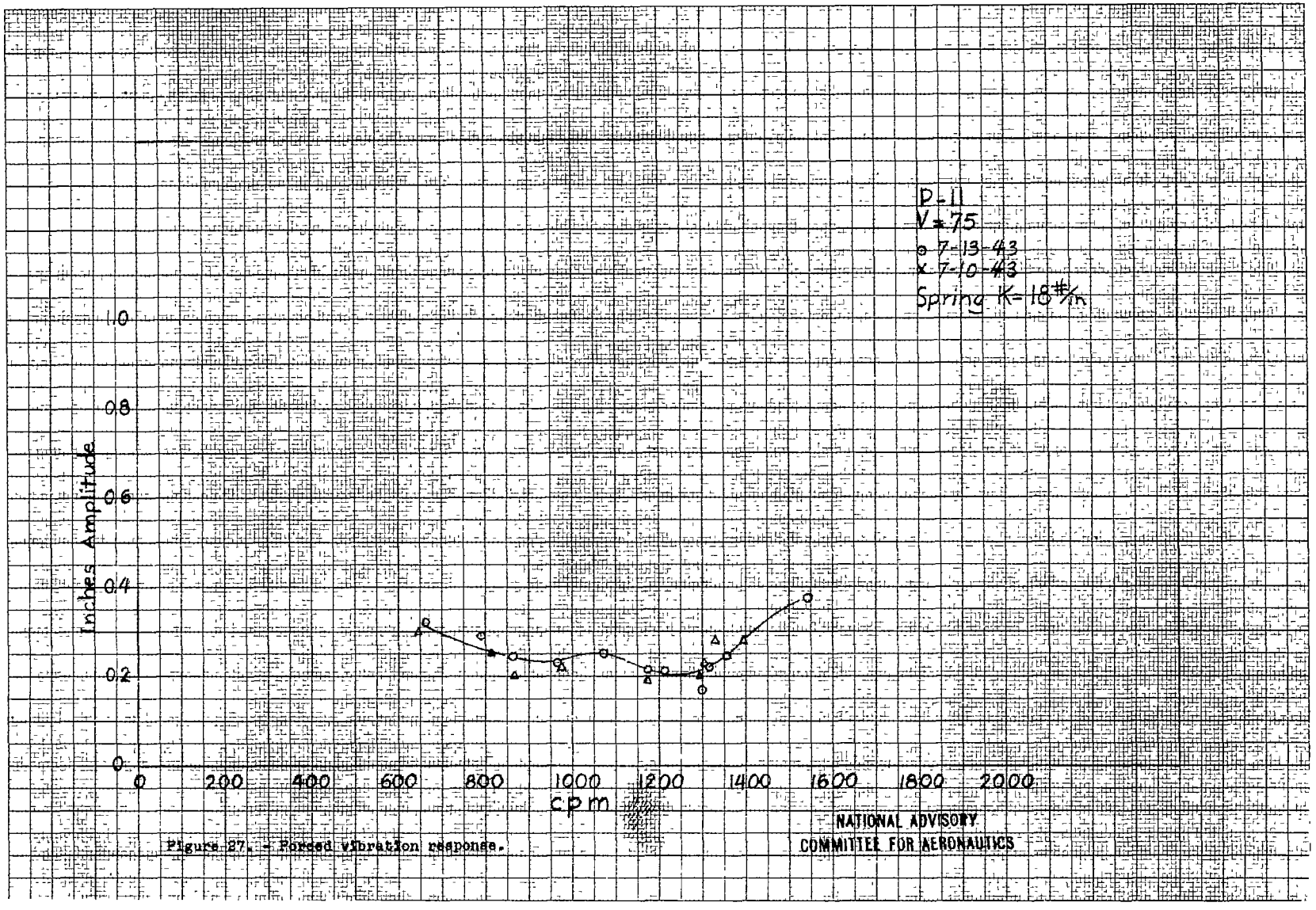

Figure 27. - Forced vibration response.

