REPORT No. 170

A STUDY OF LONGITUDINAL DYNAMIC STABILITY IN FLIGHT

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SUMMARY.

This investigation was carried out by the Aerodynamic Staff of the National Advisory Committee for Aeronautics for the purpose of studying experimentally the longitudinal dynamic stability of airplanes in flight. The airplanes selected for this purpose were a standard rigged *VE–7* advanced-training airplane and a *JN4h* with special tail surfaces. The airplanes were caused to oscillate by means of the elevator, then the longitudinal control was either locked or kept free while the oscillation died out. The magnitude of the oscillation was recorded either by a kymograph or an airspeed meter. The results show that the engine speed has as much effect on the period and damping as the airspeed, and that, contrary to theory as developed for small oscillations, the damping decreased at the higher airspeeds with closed throttle.

INTRODUCTION.

The theory of small oscillations was applied to the study of airplane stability first by Bryan and later it was amplified by Bairstow, Wilson, and others. Altogether, there has been a great deal of mathematical talent spent on this interesting problem, but, rather strangely, it has never seemed to occur to anyone to make a systematic study of the dynamic stability in actual flight. This is due probably to the fact that the practical man has never considered dynamic stability very seriously. It was therefore thought that a more or less complete experimental investigation of dynamic stability would be of considerable interest and value in confirming or showing the limitations of the theory and in giving the designer actual data on the importance of considering dynamic stability in the layout of an airplane.

METHODS AND APPARATUS.

The *VE–7* airplane used in these tests was standard in every way (Fig. 1) excepting that it carried slightly less load than normally. This airplane was selected for these tests principally because of its almost ideal static stability, which allowed the taking of oscillation records over nearly the whole speed range. The other airplane available was a *JN4h*, and, due to the fact that it had little or no static stability, it was found necessary to construct a new tail surface with a higher aspect ratio (Fig. 2). This tail fulfilled all expectations and gave excellent static stability over the whole flying range.

The longitudinal radius of gyration was measured experimentally on both of these airplanes, as this factor is an important one in the longitudinal oscillations. The measurements were made in the usual way by supporting the airplane in the hangar on a pivot, first a short distance above the center of gravity and, second, a large distance from the center of gravity and determining the period of the free oscillations in each case. From these figures the radius of gyration can be readily computed.[1] It will be noticed that the radius of gyration for the *JN4h* is considerably larger than for the *VE–7*, and this is mainly due to the longer fuselage and the much heavier tail surfaces on the former machine. The important characteristics of

[1] Aeronautics, by Wilson.

