AIRPLANE FLEXIBILITY

presented by

Ames Flight Research Branch

NACA High-Speed Flight Research Station

The desire to achieve intercontinental range and efficient flight at high speeds in large transports and bombers has recently led to long, thin, sweptback wings and long, slender fuselages. The B-47 is an example of this type of airplane. But these long, slender configurations have increased the flexibility of the structure to such an extent that bending of the wing and tail alters the flight characteristics of the airplane. As a result, many of the design procedures used for more rigid airplanes are no longer valid, and new analysis techniques are needed to design the transports and bombers of the future. It is our purpose here to give you an insight to some of the flight problems arising from structural flexibility, and to explain the NACA research which is being conducted to help solve these problems.

The fact that these airplanes are flexible does not mean that they are weak. They are made of aluminum alloys which can withstand high stress and hence are much like a highly-tempered saw blade which can bend to large angles without breaking. The B-47 wing, as indicated by this wing tip marker, can bend approximately 20 feet from a push-down to a pull-up maneuver.

Now, I would like to draw your attention to this flexible model which will be used to demonstrate some of the fundamental relationships between air loads and bending of the wing in flight. I will attach this arrow to the wing so that the angles of the wing tip relative to the fuselage will be more apparent. Notice how the wing tip is nose down relative to the fuselage when I bend the wing. As you know, the lift generated by a wing or tail is dependent upon its angle to the air stream. Hence, we see that bending of the wing in flight changes this angle, which in turn alters the distribution of lift on the wing. A similar situation exists for the tail because bending of the fuselage and of the tail itself produces changes in the angle of the tail. The study of these mutually dependent effects of air loads and bending of the wing and tail is appropriately called aeroelasticity.

Now let's see how aeroelasticity affects the airplane in flight. Assume that the airplane is flying straight and level. These springs simulate lift loads. For this weight condition the wing tip is parallel to the fuselage. Now let us assume that the airplane is carrying a payload represented by this weight. Notice how the wing tip angle is reduced with this weight condition. This causes a loss of lift near the tips which changes the balance of air forces on the airplane. A gust or pull-up maneuver has nearly the same effect on the airplane as this weight. Hence, on an elastic airplane the balance of air forces is changed by bending and twisting of the wing and tail as the load condition varies.

These deflections can be controlled to some extent by distributing the weight uniformly over the airplane. For example, if this weight is redistributed with some near the wing tips, the wing tip angle comes back to normal. In many airplanes today the effects of wing bending and twisting are alleviated by placing weight in the form of engines and fuel tanks near the wing tips.

Aeroelasticity becomes especially important when designing autopilots for airplanes. The autopilot measures the airplane motion, compares this with the desired motion, and then sends corrective signals to the controls. Systems such as these become potentially dangerous on a flexible airplane because a measuring device on the airplane cannot distinguish vibrations of the structure from motions of the airplane as a whole. Assume that the airplane equipped with an autopilot strikes a gust which causes it to shake at a given frequency. The autopilot commands the elevator to take corrective action at that frequency. We will represent the force created by the elevator by a force applied by a small electric motor at the tail. Notice the manner in which the airplane vibrates. At some points the vibration is large and at others it is small. Now, if the sensing device which gives signals to the autopilot were at a point where the vibration is large, it would generate a signal at the frequency of the vibration and would cause the autopilot to oscillate the elevator. This in turn would increase the vibration and so on until structural failures occurred. However, if the pickup were at a point where there is no vibration, such as this point, then it would measure only motion of the airplane as a whole and the autopilot-airplane combination would be stable.

Up to this point we have presented some of the fundamental problems of flexible airplanes. The next speaker, Mr____________, will discuss some of our flight-test methods and results with the B-47 airplane. Mr.______________.

