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SUBJECT Wind Tunnel Investigation of Possible Rudder Flutter on a 1:25 Scale Fin Model of CF-105 at Mach Number of 1.22

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1. Introduction

As the theoretical calculations indicated a possibility of the development of rudder flutter on CF-105, an experimental verification of the critical speed and frequency was required. A series of tests in the NAE 30 in. x 16 in. supersonic wind tunnel was performed on a fin model equipped with rudders of suitable density and hinge stiffness.

2. Models

The model was supplied by Avro Aircraft Company and consisted of a 1:25 scale model of the fin of CF-105 and two rudders (to be used alternatively). Each rudder could be elastically mounted on the fin by means of a wide cantilever spring, acting as a hinge. The fin was rigidly mounted on a circular plate, which could be clamped to the wind tunnel wall at an arbitrary angle of incidence. A sketch of the model mounted in the wind tunnel is given in Fig.1. The dimensions of the parts involved can be found on the following Avro Aircraft Ltd. drawings:

7-0283-0041	issue 1	Fin Assembly
7-0283-0042	issue 1	Modifications to Tail Fin
7-0283-0043	issue 1	Plate for Tail Model Balance
7-0283-0044	issue 1	Hub for Tail Model Balance
7-0283-0047	issue 1	Clamp
7-0284-0018	issue 1	Rudder Assembly
7-0284-0019	issue 1	Rudder

In order to decrease gradually the hinge stiffness of the rudder, cutouts were made in the hinge strip of the two rudders; this being done gradually so that cutouts were made in one rudder when the second one was tested and vice versa. In order to compensate for the difference in the hinge strip thickness of the two rudders, the length and position of the cutouts were chosen somewhat differently from what was originally proscribed by Avro Aircraft (their drawing 7-0284-0019). The dimensions and positions of the cutouts are given in Figure 2. The initial rudders were called Aa-0 and Zz-0, and the rudders with first and second series of cutouts, Aa-1, Zz-1 and Aa-2, Zz-2 respectively. A total of six rudders was tested.

3. Test Equipment

To initiate rudder oscillations at no-flutter condition a mechanical striker device (shown in Fig.1) was used. The striker arm was designed as a part of a circular arc to minimize disturbances which were likely to be caused by it in the aft part of the rudder. The same device was also used as a brake reducing the movements of the rudder during the starting and stopping of the wind tunnel and could be used for prevention of excessive oscillation if flutter conditions were encountered.

An electrical signal proportional to the deflection of the rudder (as measured at its hinge line) was obtained from a strain-gauge bridge, consisting of two active gauges cemented to the inside of the rudder hinge strip and two dummy gauges mounted inside the wind tunnel (to minimize the temperature effects). In order to better utilize the very small space available and get better distribution of strain-sensitive elements, the active gauges on the rudder Zz were composed of sets of five gauges internally connected in series.

The output from the strain-gauge bridge was connected alternatively to a Hathaway recording oscillograph or to an Oltronix dampometer, the latter being a special instrument for measuring the damping and frequency of decaying oscillations (see Ref.1 for general description of this instrument).

4. Mechanical Calibration

Stiffness and moment of inertia of the initial and the final rudders (Aa-0, Zz-0 and Aa-2, Zz-2) were determined by bench calibrations. It was found that the ratio of rudder stiffness to hinge stiffness was not high enough to permit making the desired assumption of a stiff rudder oscillating around a fixed hinge line. In fact it was found that this stiffness ratio was so low that the method of decreasing the natural frequency of the rudder by making cutouts in the hinge strips and thereby decreasing the hinge stiffness was not at all adequate and resulted in only a small frequency change.

Hinge stiffness, K_H, was determined by a static calibration with weights. The rudder was detached from the fin and elastically hinged to a surface table. The rudder was made very stiff by clamping it firmly between two stiff plates of the same shape as the rudder, thus ensuring that the deflection measured was due to bending in the hinge strip only. All calibration results are given in Table 1, where hinge stiffness appears in column 3. It is seen that for the same effective hinge width (column 7), K_H is much lower for the rudder Zz - the reason of this being a rather large discrepancy in the average hinge thickness (column 8) of the two rudders. Further, it may be noticed that the values of K_H are much lower than predicted by the simple beam theory (column 9) - possibly due to the effect of the very large beam width as compared with its length and thickness. This discrepancy decreases with decreasing effective hinge width.