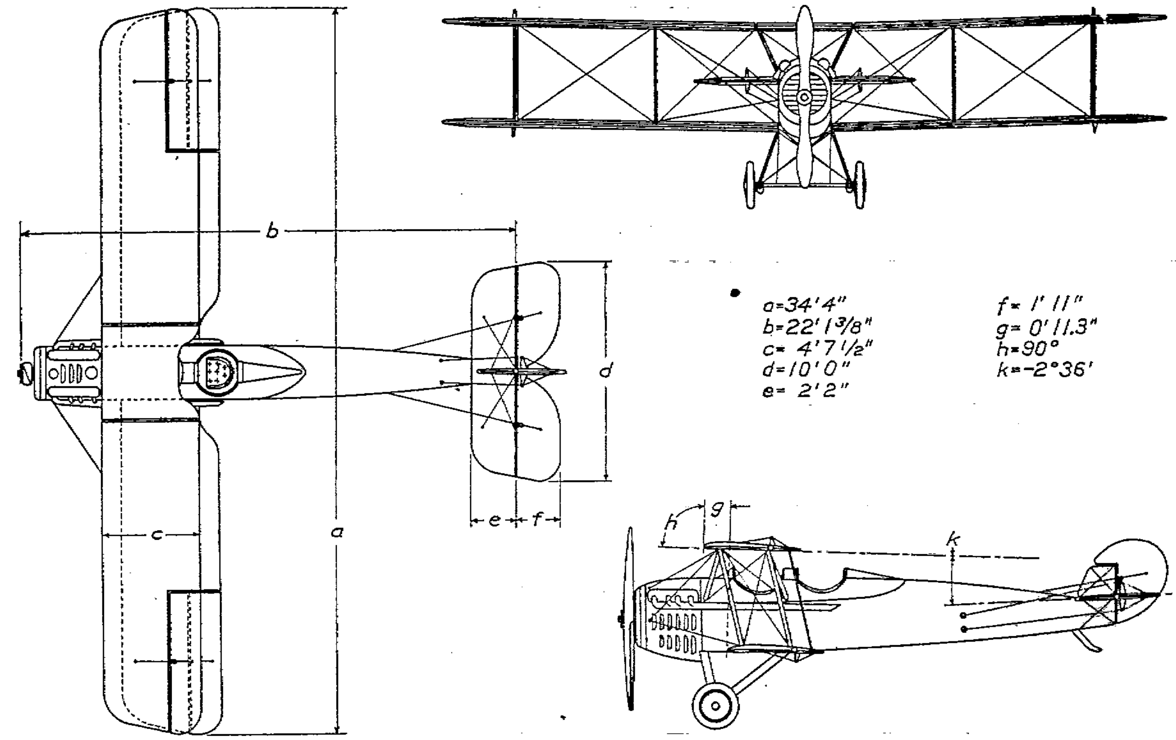

Fig. 1.—Standard VE-7 advanced training airplane.