In order to provide research data on aeroelastic problems and to evaluate design procedures for flexible airplanes, the NACA instituted a flight research program with the B-47 as a research tool, since it was the most flexible airplane available. The Air Force made this possible by lending the airplane to the NACA. Because of the specialties involved, the research was divided, as shown on the next chart (chart #1), between the Langley Laboratory, the High-Speed Flight Station located at Edwards Air Force Base, where the actual flight testing is being done, and the Ames Laboratory. The Langley Laboratory is studying the loads on the airplane to provide accurate data for the design of lighter and safer structures. The term loads, here, refers to the total forces applied to the structure which includes the air lift and weight. Under stability and control, the High-Speed Flight Station is obtaining data for determing handling qualities and static stability requirements for flexible airplanes, and the Ames Laboratory is providing data for improving autopilot design and dynamic stability and control. Of course, these projects are closely related and there is an interchange of information between the Laboratories and HSFS. Consequently, the output on any one of these subjects is the result of a cooperative effort. From these studies we are providing data to aid in the design of transports and bombers which can carry greater loads and which retain desirable margins of stability and control and safe handling qualities.

The extent of a research program of this type can be appreciated when you realize that these problems had to be studied over a wide range of flight conditions from landing at sea level to flying at high Mach numbers at 40,000 feet, and over a wide range of airplane maneuvers - aileron rolls, pull-ups, push-downs, sideslips, and many others. Also, the very nature of aeroelastic problems required study of both the motions and deformations of the airplane.

In order to accomplish the flight-test program, the Langley Laboratory installed extensive instrumentation as indicated by this chart (chart #2). The instrumentation is divided into three groups: Pilot input and airplane response, structural loads, and airplane bending and twisting. The first group measures the force and movement which the pilot applies to the wheel and rudder pedals, the movement of the control surfaces, and the resulting motions of the airplane. The long boom mounted on the nose gives accurate measurements of angle of attack, angle of sideslip, airspeed, and altitude. The second group measures the structural loads on the wing and tail. The location of the strain gages used to measure these loads are identified by yellow markers here and on the airplane. The third group measures the bending and twisting of the wing, fuselage, and tail by means of an optigraph developed by the NACA. The optigraph, which is enclosed in a canopy mounted on the top of the fuselage, records the movement of lights identified by the black triangles. At the same time, movies are taken so that an exact picture of the movement of the wing and tail is recorded. Accelerometers are also located throughout the structure to pick up structural vibrations.

The outputs of strain gages and pickups which are not self-recording instruments are recorded by oscillographs located in the bomb bay. On this chart (chart #3) we have an enlargement of a portion of the film from one of these oscillographs. There are 12 quantities recorded here and this represents only 5 seconds of testing time. These are traces from accelerometers located at the tip, midspan and root of the wing. All in all there are approximately 250 quantities recorded on film.

Now we will show some movies of a portion of a test flight. The cameras are mounted in the optigraph housing so you will be looking along the wing. A line has been placed across the screen for reference so that you can tell how much the wing is bending from its initial condition. As you watch these movies, bear in mind the problems which we have mentioned and remember that a complete record of the motions and stresses in the structure is being recorded on film.

There is considerable background movement in these movies, but you should ignore the background and watch the deflection of the wing with respect to the reference line. This movie consists of five runs. The first run is a straight and level run. The next two are pushovers into turns and the last two are abrupt aileron pulses. (A running commentary will be given during the movies which will last about 1 minute.)

Following a flight test like the one you have just witnessed in the movie, the oscillograph records are analyzed. Then the measured and theoretical results are compared to determine whether or not the present theoretical methods are adequate for the particular flight condition. This next chart (chart #4) illustrates one condition of wing bending and twisting which occurred in flight. Here we show a front view of the airplane as it appears on the ground with no load, and as it appears in flight during a pullup. The wing is bent upward and is twisted as was illustrated on the model. Graphs of the bending and twist are shown above. The circular symbols are the measured values and the solid lines are the predicted ones.

The agreement between the predicted values and the measured ones is considered to be good for this particular flight condition, which gives the designer confidence in using this particular theoretical method for similar conditions on new designs. Similar types of studies have been made on the handling qualities and stability and control but these cannot be shown here.