Rudder stiffness could not be easily defined as its value depended on the load distribution on the rudder and on the definition of the proper deflection angle. Instead, an equivalent rudder stiffness, K_R, was introduced and defined as the stiffness which together with the rudder moment of inertia gives the right value of rudder frequency in the case when hinge strip is assumed to be completely stiff and all deflection takes place within rudder only. In view of the fact that both rudder moment of inertia and rudder stiffness remained constant while hinge stiffness was changed by making cutouts in the hinge strip, this equivalent rudder stiffness could be obtained from natural frequencies observed with and without cutouts. Assuming the hinge and the rudder acting as two springs connected in series, the following expression was obtained:

$$K_R = \frac{K_{Ho}\ K_{H2}\ (\nu_o^2 - \nu_2^2)}{\nu_2^2\ K_{Ho} - \nu_o^2\ K_{H2}}$$

where indices "0" and "2" refer to rudders with no cutouts and rudders with final cutouts, respectively.

The values of K_R for the rudders tested appear in Table 1, column 2.

The total stiffness, K_T, for every rudder could now be obtained from the expression

$$K_T = \frac{K_R\ K_H}{K_R + K_H}$$

and is given in Table 1, column 4.

The moment of inertia of the oscillating system could then be calculated from

$$I = \frac{K_T}{4\pi^2 \nu^2}$$

and can be found in Table 1, column 6.

The structural damping of the oscillating rudder was found to correspond to the values of the damping coefficient $g^{\star}$ of between 2.3 percent and 5.1 percent, see column 10 in Table 1. These values were obtained with the rudder mounted on the fin and the fin tip clamped in a fixed position to prevent fin oscillations.

5. Wind Tunnel Tests

As the flutter conditions, if at all present, were most

★ Damping factor g is approximately equal to the logarithmic decrement divided by π

likely to be found at Mach Number around M = 1.25 and low frequencies, the wind tunnel tests were started at a somewhat higher Mach Number (1.35) with the stiffest rudder (Aa-0), and continued with Mach Number 1.22 and rudders with gradually decreasing stiffness. The test procedure was as follows:
The rudder to be tested was mounted on the fin, all connections to the strain gauge bridge were made and the whole assembly was mounted in the wind tunnel with the fin at zero angle of incidence. Two calibration runs were recorded on the recording oscillograph, one with the fin tip held in a fixed position and the second one with the fin tip free. Typical calibration records are shown in Figure 3a and b. In each of those runs the oscillation of the rudder was initiated by using the striker arm, described in paragraph 3. The output of the bridge was then connected[✮] to the dampometer on which the damping and frequency of oscillation was obtained.

The strain gage bridge was then connected again to the recording oscillograph and two wind tunnel runs were made.

[✮] This part of the procedure was omitted in the last four tests, after it has become obvious that damping cannot be measured in the wind-on condition (see below), and the determination of an accurate value of damping in the wind-off condition was therefore considered of smaller interest.

During the first one the bridge was balanced with a potentiometer to take into account the remaining effects of temperature difference between the gauges (this difference being minimized before by putting the two dummy arms of the bridge inside the wind tunnel) and also possibly the effect of a small misalignment between the rudder plane of symmetry and the wind direction. This misalignment was in all cases smaller than 0.3°.