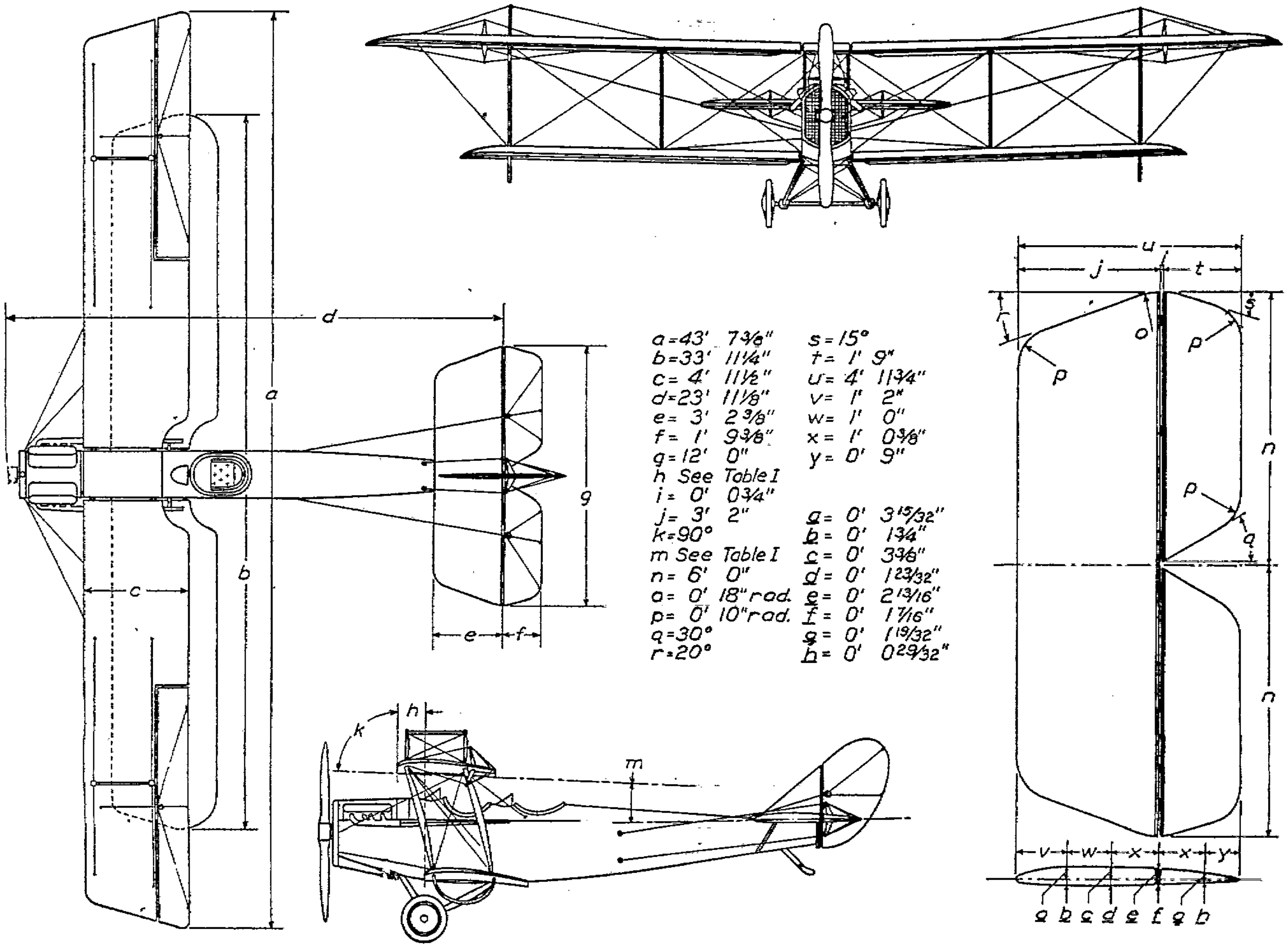

Fig. 2.—Standard JN4h airplane with a special thick horizontal tail.

the airplanes used, together with the changes that were made upon them, are summarized in Table I below:

TABLE I.

Type and rig.	Wing area.	Horizontal tail area.	Distance from C. G. to elevator hinge.	Longitudinal radius of gyration.	Weight.	C. G. coefficient.	Stabilizer setting (with wings).	Chord of wings.	Load per square foot.	Stagger.	Wing section.	Proportion of elevator area to whole tail.	Aspect ratio of tail.	Horsepower.	Stalling speed.
	Sq. ft.	*Sq. ft.*	*Ft.*	*Ft.*	*Pounds.*		°	*Inches.*	*Pounds.*	*Inches.*					*M.P H*
VE-7	285	36.4	16.1	4.74	2,049	0.364	−2.60	55.5	7.6	11.3	RAF 15	0.50	2.5	180	......
JN4h (1)	350	52	17.6	6.26	2,171	.371	−3.57	59.5	6.2	8.0	JN4h	.30	2.4	150	40
JN4h (2)	350	52	17.3	6.26	2,210	.430	−1.42	59.5	6.4	14.8	JN4h	.30	2.4	150	40
JH4h (3)	350	52	17.6	6.26	2,171	.371	−3.07	59.5	6.2	8.0	JN4h	.30	2.4	150	40
JN4h (4)	350	52	17.6	6.26	2,171	.371	−4.07	59.5	6.2	8.0	JN4h	.30	2.4	150	40

The static stability of these two airplanes with both free and locked controls are given in Figures 3 and 4 for reference.

The instruments used in this test were the N.A.C.A. kymograph and recording airspeed meter, the latter of which is described in N.A.C.A. Technical Note No. 64. On all of the first runs the oscillation was recorded by means of a kymograph, but later on the recording airspeed meter was developed and after repeated trials was found to give the same period and damping as the kymograph, when they were both used simultaneously. As the airspeed meter had the advantage that it could be used on cloudy or hazy days it was employed almost entirely in the later tests.

A number of methods were experimented with for starting an oscillation, but it was found that a very short time after the start the oscillations produced by any means were the same. The method used in all of the tests was the following: If the controls were free, the throttle was adjusted to the proper position to obtain the desired equilibrium airspeed, the nose was pulled up to a stall, and then the controls were released and the airplane allowed to oscillate of itself; if the controls were locked, a special clamp was applied to the stick so that it could be held at the required position to give the desired equilibrium speed; the stick was pulled back until a low speed was obtained, then it was immediately pushed forward against the stop into its original position and the airplane was allowed to oscillate as before. In some cases where the airspeed at equilibrium was very close to the stalling point the nose of the airplane was simply pulled up to a large angle and then allowed to fall and start the oscillation. During a long oscillation it was usually necessary to use the rudder and aileron slightly to keep a straight course, but arrangements were made so that these movements could not in any way affect the longitudinal control.

