DYNAMIC STABILITY

presented by

12-Foot Pressure Tunnel Branch

7- by 10-Foot Wind Tunnels Branch

An airplane in steady flight often encounters a disturabance which temporarily upsets the equilibrium of the flight, such as a sudden gust, or when the pilot makes some abrupt movement of the controls. The response of the airplane to these various disturbances and the nature of its transient or temporary motions depends on what we call its dynamic stability. On looking back into the history of the airplane this has always been one of the most difficult problems in aeronautics. It attracted the attention of investigators before the successful flights of the Wright Brothers. One of the first treatments of the subject was given around 1900 by Lanchester, a pioneer in the airplanes early development. The first report issued by the National Advisory Committee for Aeronautics, published in 1915 dealt with the dynamic pitching motions of an early Curtiss biplane. This report was written by Dr. Hunsaker who is now chairman of the NACA. The fundamental principles which were developed in this early period are still the basis of present analysis, but the emphasis is now on different problems. In the last ten years the speed of new airplanes has more than doubled. This has involved not only the penetration of a new speed regime but radical changes in the shape and placement of the different parts of the airplane.

These new developments have had a profound effect on dynamic stability. For example, let us consider the motion of an airplane as the elevator is moved abruptly upward. We would expect the nose to come up and the airplane to pitch to a new angle of attack. Let us compare the response of an older type airplane and a modern airplane to a motion of this type. We have plotted here (chart #1) the elevator angle indicating that the stick is moved rearward rapidly and held in the new position. Here we have a typical operational fighter airplane of ten years ago, and this curve represents the angle of pitch of the airplane as a result of this control movement. The motion is plotted in terms of distance traveled. We see that the airplane does not pitch to its new position immediately but comes up somewhat slowly compared with the elevator movement, overshoots slightly and settles back to the new pitch angle. Pilots consider this dynamic response to be satisfactory. It responds rapidly but without objectionable oscillation. Next picture an airplane, such as shown here, flying more than twice as fast as the earlier airplane. A sudden movement of the elevator here causes a much more violent reaction. There would be about three rapid oscillations of decreasing amplitude before the airplane settles down at the new pitch angle. If the desired change in pitch angle is large the normal accelerations caused by the initial overshoot may impose serious structural loads on the airplane. In this sense the overshoot limits maneuverability. This scale indicates the relative distance the airplanes travel during the oscillation. We see that the modern airplane covers a much greater distance in the transient maneuver and this complicates interception, aiming, and many other maneuvers requiring precise control of the airplane.

This comparison is typical of modern airplanes. The trend indicated in the first chart has been generalized in this next chart (chart #2) to show the variation of damping as the speed is increased. We understand damping to mean the reduction of the amplitude of an oscillation. For example, damping is the function of the shock absorbers in an automobile. Adequate damping is important in the smooth flight of an airplane. Here we have plotted the Mach number for which the airplane was designed. The change in this Mach number has changed the shape of airplanes and also increase the general level of flight altitudes. These factors combine to reduce the airplane damping, and we note this trend toward low damping with increasing design Mach number. A new family of troubles with airplanes has been encountered which are caused or aggravated by the low damping. The tendency of the airplane to overshoot the desired pitch angle and to oscillate is undesirable. In many cases special corrective devices are needed.

The damping of the airplane can be improved to some extent by aerodynamic means. It is frequently found, however, that changes in the airplane which improve damping, penalize the performance of the airplane in other respects so that it cannot achieve the needed speed or range. For example, it is known that an increase in altitude leads to a decrease in damping. Yet increased altitude is a very effective way to reduce the drag. For example, assume that at sea level it would require 50,000 horsepower to overcome the wave drag of an airplane or missile flying at a Mach number of 2, however, at an altitude of 100,000 feet only 500 horsepower or 1% of the power required at sea level would be required to overcome the wave drag of the same aircraft at the same speed. Thus in one way, it is desirable to fly at high altitudes because the drag on an airplane or missile is reduced and the performance can be improved if the powerplant can operate efficiently in thin air. However, the wings and control surfaces are not as effective in the thin air and the length of time that it takes an oscillation of the airplane to die out is increased in about the same proportion as the reduction in drag. In situations such as this, it has sometimes been necessary to sacrifice good dynamic stability for good high-speed performance. The dynamic stability can then be augmented in some other way. It is sometimes possible to correct unsatisfactory dynamic stability by the use of automatic controls which can assist in damping the airplane motions. The application of these special techniques is a large and rapidly growing field of airplane design.