We have shown you some of the problems of flexible airplanes which are confronting airplane designers today. There is much research needed on these and other aeroelastic problems, and the NACA research program is going forward to provide the information needed to design transports capable of carrying more passengers with greater safety and military aircraft with greater tactical advantages. You are now invited to inspect the airplane and test equipment as you leave the hangar.

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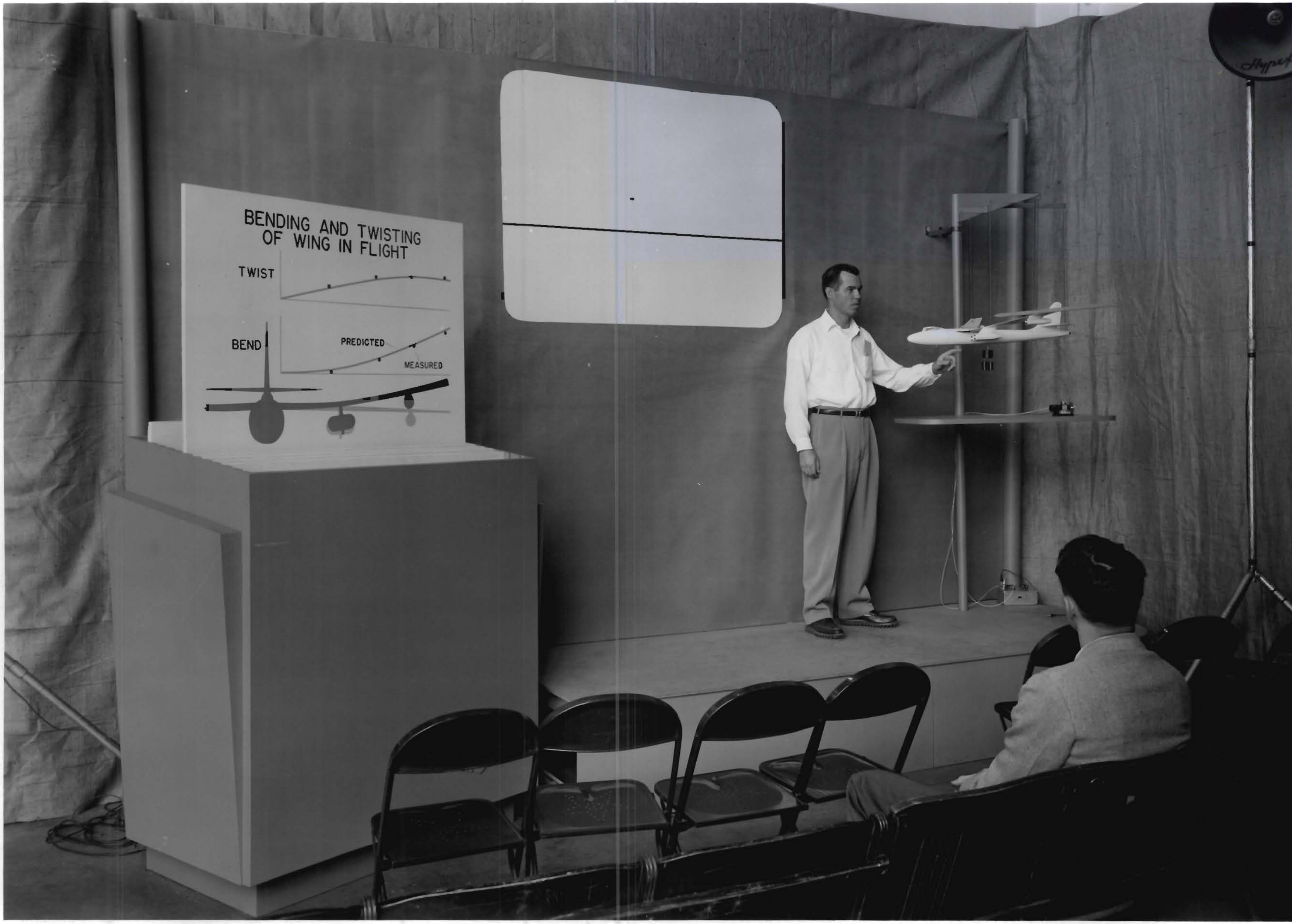