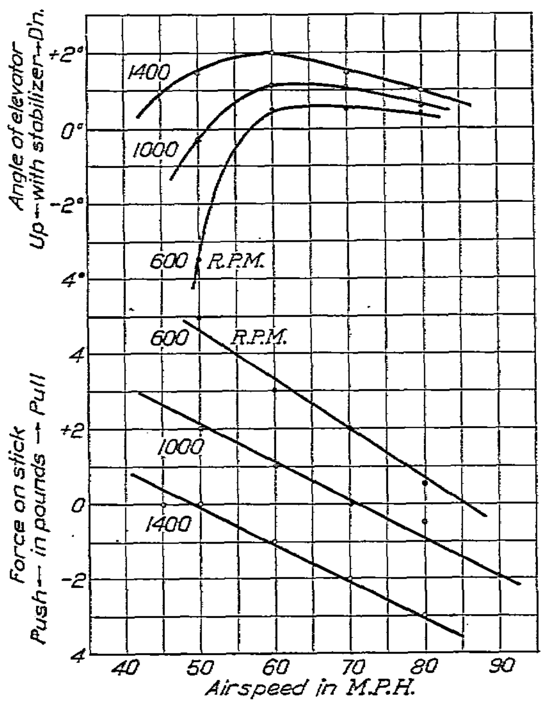

FIG. 3.—Static stability of JN4h, with thick tail, stabilizer at −1.5°, 17.5" stagger and C. G. coefficient .425.

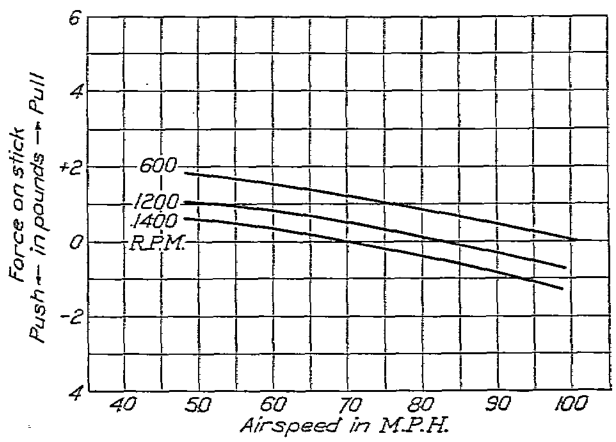

FIG. 4.—Static stability (approx.) of VE-7 with free controls.

All of the airspeeds given in this report were corrected for density and are therefore true speeds. Corrections for installation and instrumental errors were also made.

The records obtained from the instruments were all plotted against a time base [2] with either angle of inclination of airspeed as ordinates. The resulting curve in most cases approximated a damped sine curve, from which the average period and damping were measured. It was noticed on a number of records that the period and damping varied with the amplitude, in which case the average value was recorded. It was also noted especially on the records from the *JN4h* that, due perhaps to small bumps, many of the records were somewhat irregular; and therefore the periods and damping were measured with some difficulty, which accounts in a large part for the rather wide grouping of the points in many of the curves.

RESULTS.

In Figure 5 there is reproduced a typical record taken with the recording airspeed meter on a *VE–7*. It will be noticed that the curve is very smooth and regular and that the periods and damping can be accurately determined. In contrast to this a record is shown in Figure 6 taken on the *JN4h* which shows irregularities which make the accurate determination of the periods and damping difficult. These irregularities, while due in part to bumps in the air, are mainly caused by some inherent characteristic of the airplane, as many of the records

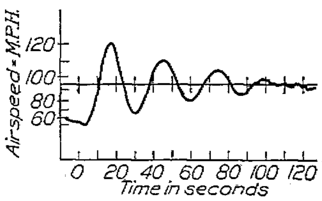

FIG. 5.—Oscillation of VE–7 with free controls.

