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RESEARCH MEMORANDUM

SOME EFFECTS OF FLUID IN PYLON-MOUNTED TANKS ON FLUTTER

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NATIONAL ADVISORY COMMITTEE
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SUMMARY

Fluid-dynamics studies were made of a tank of fineness ratio 7.0 which was pylon mounted on a simplified two-dimensional flutter model in order to determine the effects of the fluid on flutter. The flutter speed was found experimentally for three cases as follows: with various amounts of water in the tank, with weights having the same mass and moment of inertia as the fluid considered to be a frozen solid, and with weights having the same mass and moment of inertia as the actual fluid. The results of the two methods of fuel representation were compared with the actual-fluid case, and it was concluded that, in flutter analyses and tests, the fuel in wing tanks must be represented by the effective-moment-of-inertia values. The damping action of the fluid was also studied, and it was found that sufficient damping was present to limit the amplitude of the flutter and that, at a frequency ratio near 1.0, the fluid damping may produce an increase in the flutter speed.

INTRODUCTION

The representation of the dynamic effects of large fuel masses carried in airplane wing tanks is of concern to the dynamicist. He may be aware that the fuel does not behave as a frozen solid, and, therefore, in order to represent it properly, he must know the effective pitching moment of inertia of the fuel. By effective moment of inertia of the fuel is meant the actual or true moment of inertia of the fuel, which is usually less than if the fuel were a frozen solid since a portion of the fluid does not partake of the pitching motion. Consider the cases of the tip- and pylon-mounted tanks which are represented in figure 1. The abscissa is the tank fullness, and the ordinate is the ratio of the effective moment of inertia of the fluid to the moment of inertia of the fluid considered to be a frozen solid. The data were obtained for a tank of fineness ratio 7.0. As the dashed curve in figure 1 shows, an important result of a previous investigation on centrally mounted tanks (ref. 1) is that the inertia ratio varies but little for a wide variation in tank fullness. This work on centrally mounted tanks has been extended recently to cover the case of pylon-mounted or offset tanks and to inclined and swept-wing tanks in reference 2. This reference gives effective-moment-of-inertia values and damping factors, and the lower curves are representative of some of the moment-of-inertia values for the offset-tank case. Notice the large decrease in the inertia ratio of the partially full offset-tank configurations as compared with the centrally-mounted-tank case.

This large decrease in the inertia ratio may be explained as follows. When the tank is completely full, the fluid is forced to move with the boundaries of the tank and the inertia ratio is almost unity. As fluid is removed from the tank, the fluid then becomes free to move in a forward and rearward direction, and it is this horizontal translational freedom of the fluid which causes a reduction of the inertia ratio. When two solid baffles are added to the tank, the freedom of the fluid is somewhat restricted, and there is a slight increase in the inertia ratio of the partially full tank as shown by the curve passing through the triangles.

In reference 2, it was found that large decreases in the inertia ratio could result if the frequency of oscillation was close to the first natural frequency of the fluid in the tank. This condition was avoided in these tests by selecting springs which would avoid frequencies in this range so that the inertia ratio remained essentially independent of frequency.

MODEL AND APPARATUS

In order to study some possible effects of fuel representation on flutter, use was made of the simplified two-dimensional flutter model shown schematically in figure 2. The arrows indicate the rotational and translational degrees of freedom. The model was equipped with a tank of fineness ratio 7.0, and this tank was offset beneath the axis of rotation, a distance of about $2\frac{1}{2}$ times the tank radius. Some physical parameters of the model are given in table I. The flutter speeds were found experimentally in the Langley 2- by 4-foot flutter research tunnel with air at atmospheric pressure for three different cases. First, the flutter speed was found with various amounts of water in the tank. Then the flutter speed was found by using weights having the same mass and moment of inertia as the fluid considered to be a frozen solid. The third series of tests were made with weights having the same mass and moment of inertia as the fluid, thus simulating the effective moment of inertia of the fluid.

RESULTS AND DISCUSSION

Some results of these tests are shown in figure 3, where the flutter speed is shown as a function of tank fullness for the three cases mentioned: the actual fluid, the frozen or solid fluid, and the simulated fluid. The values for the uncoupled bending-to-torsion frequency ratio ω_h/ω_α are shown opposite each data point since these values are of significance in the discussion of the results. The actual flutter speeds obtained with fluid in the tank are shown by the solid curve passing through the circles. When the fluid was replaced with weights representing the frozen or solid moments of inertia, the flutter speeds are shown by the long- and short-dashed curve passing through the triangles. As can be seen they are considerably different from the speeds with the actual fluid and give conservative or unconservative results; that is, for a given tank fullness, they may lie below or above the experimental values. However, when the fluid was simulated by effective-inertia weights, good agreement with the actual case was obtained and is shown by the dashed curve passing through the diamonds. From these results it appears that the effective-inertia values are to be preferred. This is especially true in cases where the flutter speed is strongly affected by the moment of inertia or in cases where there is a large difference between the solid and effective moments of inertia of the fluid.