In the second run, in which the balancing potentiometer was in the right position from the beginning and the bridge became balanced as soon as the temperature in the tunnel became constant, the rudder was hit several times using the striker arm and the time history of the motion was recorded on the oscillograph. A typical record is shown in Figure 4. It appears that damping in all cases was very high and that the rudder immediately returned to its initial small oscillation caused by the tunnel noise (of approximate amplitude ±0.01°). With the wind forces acting on the striking arm it was extremely difficult to hit the rudder in a purely elastic manner and thus the striking arm always followed the deflecting rudder far beyond its neutral position and did not retract fast enough to permit the rudder to oscillate free. This made it impossible to evaluate damping from the oscillograph records or to measure it with the dampometer. Only the frequency of the small oscillations caused by tunnel noise could be evaluated from the records and this is given for the different rudders in Table 2. As the main purpose of the tests was to establish if the flutter did or did not occur at the test conditions, these results were considered satisfactory. To obtain measurable values of damping a different test technique would have to be used, e.g. one using an electromagnetic oscillator for the initiation of oscillations. Such a technique requires a much more complicated test set-up which was not considered justifiable for the tests here reported.

6. Conclusions

No flutter was found at the test conditions, that is at Mach Number of 1.35 at natural frequency of 389 cps and at Mach Number of 1.22 in the frequency range from 330 to 389 cps.

Because of the inadequate stiffness of the rudders tested the frequency range investigated was much smaller and much lower than originally planned (from 507 to 760 cps).

Furthermore, because of the inadequate stiffness of the rudders tested, the rudders were subjected to appreciable elastic deformations, which may have affected the results obtained so that their applicability to stiff rudders may be questionable.

Reference

1. C. O. Olsson, K. Orlik-Ruckemann — An electronic apparatus for automatic recording of the logarithmic decrement and frequency of oscillations in the audio and subaudio frequency range. FFA Rep.52 (1954).

Table 1

Mechanical Properties of the Rudders Tested

1 Rudder	2 Equival. rudder stiffn. K_R lb in/ rad.	3 Hinge stiffn. K_H lb in/ rad.	4 Total stiffn. K_T lb in/ rad.	5 Freq. ν cps	6 Rudder mom. of inert. I lb ins^2	7 Eff. hinge width in	8 Aver. hinge thick-ness in	9 Calcul* hinge stiffn. lb in/ rad.	10 Structural damping factor g
Aa-0	303	518	191	389	$3.15 \cdot 10^{-5}$	5.73	0.040	764	0.023
Aa-1	303	470	184	382	3.15	4.88	0.040	651	0.026
Aa-2	303	393	171	368	3.15	3.47	0.040	463	0.042
Zz-0	338	395	182	388	3.06	5.73	0.036	558	0.023
Zz-1	338	365	175	381	3.06	4.66	0.036	453	0.026
Zz-2	338	216	132	330	3.06	2.54	0.036	247	0.051

* According to simple beam theory

Table 2

1 Rudder	2 Mach Number	3 Rudder natural frequency (fin tip fixed) cps	4 Natural frequency (Fin tip free) cps	5 Frequency wind on (Fin tip free) cps
Aa-0	1.35	389	120	492
Aa-0	1.22	389	120	468
Zz-0	1.22	388	121	454
Aa-1	1.22	382	117	446
Zz-1	1.22	381	115	428
Aa-2	1.22	368	119	436
Zz-2	1.22	330	119	375

