DYNAMIC STABILITY

by

FLIGHT RESEARCH LABORATORY NO. 1

SPEECH I

Perhaps a number of you have experienced the rather uncomfortable feeling arising from the motions of an airplane in rough air. This behavior is but one of the examples which involve the dynamic stability of an airplane. It may be well to point out here that an airplane is considered to be dynamically stable when, if disturbed, the oscillations returning it to equilibrium are successively smaller and smaller, or, in other words, are damped.

Recently, increased emphasis has been placed on dynamic stability considerations because of troubles encountered with aircraft which are designed for higher speeds and are somewhat different in appearance from yesterday's design. In addition, operation at higher altitudes has disclosed dynamic stability problems due to the reduced damping offered by the less dense air.

The design of present-day aircraft must include rigorous dynamic stability studies in order that the motions or oscillations which may arise from a disturbance not only damp rapidly, but also die out completely. This is necessary so that military airplanes are satisfactory as gun or bombing platforms, and transport, or even personal-type airplanes have desirable flight characteristics under the more precise requirements of instrument flying, as well as providing adequate passenger comfort. Also for a missile, it is necessary to have satisfactory damping of the motions so that the missile may be accurately directed to the target.

In order to provide a background for the subsequent talks, so that a better understanding and appreciation of the motions involved in dynamic stability studies can be had, I will describe briefly the motions and supplement these descriptions with motion pictures.

The types of oscillatory problems which may arise involve longitudinal or pitching motions, lateral or rolling motions, and directional or yawing motions. The pitching motions are of two types: one lightly damped with a relatively long period of 20 to 60 seconds, which is similar to riding on an ocean swell; the other heavily damped with a short period of approximately one to two seconds.

The lateral motion is generally associated with the directional motion since the two are interrelated, the effect of each one on the resultant behavior of the airplane depending upon airspeed. Thus at high speeds the motions are primarily directional and are termed "hunting" or "snaking." At low speeds, such as in a landing approach, the lateral or rolling motion may predominate and the resultant motion is called "Dutch roll."

In order to give you a visual concept of the various types of motions just described, movies taken from an airplane will now be shown. It should be remembered that the motions shown in these pictures are typical of those to be discussed in the next talk.

In these movies you are getting a pilot's eye view, looking forward through the windshield over the nose of the airplane.

I – Longitudinal motions

(a) Long period — The motion shown here would be objectionable. Ordinarily this motion is not as severe and can be easily controlled by the pilot.

(b) Short period — This shows a well-damped motion typical of most airplanes. – This more persistent motion may occur on an airplane with low damping, such as a tailless type.

II – Lateral-directional motions

(a) Snaking – This type of motion would make aiming at a target more difficult.

(b) Dutch roll – This behavior would add considerably to the difficulty of flying under instrument conditions. – This shows difficulty in making a landing with an airplane with Dutch roll tendencies such as a swept-wing type. The pilot is attempting to maintain as smooth an approach as possible.

You have been shown some examples of undesirable dynamic stability. The next speaker, Mr. ____________, will discuss what the NACA is doing to improve dynamic-stability characteristics. Mr. ____________.

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SPEECH II

Mr. ___________ has shown us some examples of poor dynamic stability. The fact that these instabilities exist on recent designs indicates that changes in aircraft, such as increased wing sweepback, increased airspeed and increased flight altitude, have raised new problems relative to stability and control. Let us inspect the procedure with which the aircraft designer studies the dynamic stability of his design, and then we shall review how the NACA is working to improve these characteristics.

This functional diagram represents the procedure of dynamic-stability study in a simplified form. The designer wishes to predict how the motion of his airplane varies with time as shown here. This box represents the "equations of motion" of the aircraft and their manipulation into a more convenient form. In order to predict this motion the designer must insert into the computational machinery the various types of information represented by these arrows; for instance, this structural information would be supplied by the designer from the characteristics of his structure. Now, while the NACA is engaged to a limited extent in obtaining all this information, an important portion of our work is obtaining this aerodynamic information and presenting it in a form for convenient use by designers.

Recent study of the three instabilities presented by Mr. ____________ are examples of NACA work directly adding to the available aerodynamic information.