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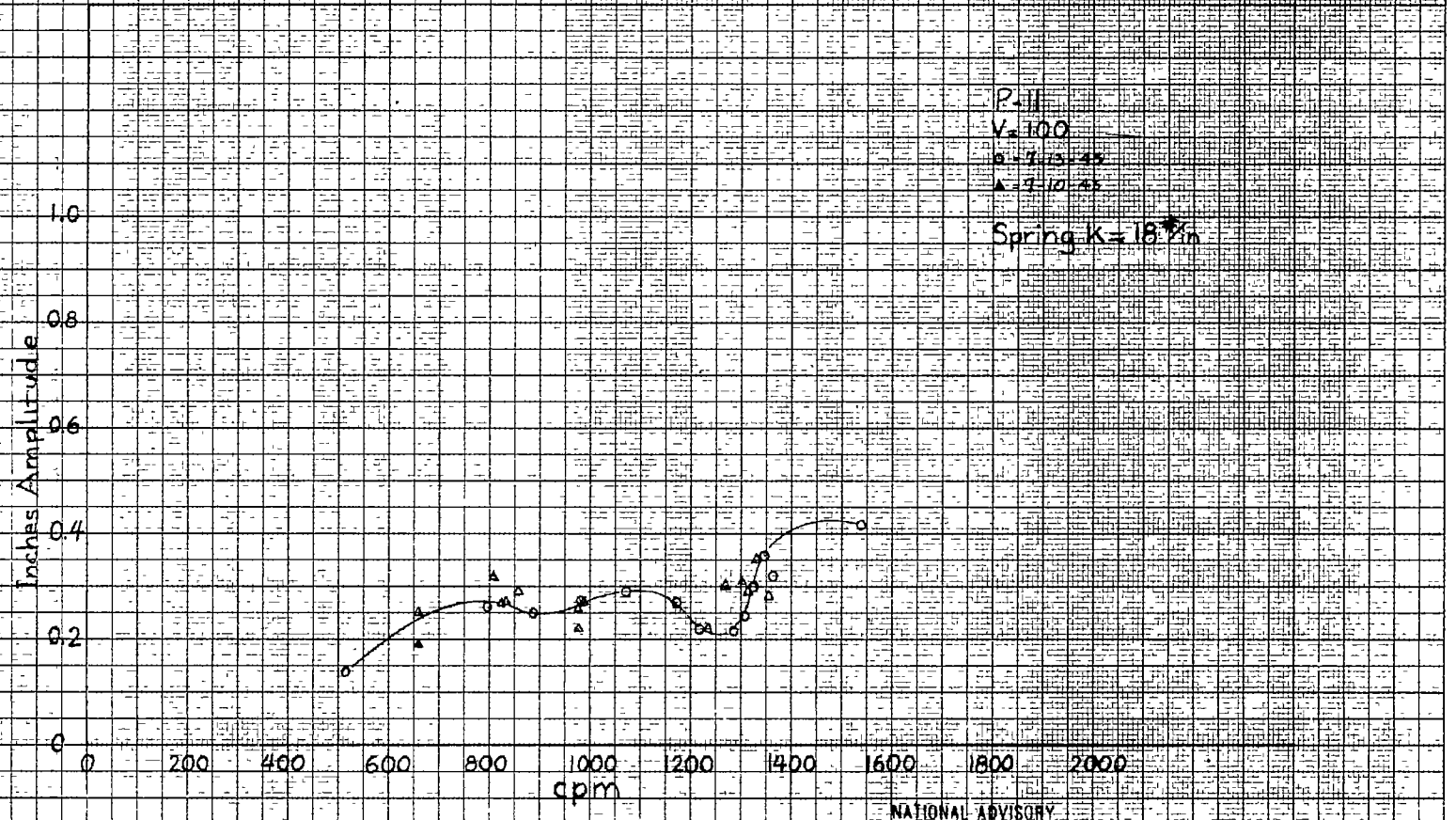

Figure 28. - Forced vibration response.

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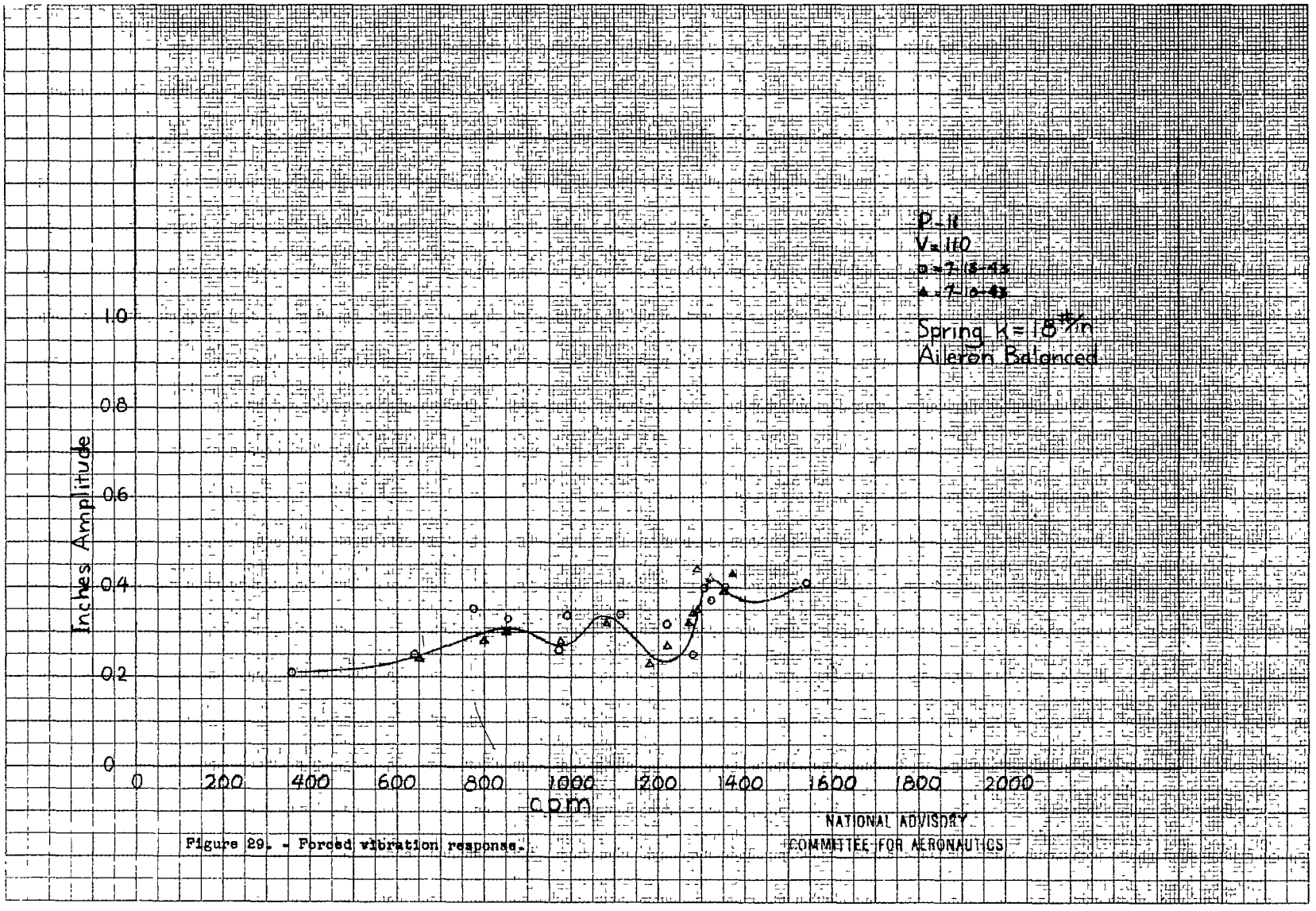

Figure 29. - Forced vibration response.