These are only some of the problems that must be considered in great detail with modern airplanes. In these studies it is necessary to have the most complete knowledge of the aerodynamic properties of a new airplane before it is actually built. Some of the methods used to obtain the required information will be described in the next talk. I would like to introduce Mr. _______.

The changes that have taken place in airplanes have pointed up critical need for basic information on dynamic stability. Dynamic motions of the airplane can take place in either direction about any one of three airplane axes - pitching, rolling, and yawing (chart #3). Analysis of the problem also shows that the rolling and yawing motions cannot be separated. For example, as the airplane yaws wind forces on the wings and the tail tend to roll the airplane. The problem of solving equations describing these motions is formidable but much has been done in recent years, especially with automatic computing machines and simulators which you will see elsewhere today. One important problem in this field is in the estimation or prediction of the aerodynamic forces and moments acting on an airplane as it executes these rapid maneuvers. These would include particuarly all the additional forces generated by the velocity of the rotating motions and the resulting changes in air flow past the airplane. A knowledge of these effects is necessary to predict the damping of the airplane.

Wind tunnels tests have always played a prominent part in providing data on these forces. The first three techniques listed on this chart (chart #4) are wind tunnel techniques. The first method - oscillation tests - have been used for many years. We have in the wind tunnel an example of the equipment used in this type of test. This model and support were built for the measurement of air damping forces at high Mach numbers. Light weight is one of the requirements for models used in these oscillation tests and this model weighs only 18 pounds but the wings can support the lift loads of nearly a ton which occur in tests in other wind tunnels at high air speeds. The model is mounted on a flexible support so that it can oscillate in pitch as air is passed through the tunnel. The oscillation which you see here dies out rather rapidly in the air stream and this complicates the measurement. For this and other reasons it is most desirable if the model could be made to oscillate continuously as the measurements are made. This continuous oscillation is accomplished by supplying the necessary alternating force with this electromagnetic shaker housed in the model support.

This bank of electronic equipment is linked with the oscillation test apparatus and has two functions. One of these is automatic control of the amplitude of the model oscillation. Oscillation of the model can be induced by setting the desired amplitude on this electronic control. You will observe that the amplitude of the oscillation is at first very small and then rapidly builds up to the desired value. The oscillation of the model can also be seen in this oscilloscope which displays a trace of angular motion of the model. The other function is that of an analogue computer that performs mathematical operations on strain gage signals from the oscillating model for the rapid and accurate indication of the damping. This electronic counter with the flashing lights indicates the time it takes for the model to make one complete oscillation. The motion demonstrated here is a pitching motion, however this equipment has also been applied to measurements of rolling and yawing motions and various combinations of these motions.

Other wind-tunnel test techniques which have played a prominent part in providing data on this subject include methods whereby the model is rolled steadily in the wind tunnel. Thus in place of an oscillatory pitching motion such as demonstrated the model would roll continuously in one direction. The advantage here lies in that the additional forces due to the motion are measured as steady forces rather than oscillatory forces. In another variation the wind-tunnel walls are curved so that the air follows a curved path past a stationary model. This corresponds to an airplane following a curved flight path through still air. The forces in each case are similar.

The last three techniques differ from the first three in that they are basically flight tests. Here the emphasis is on duplicating the actual motions that would occur with airplanes and missiles. In free-flight or ballistic range tests a model such as this is fired from a gun into an air stream. Photographic records are made of the motions of the model as it flies at speeds which can exceed ten times the speed of sound. A careful analysis is then made of the observed motion to determine the forces acting on the model.

Rocket propelled models of airplanes and missiles are fired over desert areas or open ocean. The nose of the model contains instruments and a radio transmitter which sends the data on missile behavior back to the launching site. As part of this technique we might also include tests of freely falling models dropped from airplanes. Specified maneuvers can be programmed into the flight and much valuable information obtained under conditions which might be very dangerous for a piloted airplane.