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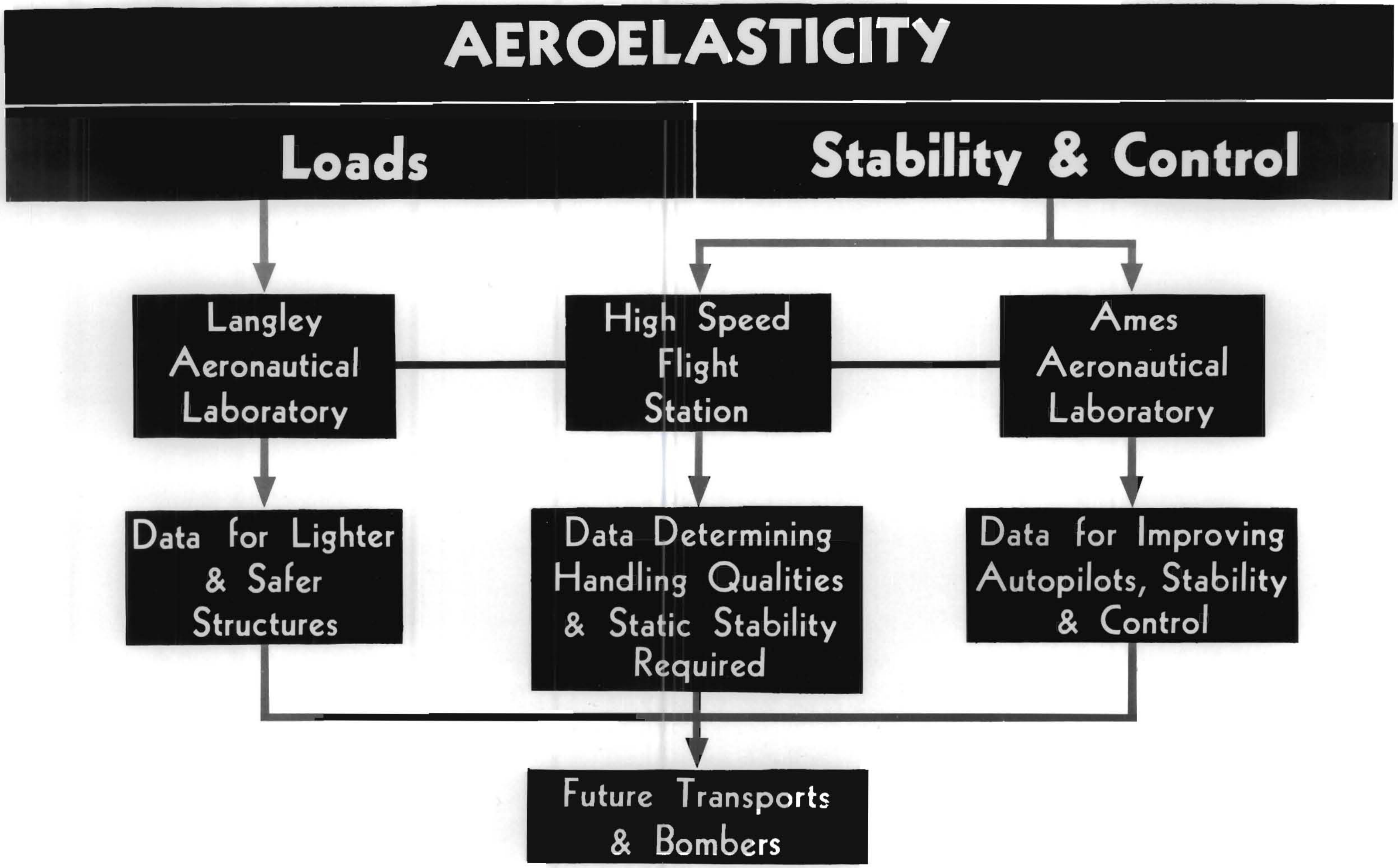
NACA AEROELASTIC RESEARCH