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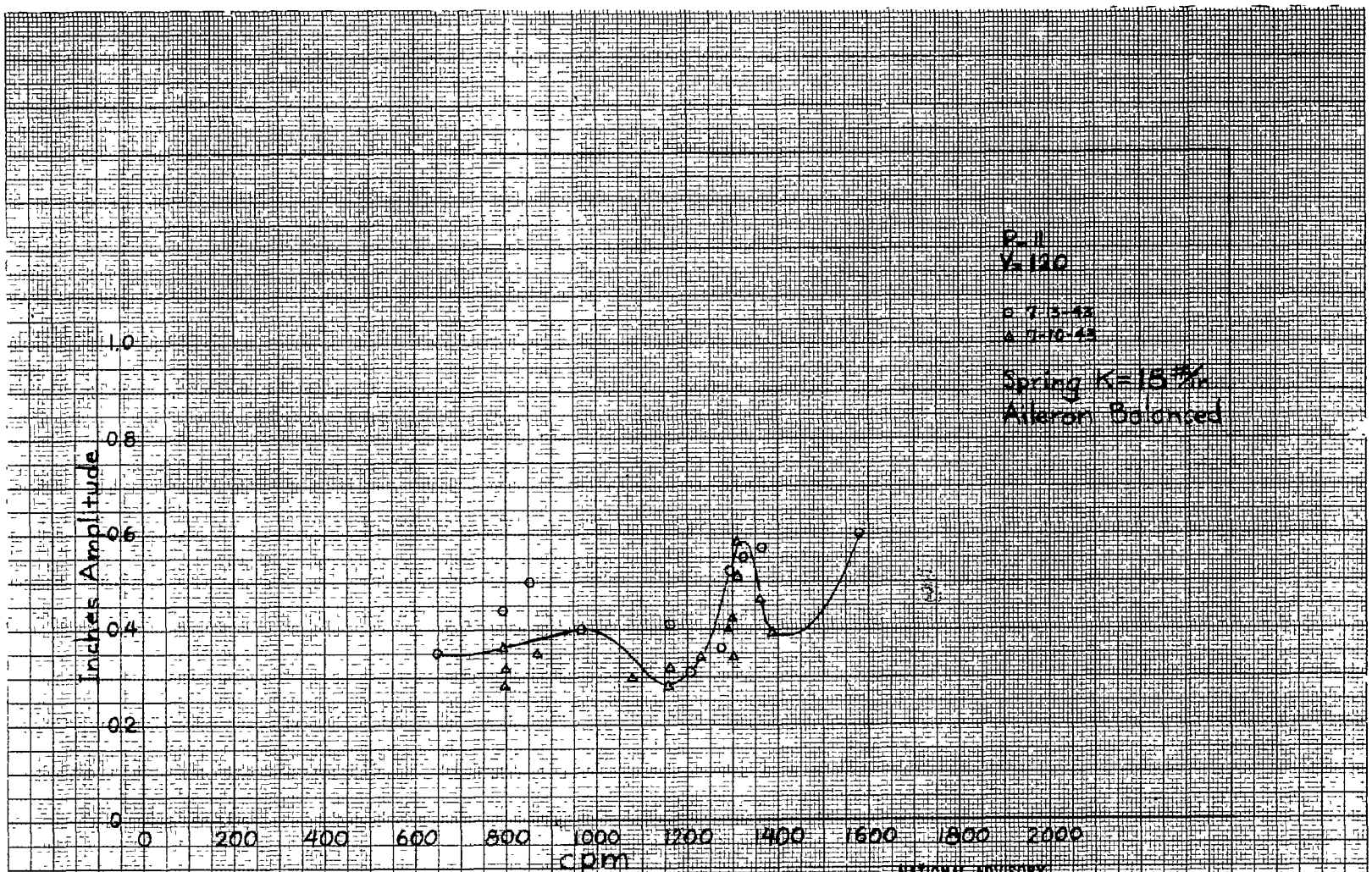

Figure 30. - Forced vibration response.