One of the most important sources of information is provided by the last technique listed, the actual flight of piloted airplanes. Many of these airplanes are much more elaborately instrumented than any of the models. In some cases, as in the so-called "variable stability" airplanes, the apparent damping of the airplane can be varied by special linkages inserted in the control system. Here the accuracy and applicability of the other techniques are tested and additional information collected. During recent flight tests of some modern airplanes capable of sonic and supersonic speeds, one specific problem in maneuvering flight has assumed great importance. Mr. ______ will discuss this problem in the next talk.

Within the last year it has been found that several modern airplanes have encountered difficulty in rolling maneuvers. Sometimes when the pilot has attempted rapid rolling, a violent yawing and pitching motion has ensued which was uncontrollable by the pilot. Examination of flight records revealed that the violence of the maneuver strained the airplanes beyond safe limits. Fortunately, the airplanes in several of these flights were well instrumented and enough data were obtained to permit thorough studies to be made. The principal results of these studies can be described in fairly straightforward terms, and agree with certain simplified theoretical predictions made by the NACA and others, several years ago.

The reason this particular type of dangerous motion has not been experienced in airplanes until quite recently lies in increasing speed and the manner in which the weight distribution has been changing. We have here a chart (chart #5) showing how the spanwise and lengthwise distribution of weight has been changing as the design Mach number has increased. In earlier airplanes more of the weight was distributed along the wings as shown here. In modern airplanes with thin, stubby wings this weight which was formerly in the wings has been placed in the fuselage. In addition, as the flight speed increased it has been necessary to make the fuselage longer and this has required that the weight be distributed farther forward and aft of the center of gravity. For example, the guns, fuel tanks, and landing gear on many modern airplanes are now in the fuselage rather than in the wings as in former years. These changes have been dictated by new performance requirements to get airplanes to fly faster and higher. This airplane having a triangular wing is only one of a number of possible future designs in which this trend in weight distribution will continue. Thus, the trend is toward long airplanes with most of the weight distributed lengthwise in the fuselage. This has been found to be an important factor in these uncontrolled maneuvers at high roll rates, as will be demonstrated later.

Another significant trend is disclosed by a comparison of the oscillation frequencies of an airplane with its maximum rate of roll. You will recall that the first speaker, Mr. ________, discussed the pitching oscillation of a modern airplane. We can also demonstrate the yawing oscillation by this model. When the airplane is yawed, the air forces on the tail tend to keep it pointing in the wind direction like a weathercock, but the inertia of the airplane causes it to overshoot slightly and as a consequence an oscillation develops. This oscillation occurs with nearly all airplanes, and, while it is sometimes a control problem, it is not considered dangerous.

If we compute the frequency of yawing oscillation for several past and present airplanes we find that as the design Mach number has increased the oscillation frequency has decreased as indicated by the yellow line on this chart. It has been found (chart #6) that airplanes are capable of higher roll rates as the design Mach number has increased. This has been indicated by the red line on the chart. In past airplanes it was never possible to roll the airplane fast enough to interact with the yawing oscillation, but now we see it is possible to roll the airplane completely around in the time of one cycle of yawing oscillation. This has been another extremely important factor in the type of divergent motion encountered. We have prepared this demonstration to emphasize these two points. We have two models, one representing a fighter airplane of ten years ago, and one representing a modern research airplane. The spanwise and lengthwise distributions of weight in these models have been adjusted to correspond with the airplanes they represent. The supporting wires provide restoring force for the model in the same way as the air forces acting on the airplane provide weathercock stability. The wires are of a size that will provide a yawing oscillation frequency of the models proportional to the oscillation frequency of the airplanes.