B-47 AIRPLANE



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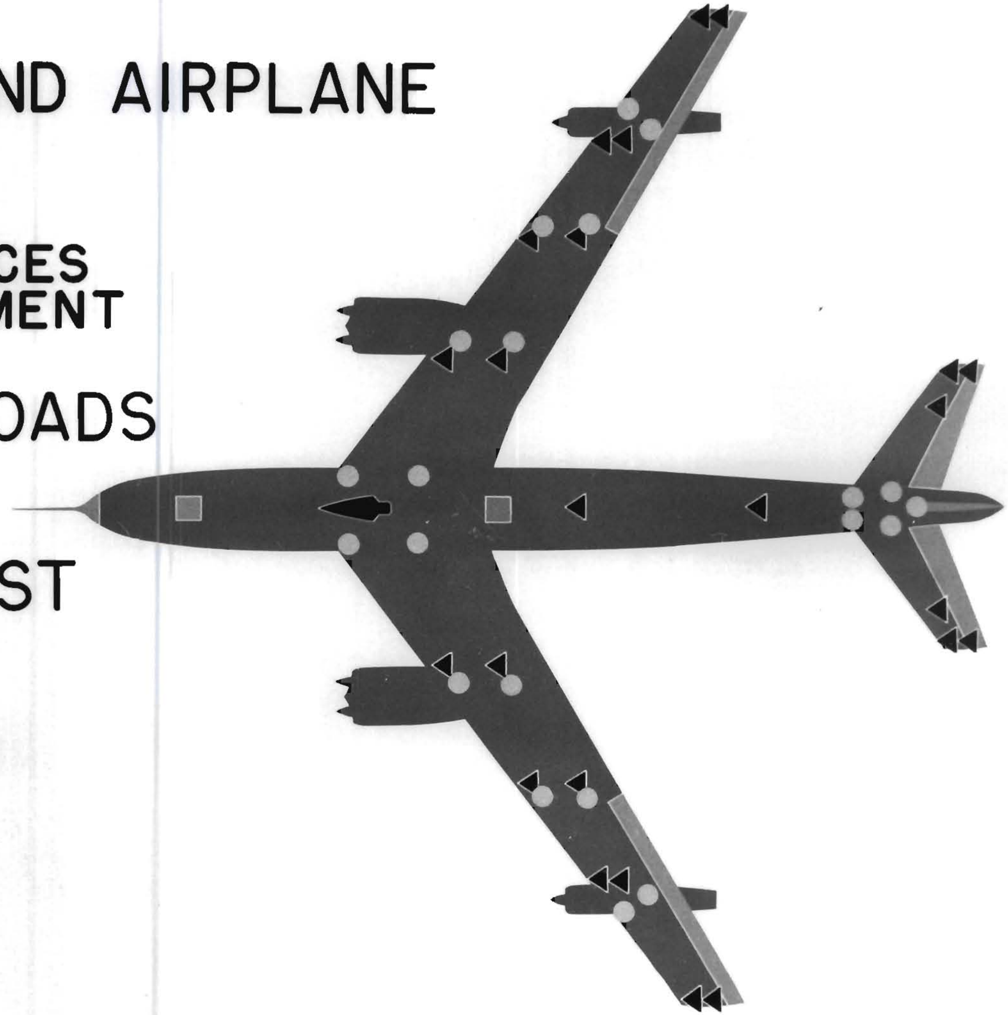
INSTRUMENTATION

- ■ PILOT INPUT AND AIRPLANE RESPONSE
  - PILOT CONTROLS
  - CONTROL SURFACES
  - AIRPLANE MOVEMENT
- ● STRUCTURAL LOADS
  - STRAIN GAGES
- ◀ BEND AND TWIST
  - OPTIGRAPH
  - CAMERAS
  - ACCELEROMETER