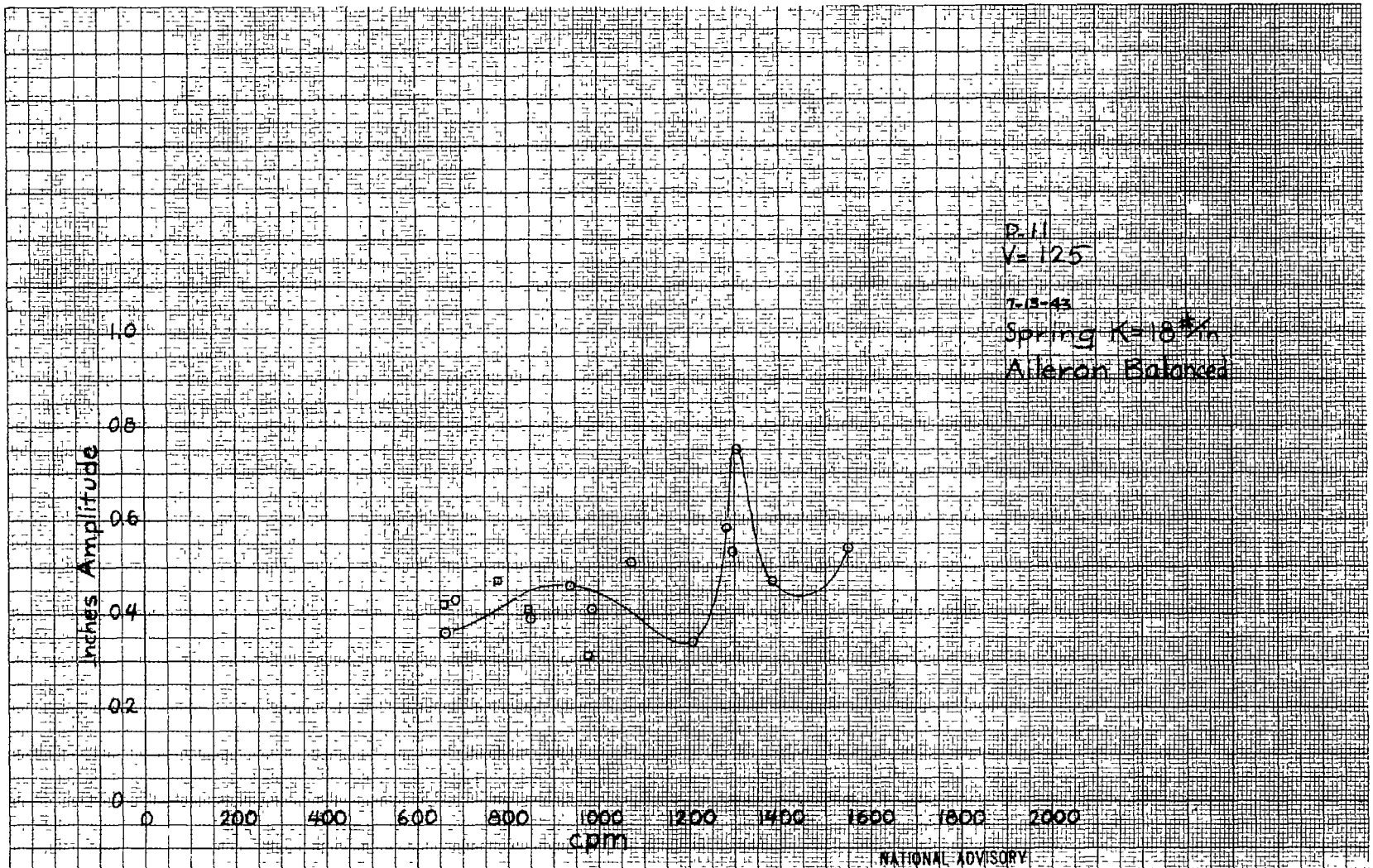

Figure 31. - Forced vibration response.

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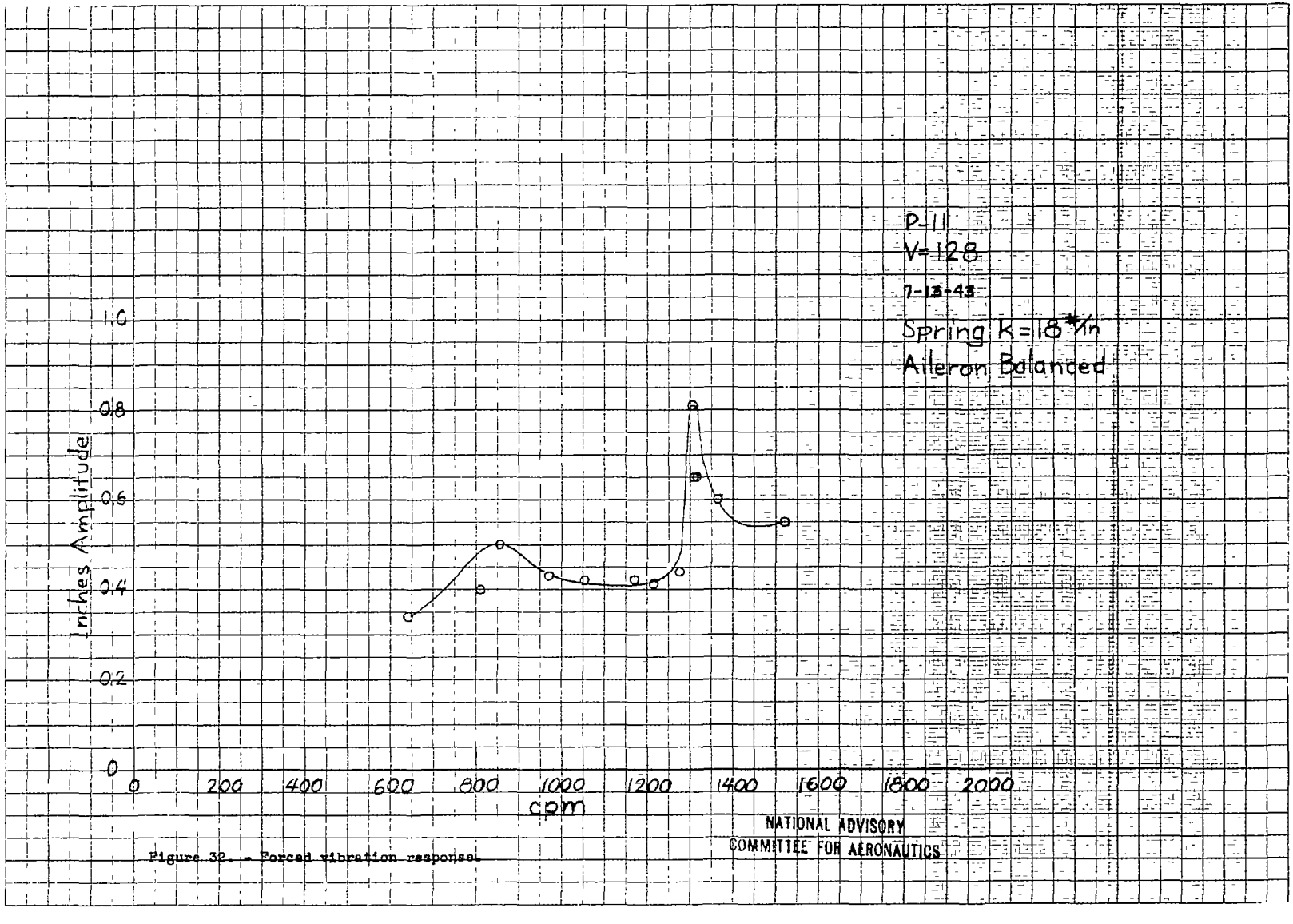