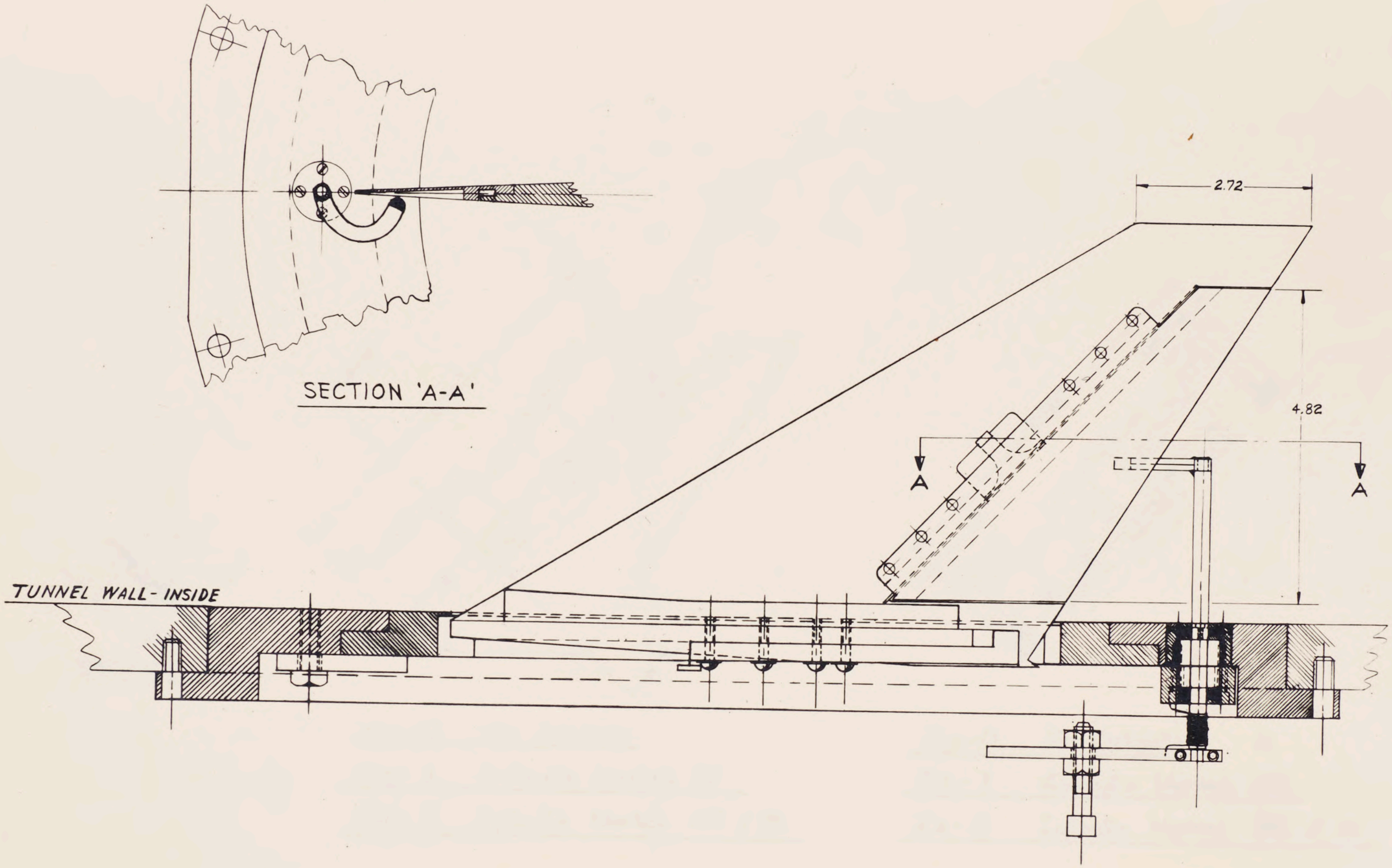
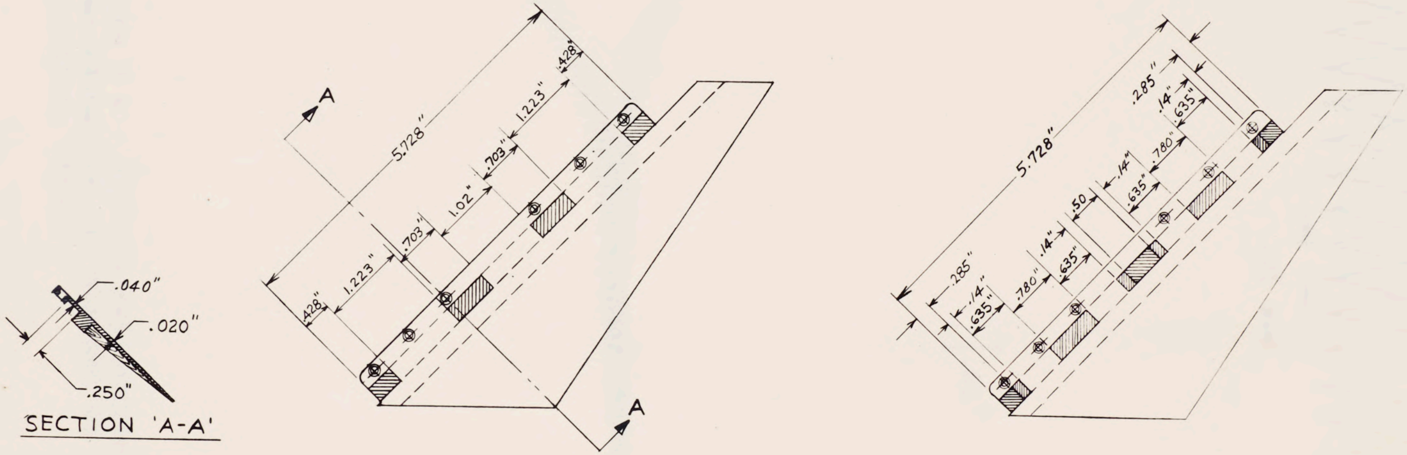