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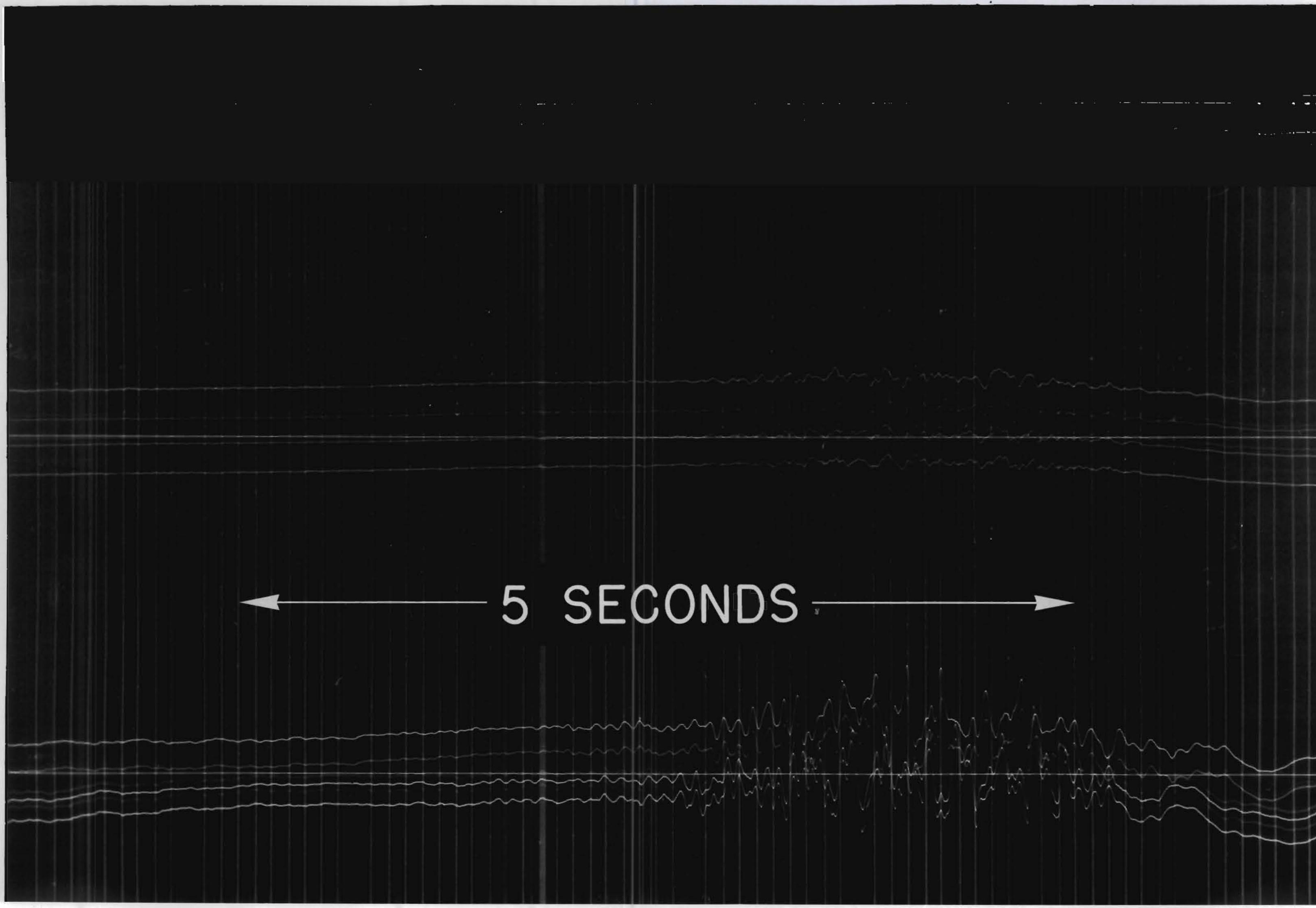
TYPICAL OSCILLOGRAPH RECORD