Figure 32. - Forced vibration response.

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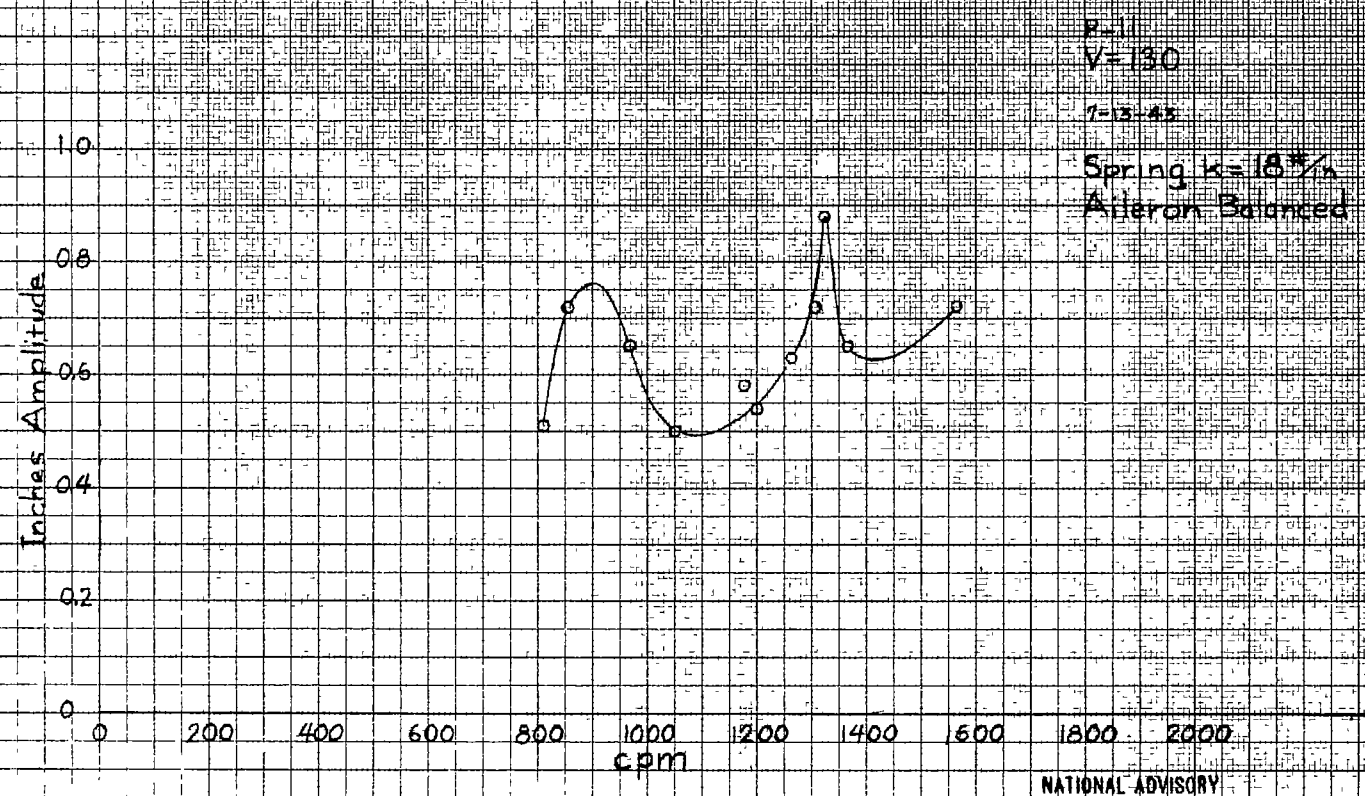

Figure 33. - Forced vibration response.