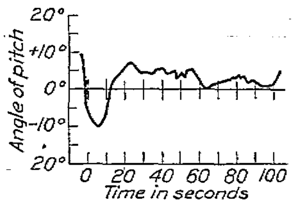

FIG. 6.—Oscillation of JN4h with locked control.

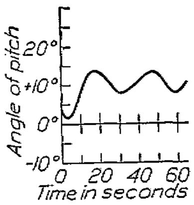

FIG. 7.—Oscillation of JN4h, 600 R. P. M. 66 M. P. H.

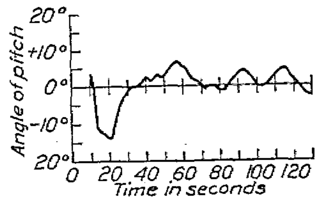

FIG. 8.—Oscillation of JN4h.

obtained on the *JN4h* are more or less irregular whereas the majority of those obtained on the *VE–7* are smooth. In Figure 7 there is shown a record taken on the *JN4h* with closed throttle and at a rather high speed, and it is clearly evident that the damping is extremely small. This particular record is shown as it is quite in contradiction to the theory, which states that the damping increases with airspeed. In Figure 8 is shown a curve taken on the *JN4h* to illustrate the phenomenon which was observed in a few cases; that is, the breaking up of an oscillation into one-half the fundamental period. This characteristic is very interesting and should receive more extended study.

In other records it was noticed that an oscillation would damp rapidly down to a certain small amplitude and then hold this amplitude until the end of the record. In other cases an oscillation would damp down to a small amplitude and then start to increase. Such anomalous records could not in general be repeated under the same conditions and were therefore not included with the other data. It would be interesting, however, to give this matter further study.

Some of the oscillations, especially on the *VE–7*, covered a very large speed range—sometimes traveling between 30 and 120 M. P. H. The angle of pitch ranged through an angle of 60°, so that they could hardly be termed small oscillations.

In order to obtain greater consistency the throttle was set at the values given on the curves when the airspeed was 64 M. P. H. Of course, when the airspeed was changed from this the engine speed would be slightly different. That is, if a point on the curve was labeled 900 R. P. M. at 80 M. P. H., it would mean that the throttle had been set to 900 R. P. M. at 64 M. P. H. and then the speed was advanced to 80 M. P. H., with a slight increase in R. P. M. above 900.

[2] N.A.C.A. Technical Note No. 117.

In Figure 9 there are plotted the periods and amplitude for the oscillation of the *VE–7* with locked controls. It will be seen that the period varies between 13 and 25 seconds from a speed of 50 to 100 M. P. H. at 600 R. P. M., while at 1,400 R. P. M. the period is 60 per cent greater. All the curves are slightly convex upward. The maximum damping of 0.50 comes at the highest airspeed and engine speed. At an engine speed, however, of 600 R. P. M. the damping is a maximum at 85 M. P. H. and decreases at higher speeds. All of the damping curves decrease very sharply at the lower speeds, but in no case was an actual negative damping found. It should be noticed that on this airplane the speed of the engine had quite a marked effect on the damping.

The curves of period and damping for the *JN4h* are shown in Figure 10 for conditions of locked controls. The period on this airplane is affected by changes in airspeed and R. P. M. to a much larger extent than they were on the *VE–7*. For example, the period at 600 R. P. M. varies from 8 seconds at 45 M. P. H. to 38 seconds at 70 M. P. H., while at 1,350 R. P. M. the