Let us first consider the reduction of damping in pitch that has been troublesome in several recent designs at transonic speeds. In flight tests of a tailless research airplane, prolonged oscillations in pitch unexpectedly occurred when the airplane was disturbed from steady flight at high speed. This is a plot of persistence of pitching oscillations versus Mach number. Stability predictions had indicated a variation in persistence as shown here, but actual flight tests displayed the sudden increase shown by this curve.

To clarify the factors which were causing this reduction in damping, wind-tunnel measurements were made over a wide range of subsonic and supersonic speeds. The results of one of these investigations are shown on this chart. Here rate of damping of pitching oscillations is plotted versus Mach number.

The subsonic tests were made in the Ames 12-foot wind tunnel. While theory shows a continued increase in stability, wind-tunnel tests again show this rapid reduction in stability that was noted in flight tests.

It is to be emphasized that this divergence occurs in the transonic range. This gap in our available information is being filled by flight-research and rocket-model tests. Departure from prediction is not anticipated in flights in the completely supersonic region, for agreement between theory and wind-tunnel tests is good. An example is the right-hand portion of this curve showing the results of wind-tunnel investigation made in the Ames 6- by 6-foot supersonic tunnel.

The second type of instability, Dutch roll, you will remember, as that rather violent rolling oscillation that you saw in Mr. ____________ movies.

Here is a plot of the variation in the amplitude of rolling oscillations that are developed at different lift coefficients. The influence of sweepback upon the development of large oscillations can be seen by comparing this plot of swept-wing characteristics with this curve for a conventional straight-wing design. You might note that this is a defect occurring to a much greater degree on swept-wing aircraft at low speeds.

Among the researches that were made in the attempt to correct Dutch roll, it was discovered that the variation of the angle of incidence of the wing relative to the fuselage, as can be altered in this model, had a strong effect upon lateral stability in general. It was found that a decrease in angle of wing incidence would reduce Dutch roll in this improved level.

The third dynamic instability, called "snaking" is a yawing oscillation often encountered at high speed, especially at high altitude. We have plotted in this chart the persistence of snaking oscillation versus altitude. There is a steady reduction in directional damping with altitude or, as plotted here, an increase in the persistence of snaking. This dotted line represents the dividing line between an allowable and an intolerable amount of oscillation.

While the usual straight wing design has these satisfactory characteristics, the swept-wing airplane represented by this curve was not acceptable with the persistence inherent in the design. While the instability can often be explained in terms of sloshing of fuel, rough air, and loss in damping at high Mach numbers, the designers, in this case, looked to the low effectiveness of the vertical tail as the source of the difficulty. The vertical tail is the main contributor to the directional stability and a larger size would have solved the problem. The same result was attained by increasing the effective size of the tail by introducing an automatic control that moved the rudder in such a fashion as to resist any yawing motion, just as though the tail itself were larger. Thus, the designers effectively increased the directional stability and moved the persistence of the oscillations to this satisfactory level.

At this time the NACA is engaged in several projects studying this subject and is now flying an airplane upon which it is possible to vary several stability characteristics at once.

This airplane will be part of the subject of further discussion by Mr._______________, our next speaker.

Mr._______________.

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SPEECH III

Perhaps some of you have wondered where the previous speaker obtained the information that appeared on the charts regarding the motions that were satisfactory and those which were not satisfactory. After all, when a designer goes through the process of computing the motions of his projected airplane, the results are nothing more than a lot of wavy lines on a piece of paper. How can the designer interpret these motions? How would the pilot react to the motions ?

The NACA has under way an extensive program which is pointed toward helping the designer to interpret the motions of his airplane once those motions are predicted.

One project in this general program which might be of interest to you is being carried on here at the Ames Laboratory. A conventional, propeller-driven, fighter airplane has been fitted with some special servo equipment which makes it possible to subject pilots to numerous combinations of flight motions which are typical of future airplanes.