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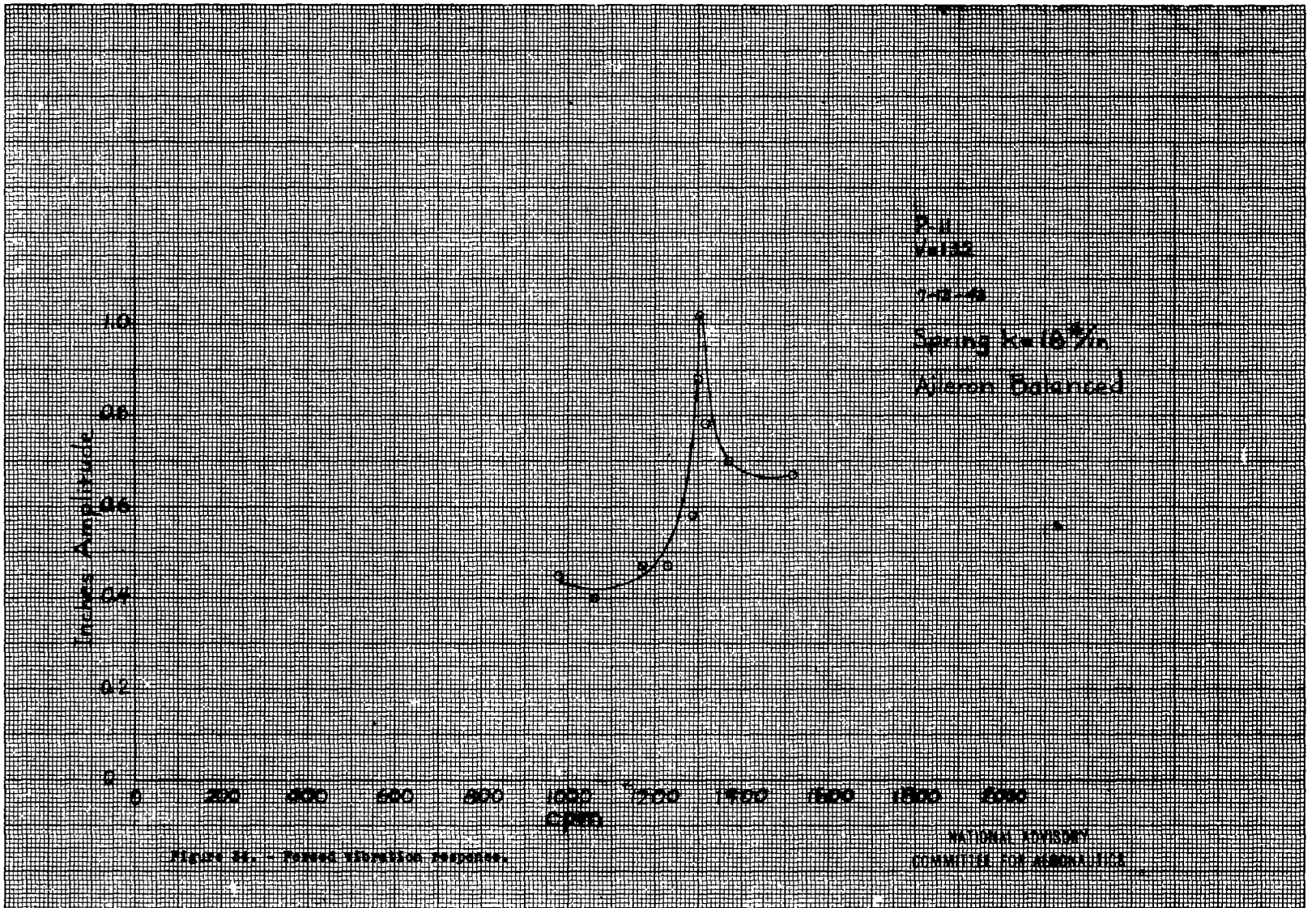

Figure 34. - Forced vibration response.