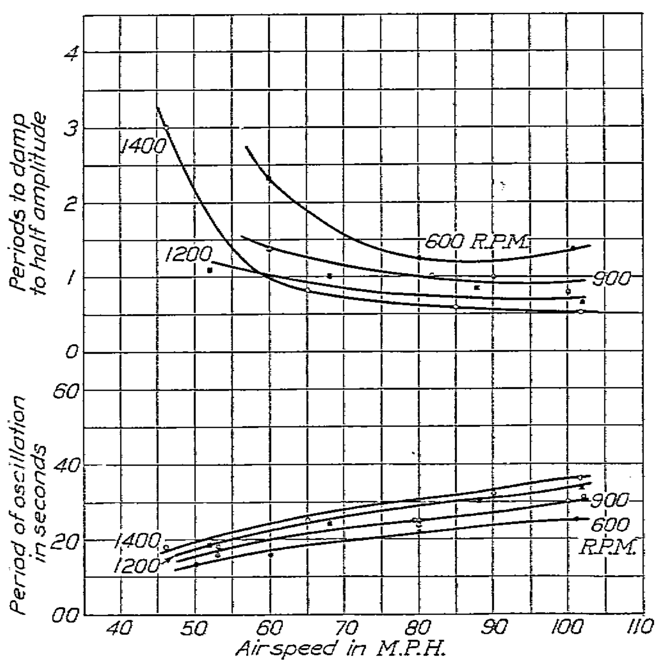

FIG. 9.—VE–7 with locked controls.

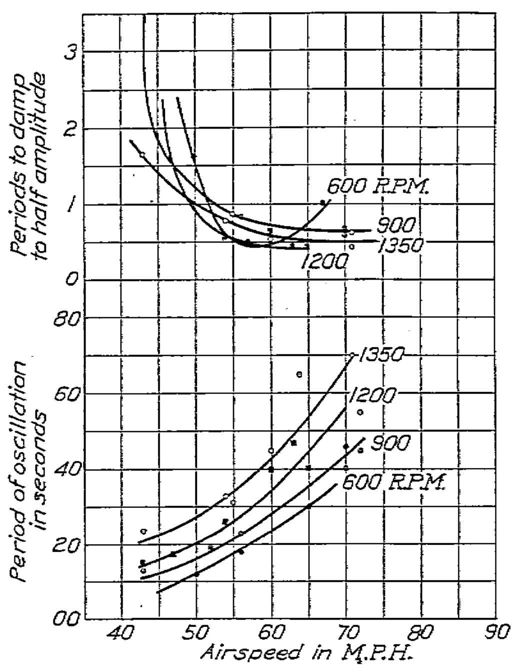

FIG. 10.—JN4h with locked controls, stabilizer at —3.57° and C. G. coefficient .371.

variation for the same range of airspeeds is 23 seconds to 70 seconds. This gives a range of period of nearly 10 to 1, which is considerably more than would be expected in a single airplane. It is also noted that the curves are all slightly concave upward, but this may be due entirely to difficulty in drawing representative curves through the rather scattered points. The damping on this airplane is less affected by the propeller speed than with the previous airplane, but on the whole the damping increases slightly at the high airspeeds but decreases sharply near the stalling speed, and one point of negative damping was obtained at 3 M. P. H. above stalling. It will be observed that the damping curves for 600 R. P. M. show a decrease at higher speed in the same way as for the *VE–7*, which lends confirmation to this rather unexpected condition.

The periods and damping of the oscillations on the *VE–7* with free controls are shown in Figure 11. The period is seen to be practically constant at 29 seconds, and the reason for this is that the effect of airspeed is just counterbalanced by the effect of change in propeller speed, as can readily be seen by comparing with the periods obtained with locked controls. This has been done in Table II below and the agreement is seen to be excellent.

TABLE II.