For instance, this is a model of the test airplane. Now, by turning a knob the pilot can effectively do this to the airplane. (Demonstrate.) He can effectively increase the dihedral, or he can (demonstrate) decrease the dihedral. Also, by making other adjustments, the pilot can effectively increase the size of the vertical tail (demonstrate), or he can decrease the size of the tail (demonstrate). Note that I use the word "effective" here. The equipment does not actually change the shape of the airplane, it merely moves the rudder and the ailerons in such a manner that the airplane acts as though these changes in shape had been made. These effective changes naturally change the dynamic characteristics of the airplane radically. By increasing the effective dihedral the pilot can cause the test airplane to assume the handling characteristics of an airplane like this in a landing approach; or, by making other adjustments, he can effectively fly an airplane like this at supersonic speed. Thus, the equipment affords us a preview of the pilot's reactions to motions we expect from future airplanes.

To date several Air Force and Navy pilots have flown the test airplane and have been exposed to the wide range of characteristics obtainable with the equipment, and an analysis of their opinions has indicated that the rolling and yawing oscillations of fighter airplanes should be limited in a manner similar to that shown in this figure. Here we have the persistence of the oscillations plotted against the amplitude of the rolling motion. This line represents the boundary between satisfactory combinations of these two quantities and unsatisfactory combinations. It has been found that if the airplane doesn't roll much the pilots require relatively little damping – that is, they will accept fairly long persistence of the oscillations. But if the airplane rolls a lot the pilots require that the oscillations die out rapidly. These little insets on the figure show the nature of the motion. In this area the persistence of the oscillations is long; they do not damp out readily. In this area the amplitude of the rolling motions is large (demonstrate). Here are the desirable characteristics; the persistence is short and the rolling motion is small.

Let's take a look at some movies which show how these motions appear to the pilot (slide). First, let us examine a good airplane – one whose characteristics fall in this general area on the figure. (Movies) We are looking forward here through the gunsight. The sighting point is on the target. Now the pilot abruptly kicks the rudder pedal and returns it to neutral. We see how the sighting point returns. (Slide) Now let's see how the oscillations appear to the pilot if their characteristics fall across the boundary in this direction – – that is, if the oscillations persist longer. (Movies) Here again the sighting point is on the target; the pilot kicks the rudder and returns it, and we see how the oscillations fail to damp out quickly. (Slide) Now let's see how the oscillations would appear if their characteristics were to fall too far out in this direction. (Movies) The sighting point is on the target; the pilot kicks and returns the rudder, and we see that the oscillations are fairly well damped, but the airplane rolls in an awful fashion.

(Lights on, screen slid back, chart still showing.)

It is from tests of this nature that boundaries such as this are established to help the designers to interpret the predicted motions of their projected airplanes.