So far, the effects of inertia on flutter have been discussed. A few remarks about the effect of damping are now in order. Notice that the chief difference between the flutter speed obtained with actual fluid and the speed obtained with the effective-inertia weights occurred in this experiment at a frequency ratio near 1.0. This suggests that the damping of the fluid in the tank may produce an increase in the flutter speed near a frequency ratio of 1.0. As was shown in reference 1, fluid damping is generally quite low, g_α less than 0.01, for the first few cycles of oscillation. After the fluid breaks up into turbulent motion, the damping can become quite high, g_α reaching values of the order of 0.10 to 0.20, depending on the amount of fluid and the amplitude and frequency of oscillation. Thus it can be expected that the start of flutter will not be affected much by the fluid damping, except where the flutter speed is critically dependent on the damping, as is usually the case near a frequency ratio of 1.0.

If the amplitude of flutter builds up slowly enough, the fluid will break into turbulent motion, with resulting increases in damping which may limit the amplitude of the flutter. This occurred in this series of tests for all partially full configurations, and the results are shown in figure 4. Here the torsional flutter amplitude is shown as a function of the speed. The tank was equipped with two baffles, and each baffle had 13 evenly distributed 1/2-inch holes. For each amplitude, the value for the torsional damping factor g_α calculated from frequency-response curves obtained at zero airspeed is shown opposite each data point. The frequency-response curves were obtained by forcing the model at eight different amplitudes for each tank fullness studied. The figure shows that as the airspeed was increased the amplitude of the oscillations was increased and was limited by the effect of additional fluid damping since the damping of fluid in the tank increased with increased amplitude of oscillation.

CONCLUSIONS

These preliminary experiments indicate that, in flutter analyses and tests, the fuel in wing tanks must be represented by the effective-moment-of-inertia values. This is essential in cases where the flutter speed is strongly affected by the inertia of the fuel or where the effective moment of inertia of the fuel is considerably different from the solid inertia.

With regard to the damping action of the fluid, it was found that sufficient damping was present to limit the amplitude of the flutter, and at a frequency ratio near 1.0 the damping of the fluid in the tanks may produce an increase in the flutter speed.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., May 20, 1955.

REFERENCES

1. Widmayer, Edward, Jr., and Reese, James R.: Moment of Inertia and Damping of Fluid in Tanks Undergoing Pitching Oscillations. NACA RM L53E01a, 1953.

2. Reese, James R., and Sewall, John L.: Effective Moment of Inertia of Fluid in Offset, Inclined, and Swept-Wing Tanks Undergoing Pitching Oscillations. NACA TN 3353, 1955.

TABLE I

SOME PHYSICAL PARAMETERS OF THE MODEL

Wing span, ft	2
Wing chord, ft	1
Tank diameter, in.	4.25
Tank length, in.	30.0
Bending stiffness, lb/in.	168
Torsional stiffness, in-lb/radian	4,120
Bending damping coefficient, g_h, empty	0.009
Torsional damping coefficient, g_α, empty	0.018
Model weight, lb	
Empty	11.8
Full	21.7
Model moment of inertia, in-lb-sec^2	
Empty	0.103
Full	2.000
Model center-of-gravity location, percent chord	
Empty	43
Full	40
Axis of rotation, percent chord	40