FIG. 1 FIN ASSEMBLY MOUNTED IN WIND TUNNEL



Aa-0 No Cutouts

Aa-1 Cutouts Marked ▤

Aa-2 Cutouts Marked ▤ & ▥

Zz-0 No Cutouts

Zz-1 Cutouts Marked ▤

Zz-2 Cutouts Marked ▤ & ▥

FIG. 2 RUDDERS TESTED

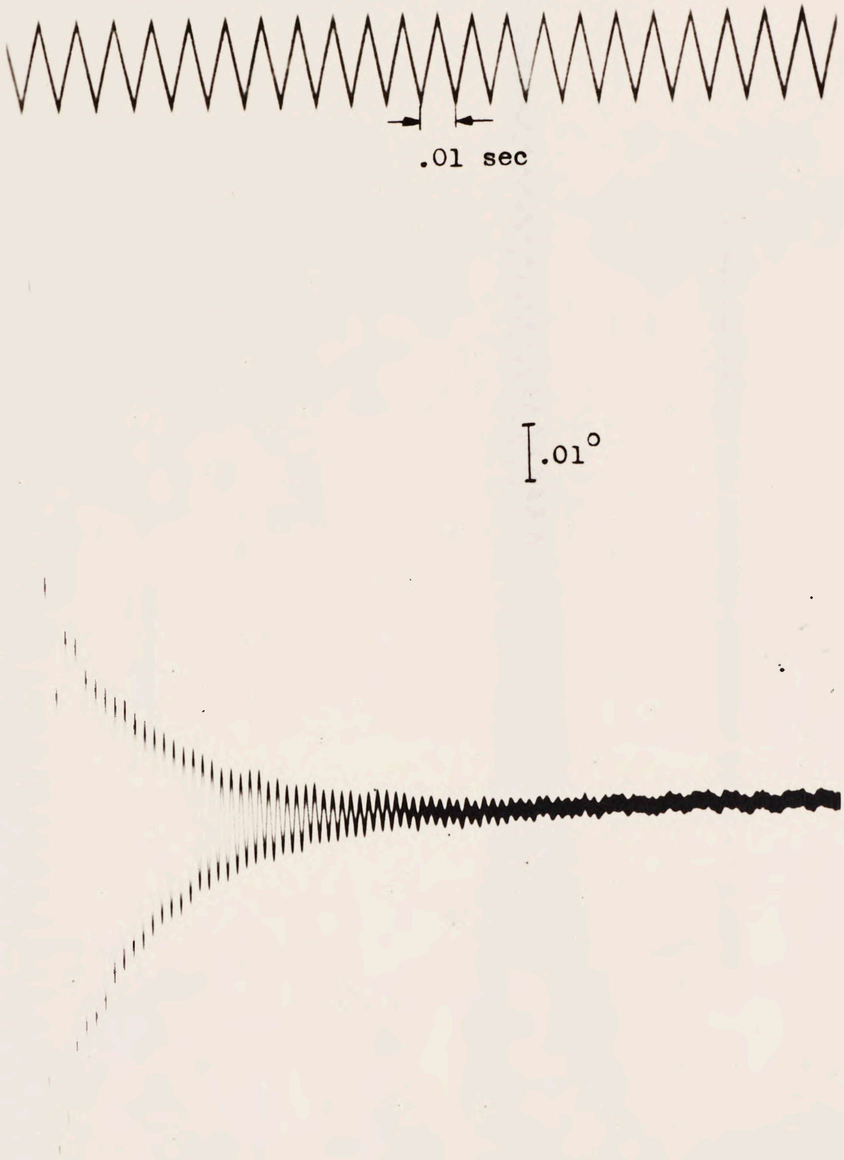


Figure 3 a . Typical calibration recording.Fin tip clamped in a fixed position. (Aa-1).

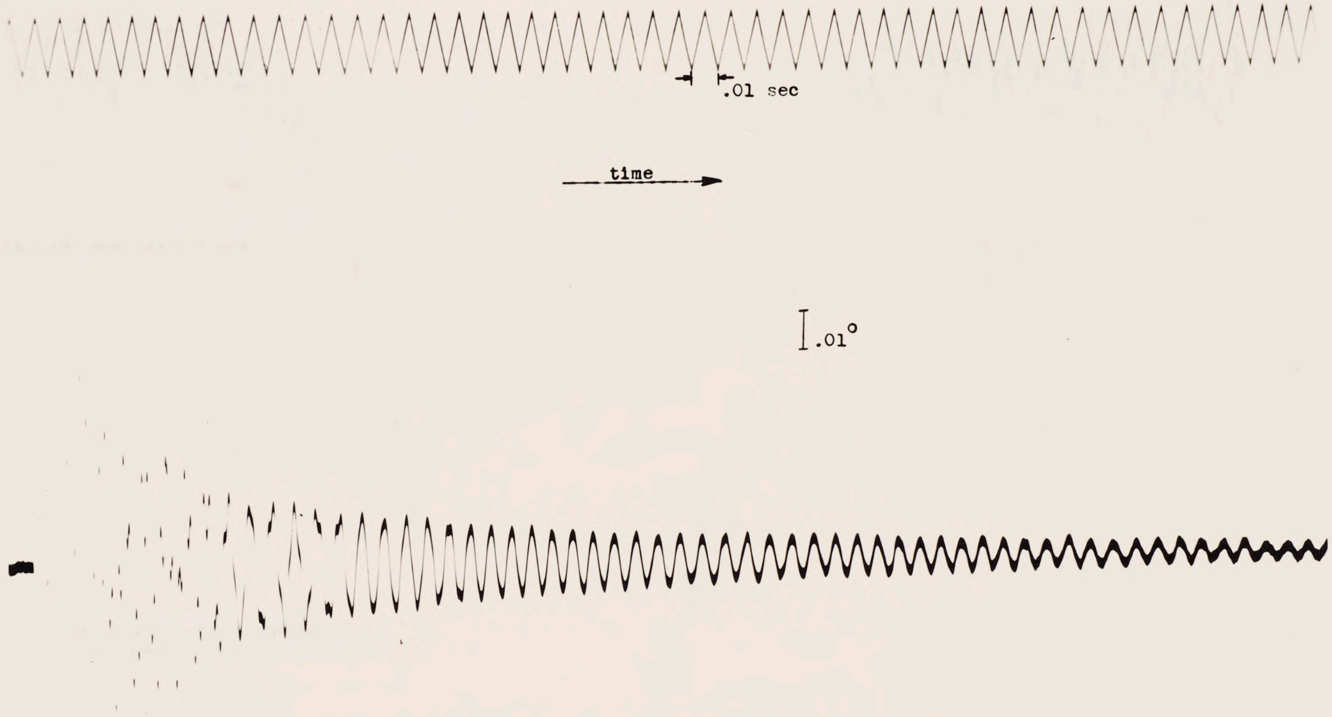


Figure 3 b . Typical calibration recording with fin tip free (Aa-1)