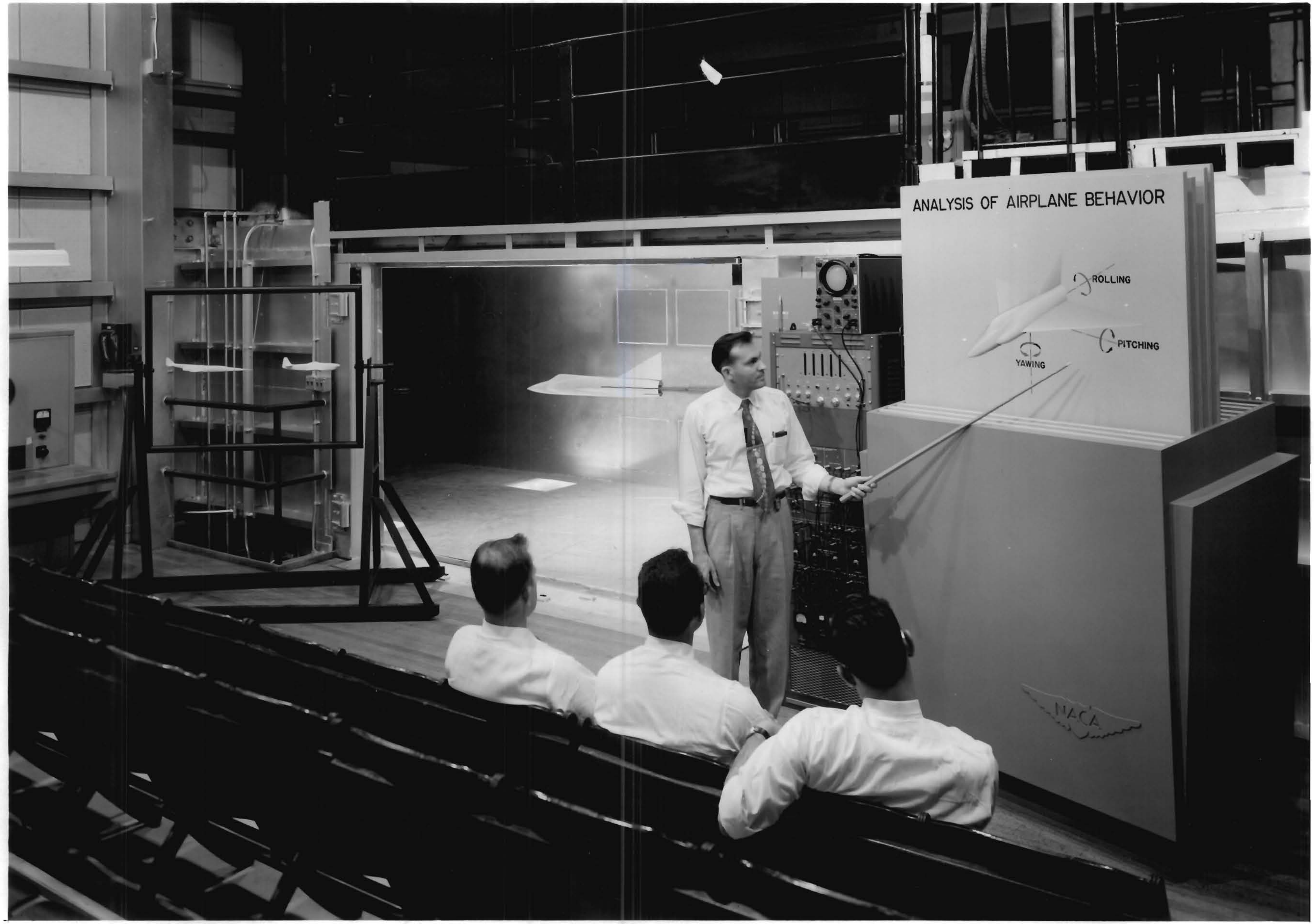
We will now roll the models through a range of roll rates. (Roll models.) As the rolling revolutions per second approach the yaw oscillations per second the tendency toward divergence is immediately apparent in the modern airplane. Most of the mass is distributed along the length of the airplane and the centrifugal forces set up by the rolling motion tend to swing the nose and tail outward from the roll axis. As a consequence, the airplane yaws about its center of gravity. When the airplane performs one roll revolution in less time than that required for a yawing oscillation the centrifugal forces exceed the forces tending to restrain the airplane in yaw. We will now demonstrate this sequence again.

You will note that nothing violent occurs with the model of the older type airplane. Its design, both with regard to mass distribution and roll rate, was such that it could not get into difficulty in this way. Also, since the problem has been recognized in modern airplane design a number of ways have been found to alleviate it, although it will probably always require consideration in the design of high-speed airplanes.

This demonstration is intended to bring out the most important features of the problem. We see, however, that if an initial yawing oscillation exists the motion may proceed differently but be just as violent. It is helpful to watch a point on the nose of the model to follow the motion. (Demonstrate.) Actually it is necessary to make very complete studies including many effects which have been omitted from this demonstration in order to insure that an airplane rolling maneuver will be safe.