EFFECT OF TANK OFFSET ON MOMENT OF INERTIA
TANK FINENESS RATIO=7.0

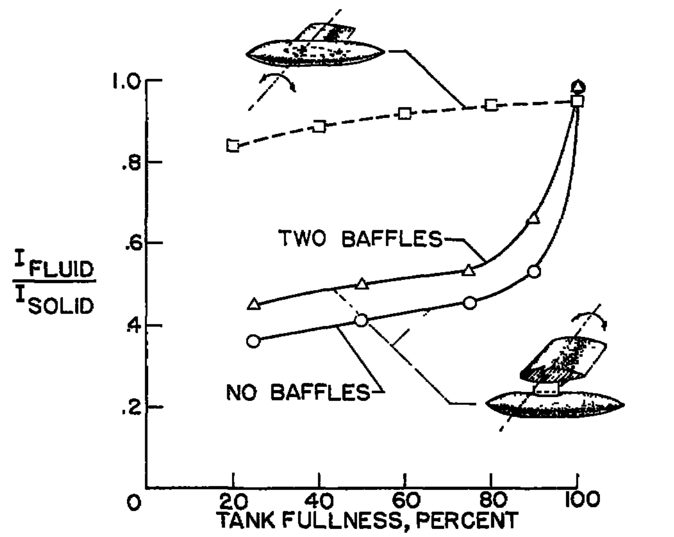

Figure 1

TWO-DIMENSIONAL FLUTTER MODEL AND APPARATUS

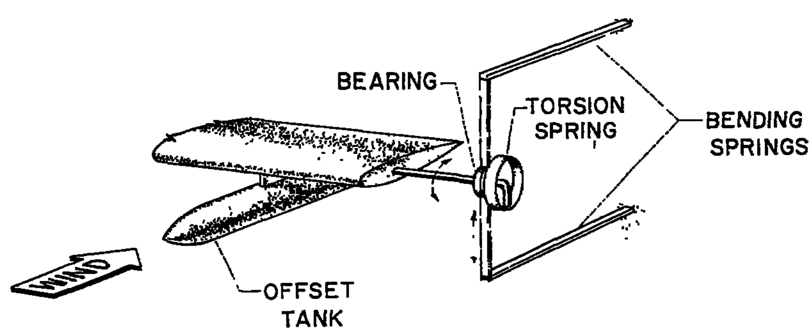

Figure 2

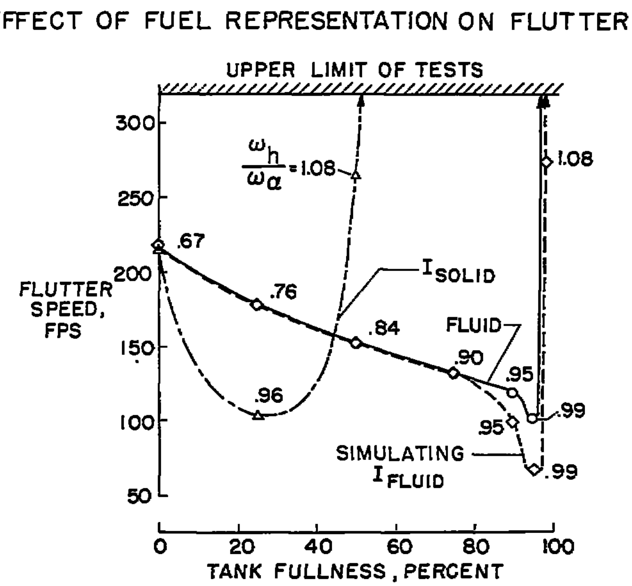

Figure 3

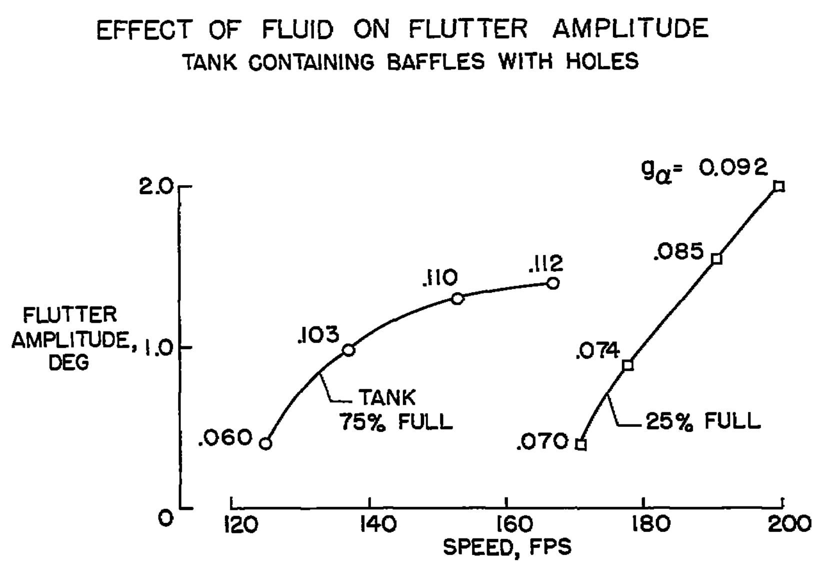

Figure 4