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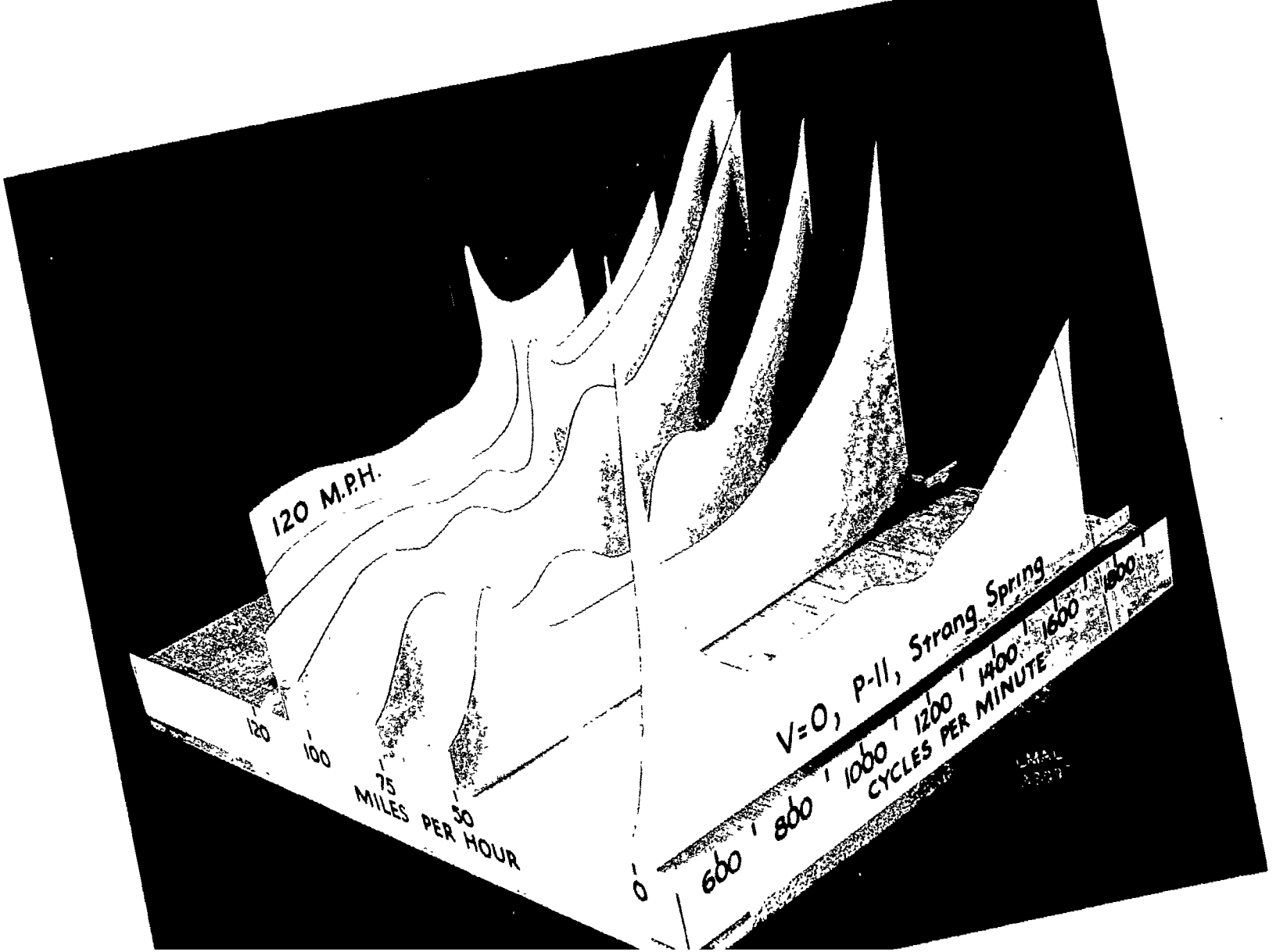
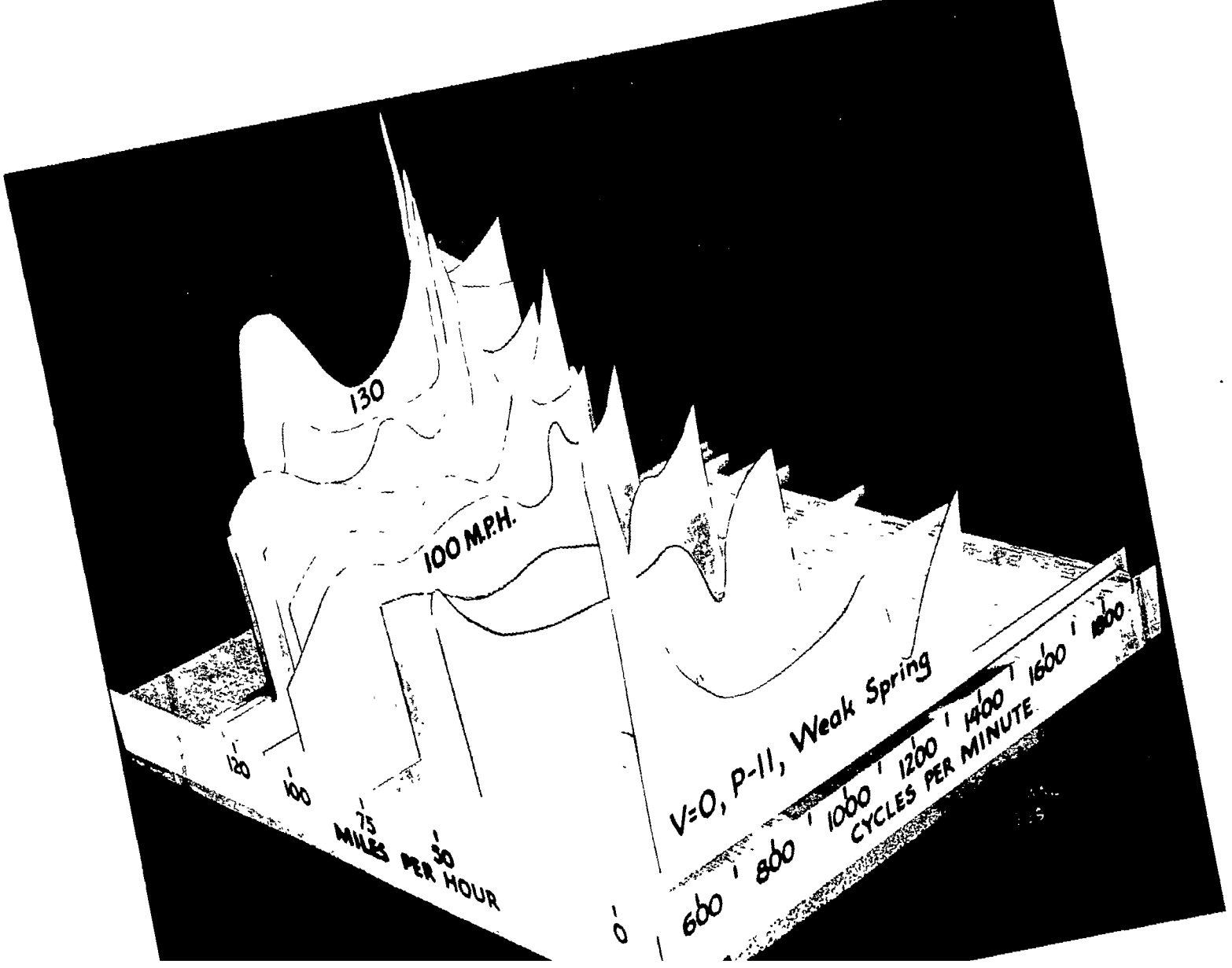