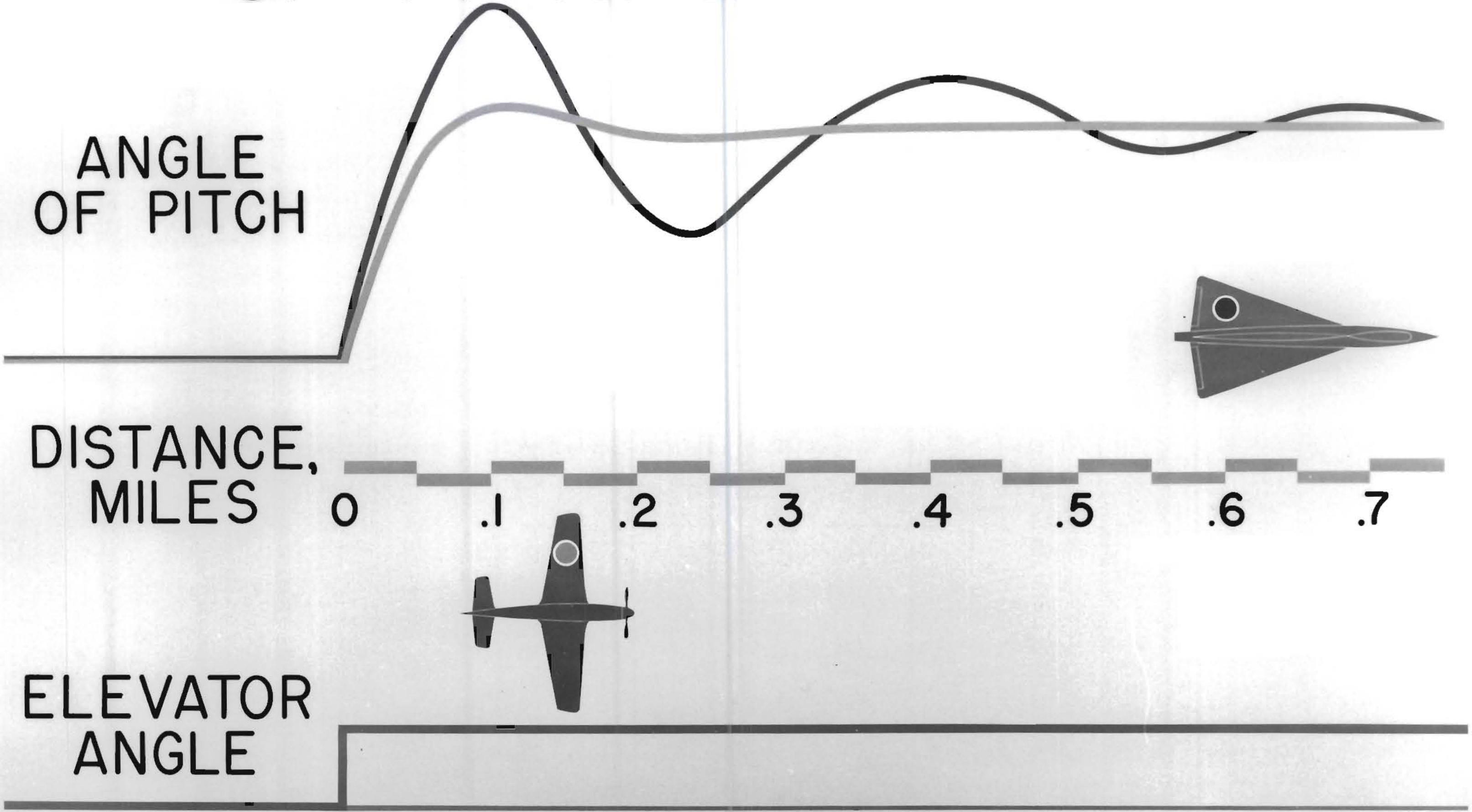
In concluding this discussion of dynamic stability we would like to sum up by saying that in many ways the problems described are not fundamentally new. However, they have become much more important with modern airplanes and will probably become more so in the future.