R. P. M.	Airspeed.	Observed period.	Computed period.
		Seconds.	*Seconds.*
1,400	70	28	28
1,200	83	29	29
1,000	89	29	28
750	94	29	27

The damping is a maximum of 0.70 at 83 M. P. H. and falls to a value of 1.25 at 70 and 95 M. P. H., again showing that the damping decreases with an increase in airspeed above a certain point. The free control damping as computed from the locked control curves is given in Table III

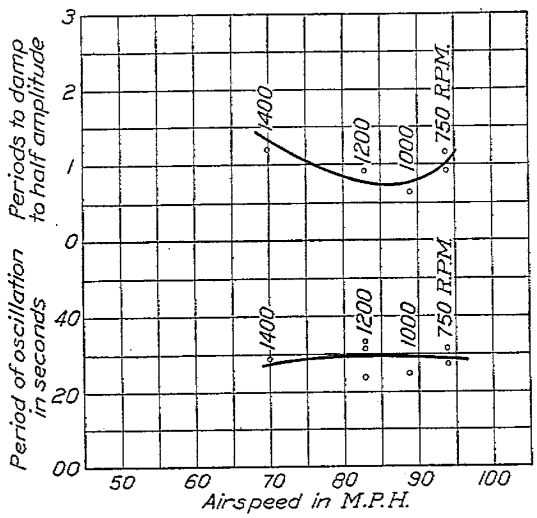

FIG. 11.—VE-7 with free controls.

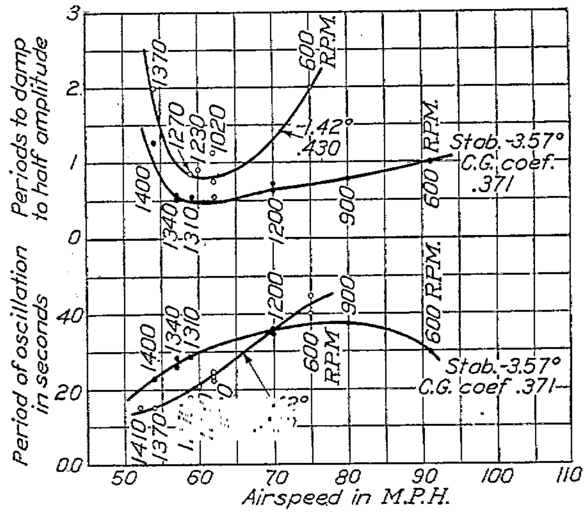

FIG. 12.—JN4h with free controls.

below, but it will be seen that the agreement with the observed values is not as good as it was for the period.

TABLE III.

R. P. M.	Airspeed.	Observed damping periods to half amplitude.	Computed damping periods to half amplitude.
1,400	70	1.20	0.75
1,200	83	.90	.75
1,000	89	.75	1.00
750	94	1.10	1.20

In Figure 12 are shown the free control characteristics of the oscillation of the *JN4h*. With the stabilizer set at $-3.57°$ with the wings and with a center of gravity coefficient of 0.371, the period is seen to vary somewhat with the airspeed, reaching a maximum of 38 seconds at 80 M. P. H. and falling to 30 seconds at 91 M. P. H. and 23 seconds at 54 M. P. H. For the more backward position of the *c. g.* and the more positive angles of the stabilizer the period is less at low speeds but increases more rapidly, giving a maximum of 42 seconds at 75 M. P. H. The damping curves show a maximum value at about 60 M. P. H., increasing rapidly at speeds below this and more slowly at higher speeds. The damping is seen to be somewhat greater at all speeds with a more forward position of the center of gravity.

In Figure 13 is shown the effect on free control oscillations of the *JN4h* of varying the stabilizer angle while keeping the center of gravity in one position. The main effect of making the stabilizer setting more negative is to decrease the period about 5 seconds for a change of half a degree and to slightly decrease the damping. On the whole, however, the changes in general are so small for the various stabilizer settings that they would lie well within the experimental error.

CONCLUSIONS.