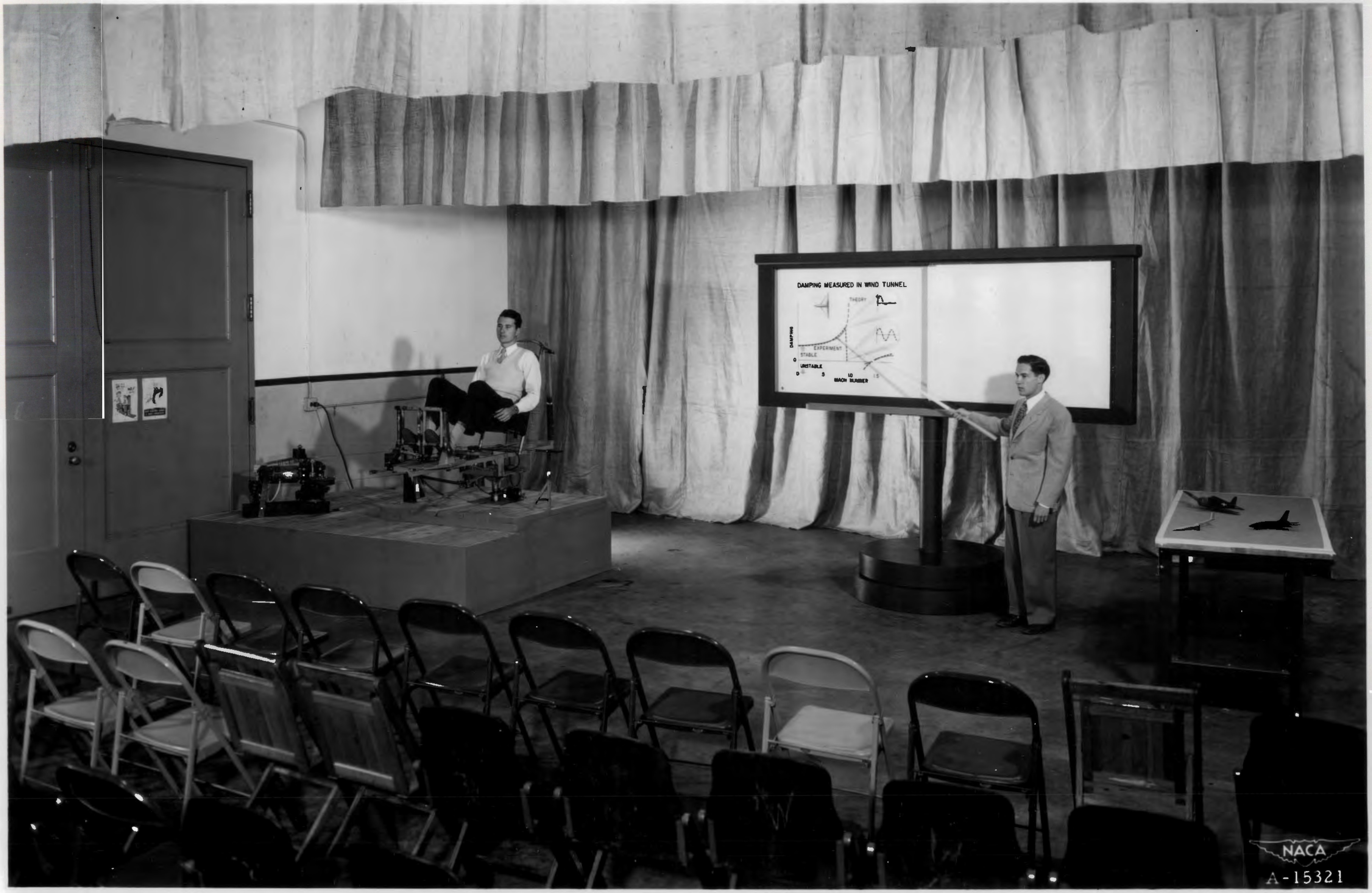
Another useful project in this over-all program of research on flying qualities is going on at the Langley Laboratory. They are making use of a device called a yaw chair, which is shown here. The chair is free to oscillate in yaw much as an airplane oscillates in yaw. We see that the chair is dynamically stable as it is now adjusted - - that is, the oscillations become successively smaller after we disturb it - - and we see that the pilot has no trouble bringing the chair under control. Now, if we turn on this hydraulic device, we see that the chair becomes unstable - - the oscillations build up after a disturbance - - and we see that the pilot finds it difficult to bring the chair under control. Now by making adjustments to the hydraulic device the degree of instability can be changed, and by changing the stiffness of the restoring springs the period can be varied — that is, the oscillations can be slowed down, which means a longer period, or they can be speeded up, which means a shorter period.

This next figure shows some results of an investigation using this device to determine just how unstable the chair could be made before it became completely uncontrollable for the pilots. We have here the degree of instability plotted against the period of the oscillations. This curve represents the boundary between controllable conditions and uncontrollable conditions. It is seen that as the period was reduced, the degree of instability which could be controlled gradually fell off until a critical value of the period was reached, below which no instability at all could be controlled. On the previous demonstration the chair was adjusted so its characteristics fell about here on the chart. With these heavier springs, the period has been reduced. And, with the hydraulic device in operation, the pilot finds it impossible to bring the chair under control.

To illustrate the importance of keeping the yawing oscillations well damped as the speed is increased, a typical high-speed airplane of today has a natural period about here when traveling at a speed of 500 mph. Now if we were to fly that same airplane at 1500 mph we would expect the natural period to be reduced to about here – – well into the region where the airplane would be completely uncontrollable if any instability at all existed.