A 0460-5-1

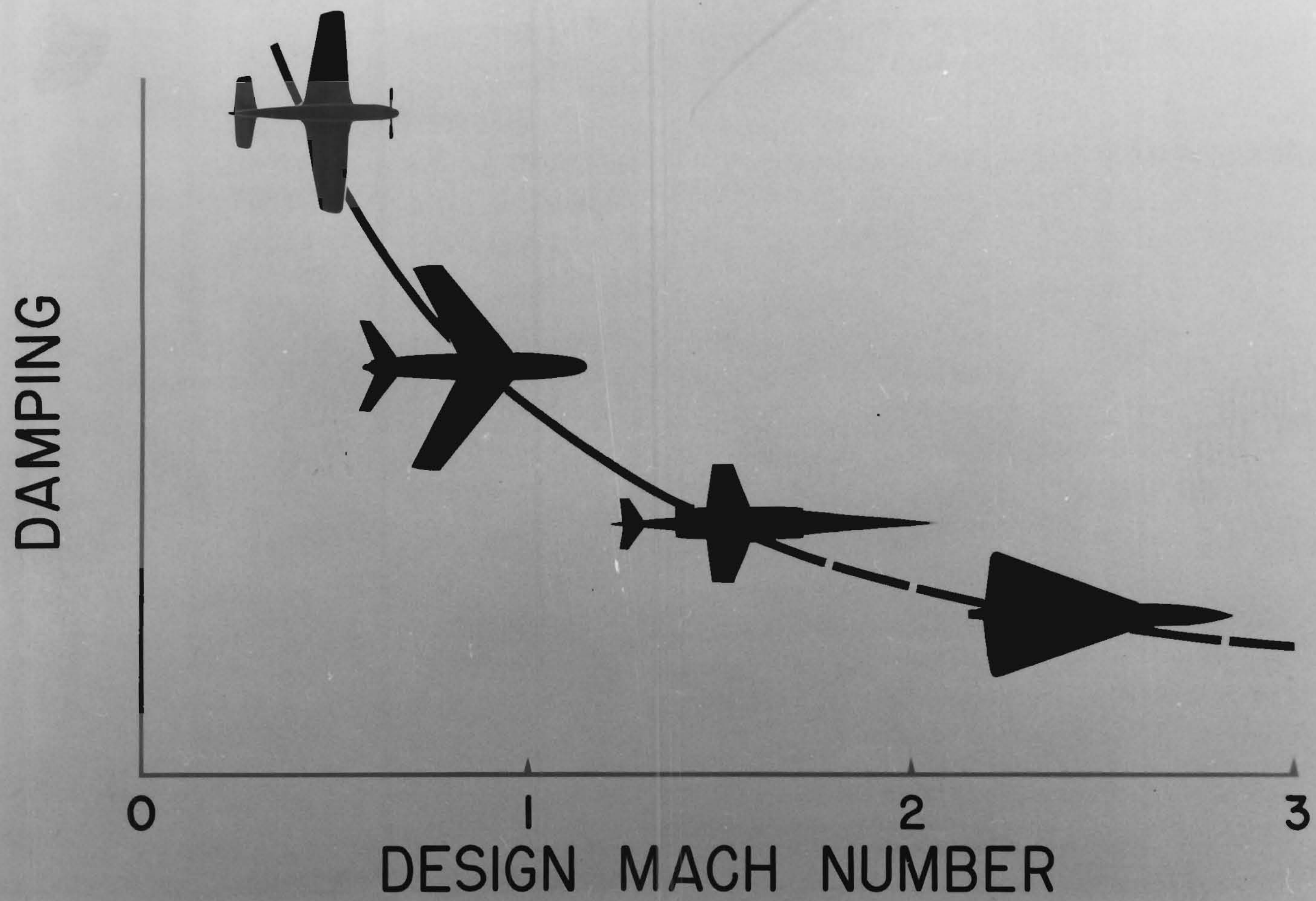


NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS
AMES AERONAUTICAL LABORATORY, MOFFETT FIELD, CALIF.