It is interesting to compare the experimental results obtained in this investigation with those predicted from theory. Unfortunately, however, no wind tunnel tests have been made on exact models of the airplanes used here. Therefore we must rely upon tests on airplanes as near like these as possible. In Figure 14 there is plotted the data on the periods and damping computed for three models, a *JN2*,[3] a Clark [3] biplane, and a British machine [4] on which data is not available. A point of interest, however, is that all of the computed values for these airplanes lie very close together for both damping and period; so that we may safely assume that the wind-tunnel tests of exact models of the *JN4h* and *VE-7* would give us computed values of about the same order as those given here. On the same illustration with these computed curves there are plotted for comparison curves obtained in flight on the *JN4h* and *VE-7* with the engine throttled in order that conditions between the model and full scale

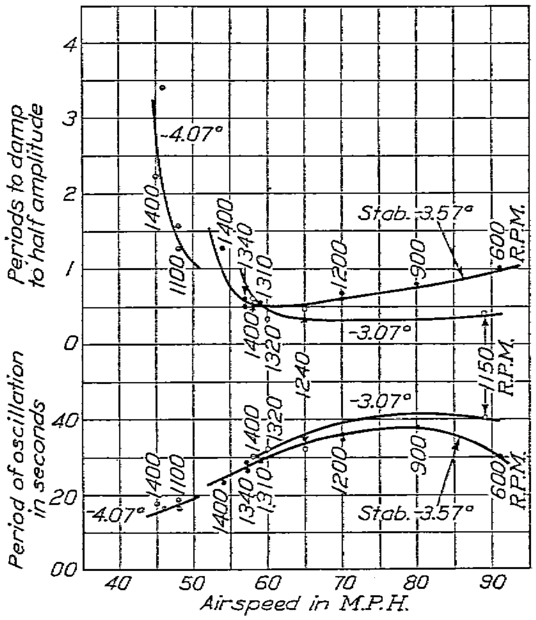

FIG. 13.—JN4h with free controls—C. G. coefficient .371.

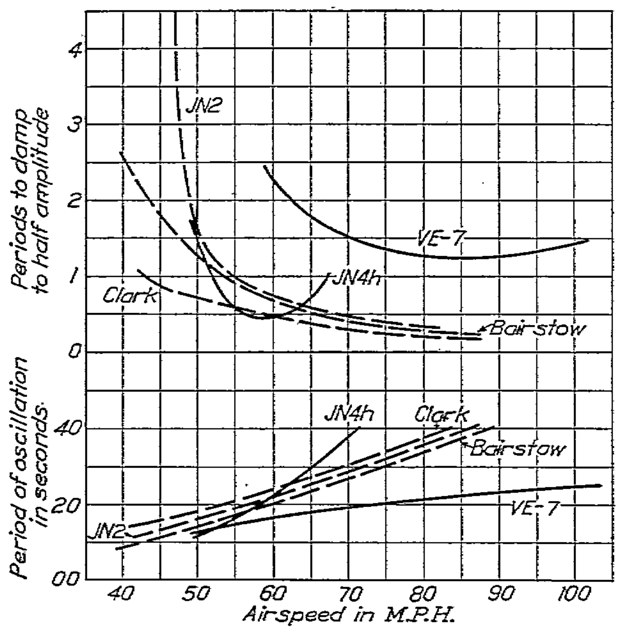

FIG. 14.—Locked controls at 600 R. P. M.

tests may be as near alike as possible. The actual periods as determined on the *JN4h* are somewhat longer at high airspeeds than the theoretical curve whereas the period of the *VE-7* is somewhat lower at the higher airspeeds. At low speeds, however, the various values check up very well. The damping of the *JN4h* in flight shows that at the lower speeds the values agree very well with the theoretical curves but shows a tendency to increase at the higher speeds, whereas theoretical curves uniformly decrease. The damping of the *VE-7* in flight is quite markedly less than for the other airplanes, which is probably due to its shorter fuselage and smaller tail surface.

Of all of the large number of records taken during this investigation, in only one case was a negative damping found, and in that case it was not considered either dangerous or uncomfortable by the pilot. We can probably conclude from this that dynamic instability occurs only rarely, and when it does occur it is not at all dangerous. In fact, it is far more dangerous to have an airplane statically unstable than it is dynamically unstable. While dynamic stability is interesting from a scientific point of view, the designer may entirely disregard it unless the airplane is such a radical departure from the usual practice as to make an investigation of this property advisable.

[3] Aeronautics—Wilson.
[4] Applied Aerodynamics—Bairstow.