120 M.P.H.
V=0, P-11, Strang Spring
120
100
75
50
0
MILES PER HOUR
600
800
1000
1200
1400
1600
1800
CYCLES PER MINUTE


130
100 M.P.H.
120
100
75
50
MILES PER HOUR
0
600
800
1000
1200
1400
1600
1800
CYCLES PER MINUTE
V=0, P-11, Weak Spring

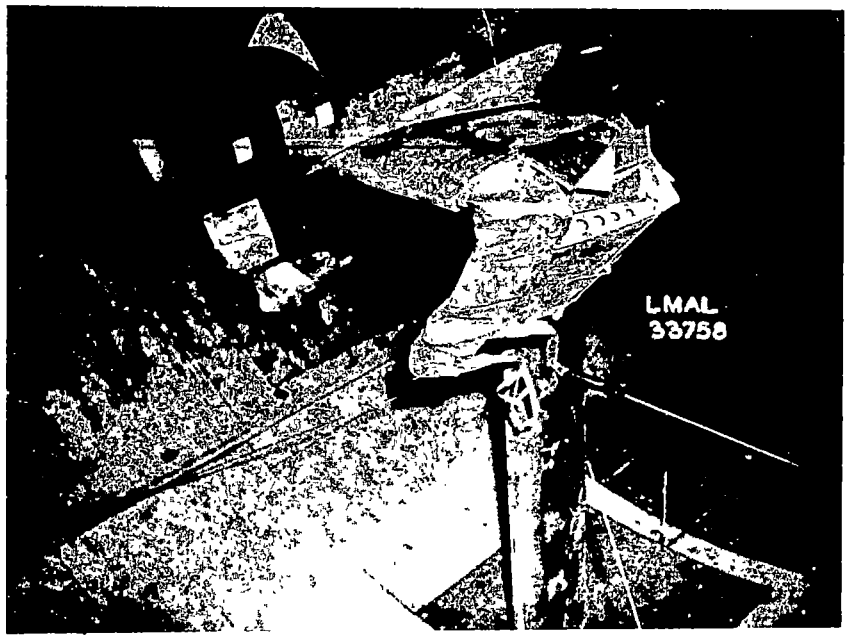


Figure 37.- The wing after flutter.

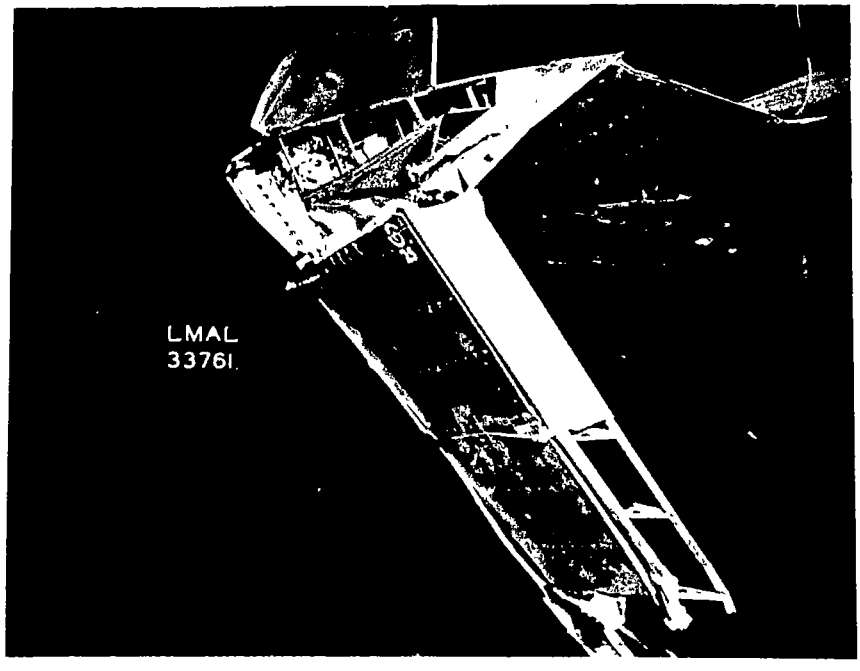


Figure 38.- The wing after flutter.

Figure 39.- The wing after flutter.

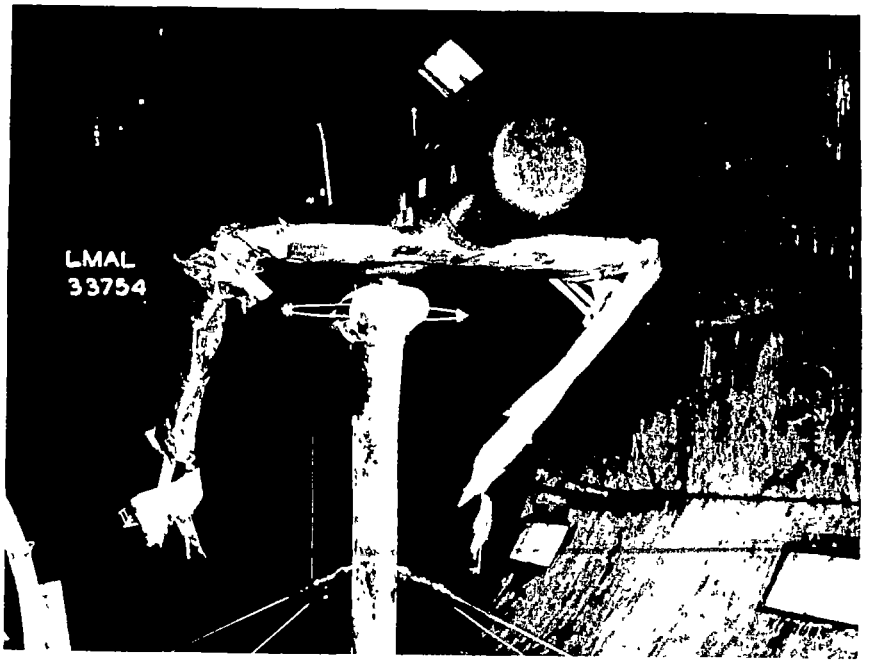


Figure 40.- The wing after flutter.

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