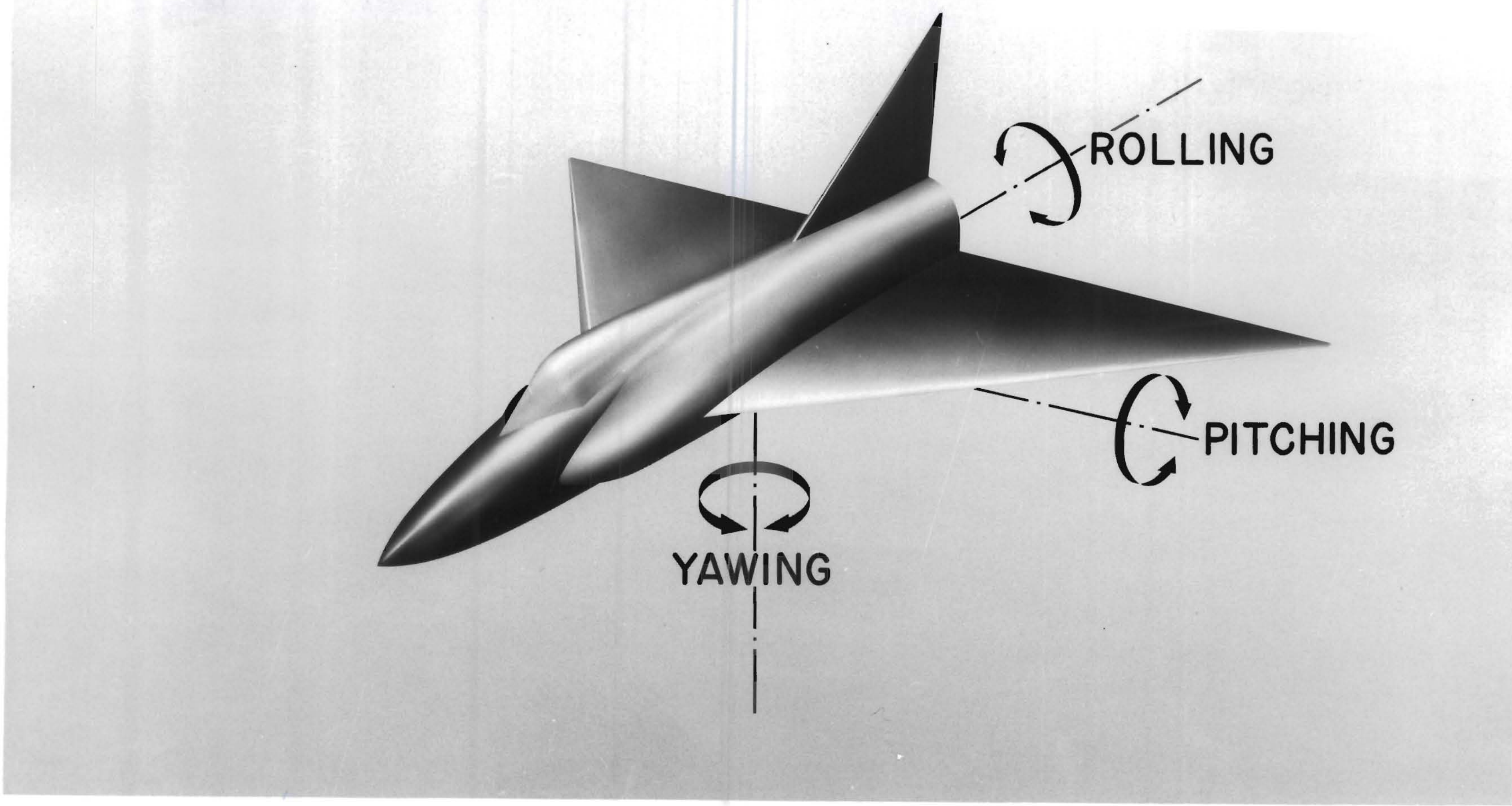
PITCHING OSCILLATIONS OF TYPICAL AIRPLANES



HIGH-SPEED DESIGNS SACRIFICE DAMPING



ANALYSIS OF AIRPLANE BEHAVIOR



NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS
AMES AERONAUTICAL LABORATORY, MOFFETT FIELD, CALIF.