It has been shown at this stage of your inspection that, as the performance of aircraft increases, dynamic stability problems are becoming more and more serious. It has been possible to give here only a brief glimpse of the extensive program the NACA is following in attempting to aid aircraft designers in all phases of the dynamic-stability problem.

Thank you.



Display for Presentation of "Dynamic Stability"
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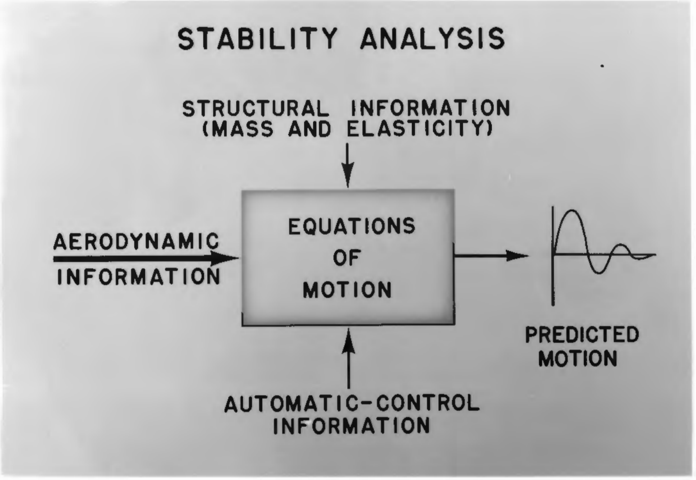

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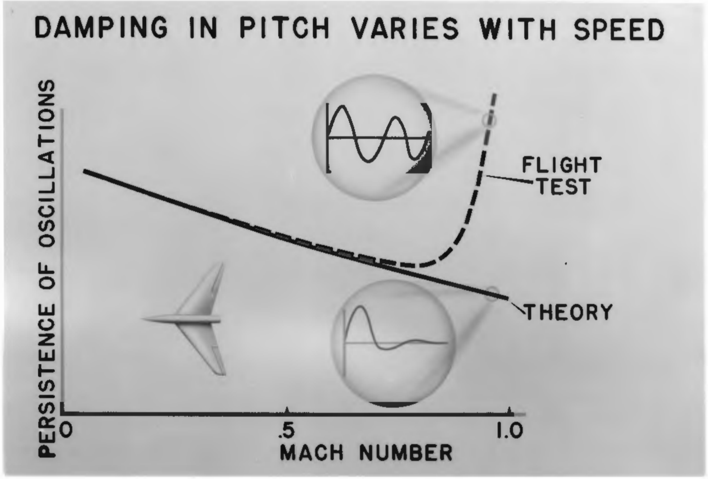

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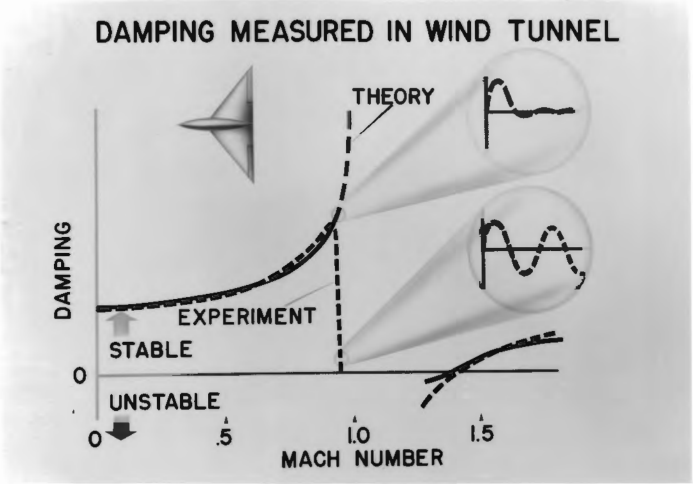