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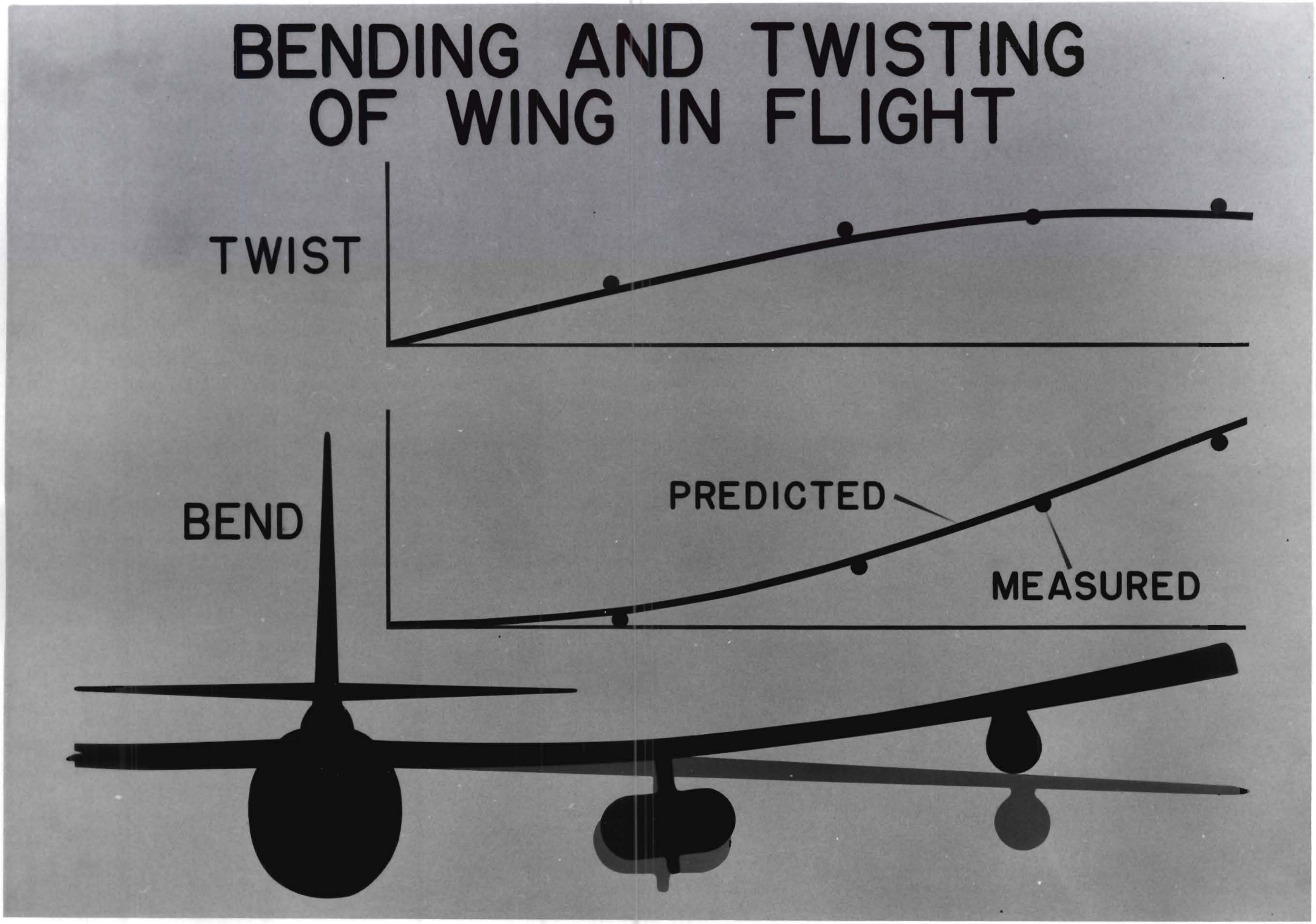

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