TECHNIQUES FOR STABILITY RESEARCH

1

OSCILLATION TESTS IN WIND TUNNELS

2

STEADY ROLLING TESTS IN WIND TUNNELS

3

SPECIAL WIND TUNNELS WITH CURVED FLOW

4

FREE-FLIGHT TEST RANGES

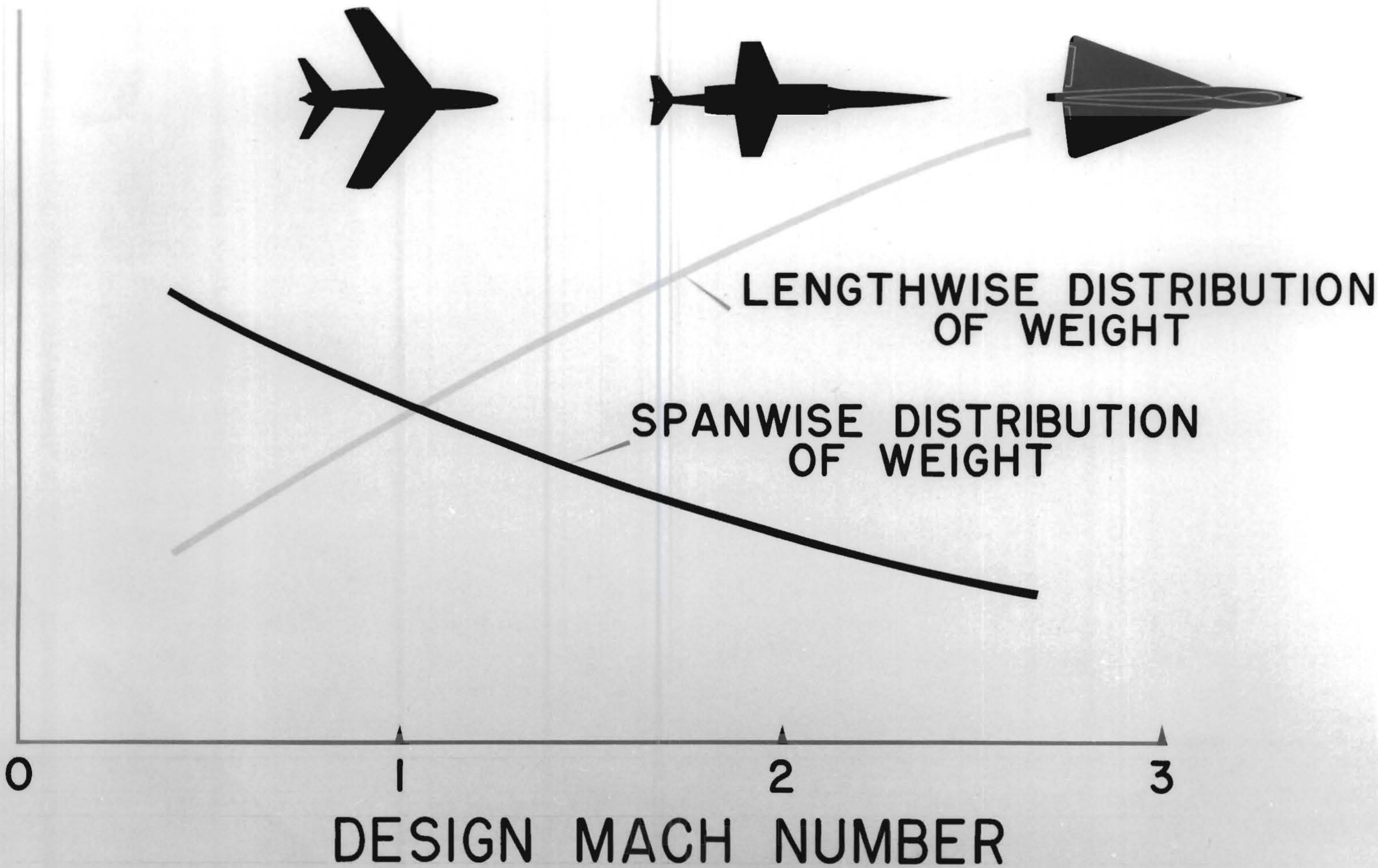
5

ROCKET-PROPELLED MODELS

6

PILOTED AIRPLANES

TRENDS IN WEIGHT DISTRIBUTION



NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS
AMES AERONAUTICAL LABORATORY, MOFFETT FIELD, CALIF.

TRENDS IN ROLL AND YAW RATES