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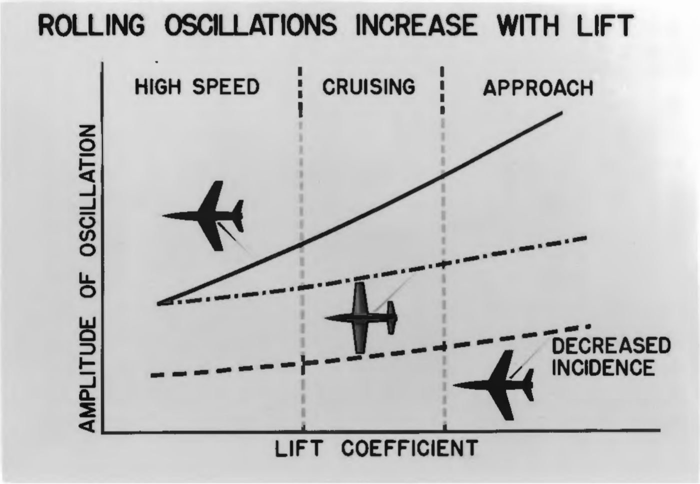

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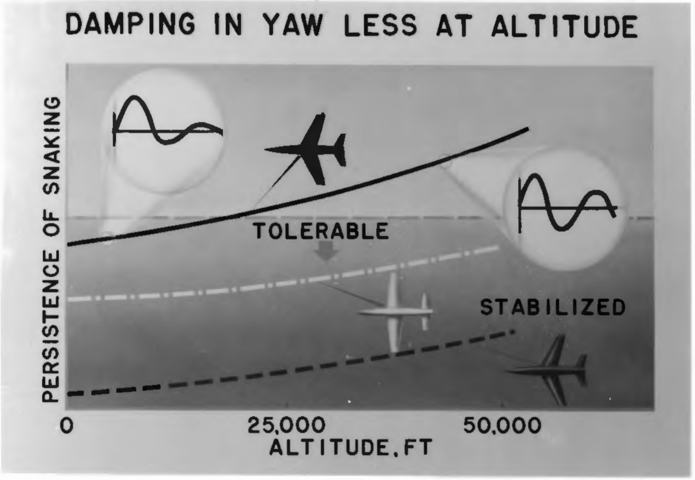

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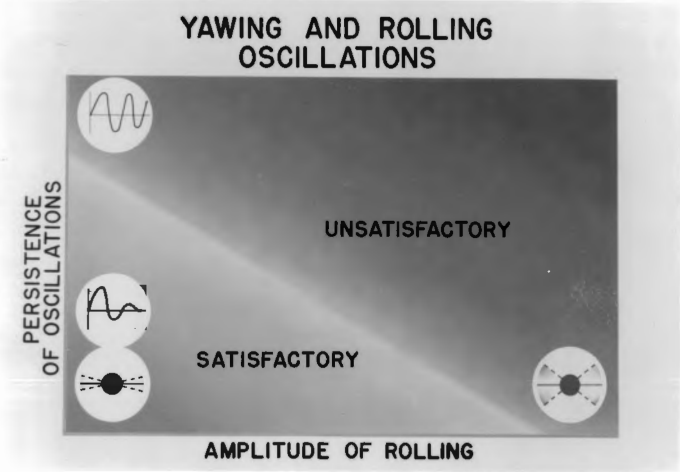

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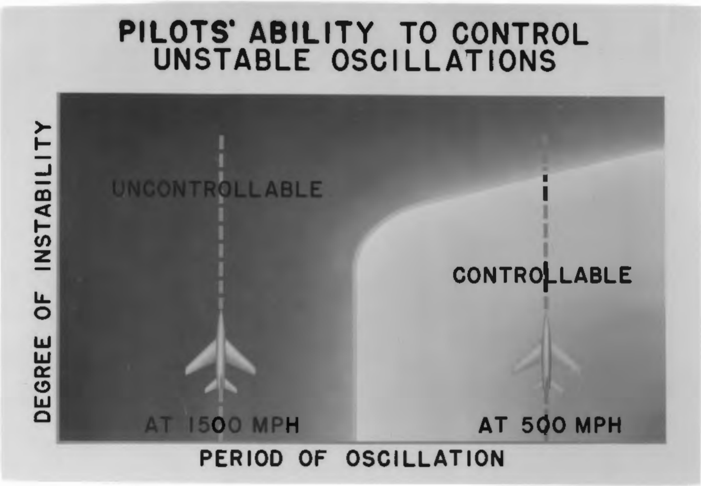

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