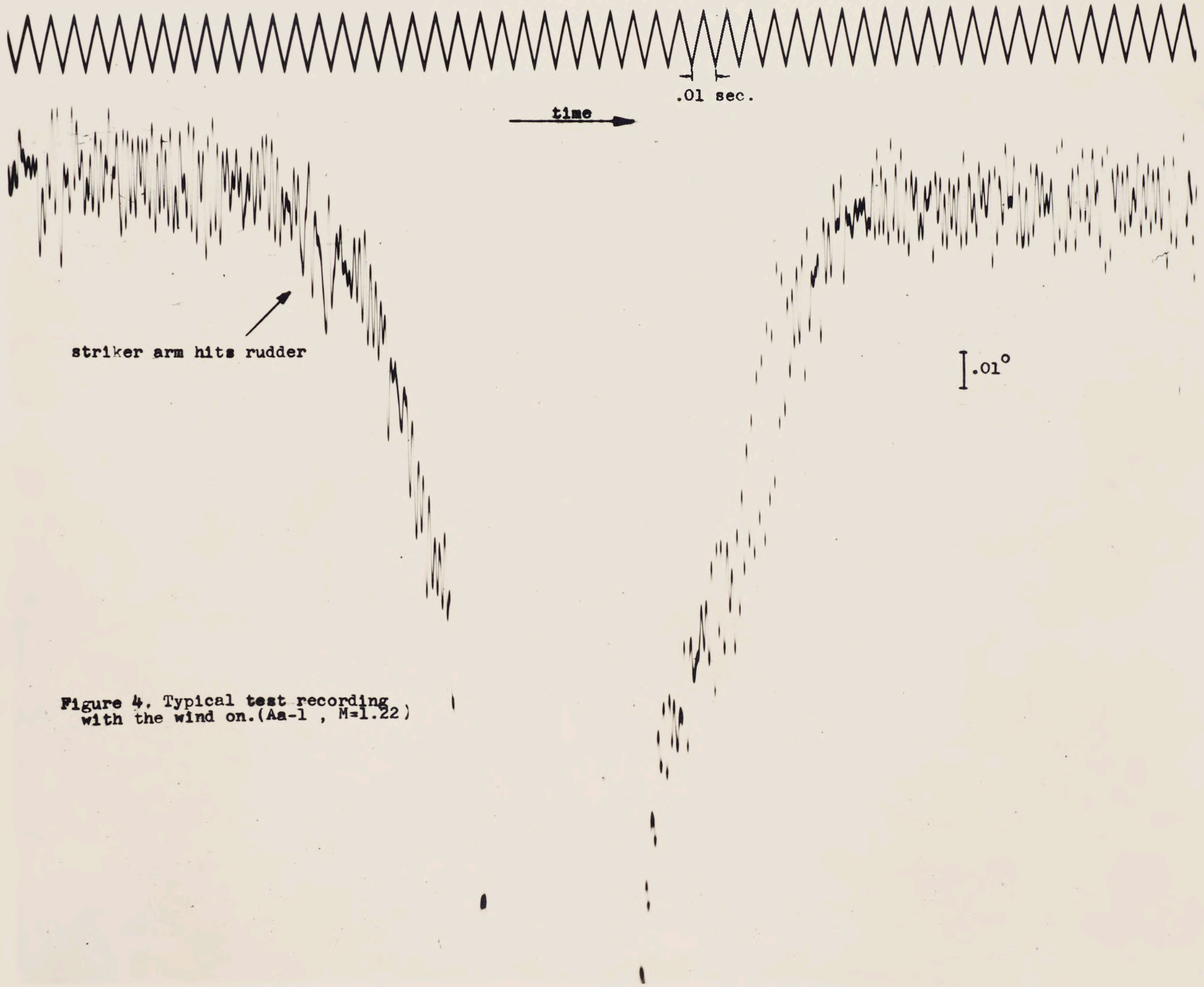


Figure 4. Typical test recording with the wind on.(Aa-1 , M=1.22)