40- BY 80-FOOT WIND-TUNNEL TOUR

Charles N. Harper or
Nicholas H. Van Dorn

First, let me orient you in the tunnel by reference to this scale model (fig. 10(a)). You have entered at this point and are seated inside this section of the tunnel.

A wind tunnel is a scientific instrument used to obtain the information necessary to predict the manner in which an airplane will fly. The shape of a wind tunnel results from efforts to use the available power in a most efficient manner. To see how this is done in the 40- by 80-foot tunnel, let us examine this scale model (fig. 10(a)).

You will note that the tunnel forms a closed circuit. The air travels from the return passage, where we are sitting, through the entrance cone, through the test section, through the expanding portion of the tunnel, the motor section, and once again reaches the return passage. A closed circuit such as this means that the same air recirculates in the tunnel and that once the air is in motion all of the power required is expended in overcoming the friction between the air stream and the tunnel walls.

You will also note that the cross-sectional area varies throughout the tunnel. At this point the tunnel is 132 feet high and 172 feet wide. Through here the air has a maximum velocity of 30 to 35 miles per hour. This return passage serves as a settling chamber allowing any turbulence to die out so that a

smooth air stream will flow over the airplane.

From here the air passes through the entrance cone which reduces the tunnel cross-sectional area and so forces an eight-fold increase in air-stream velocities. The maximum velocity in the smallest portion of the entrance cone and in the following test section is in excess of 250 miles per hour.

The 80-foot-long closed test section is 40 feet high and 80 feet wide. It is of constant area through its length, so that the air-stream velocities are constant throughout this section.

Leaving here the air enters the expanding portion of the tunnel which serves to decelerate the air, as rapidly as possible in order to reduce the wall friction losses encountered with high air-stream velocities. These friction losses in the test section account for approximately 90 percent of the power required to drive the tunnel at top speed. For this reason you will note that through the higher-speed sections the tunnel skin is of smooth sheet steel, whereas in the lower-velocity sections the skin is of a more economical corregated construction.

The expanding section contains two 90° turns, and the power section of the wind tunnel, and brings the air through a third 90° turn into the return passage. This passage contains a fourth 90° turn and thus completes the circuit of the tunnel. Each of the four 90° turns contains a set of turning vanes similar to those that can be seen here. These serve to bring the air smoothly and efficiently around each corner.

At the entrance to the power section the tunnel is 60 feet high and 120 feet wide. Here it separates into six tubes each containing a 6,000 horsepower motor driving a six-bladed 40-foot-diameter fan. Recourse was had to these separate units because of the obvious difficulties and expense involved in designing and building a single fan large enough to absorb a total of 36,000 horsepower. All of the fans turn at exactly the same speed, the maximum being 290 rpm. The highest air velocity reached at this point is about 65 miles per hour.

The 40- by 80-foot wind tunnel is, to the best of our knowledge, the largest wind tunnel in the world. The tunnel structure is 870 feet long, 400 feet wide, 160 feet high, and covers an area of 8 acres. It encloses some 900 tons of air, 41 of which pass any given section every second at top tunnel speed. The air travels about 1/2 mile in completing its circuit of the tunnel.

Now let us turn our attention again to the test section. Airplanes or models undergoing investigation are supported here by a conventional three-strut support system. These struts are attached below the test section floor to a frame which in turn is supported by a force-recording scales. The scales are capable of measuring 90,000 pounds of lift and 16,000 pounds of thrust or drag. Airplanes may undergo investigation with their engines operating, whether they be reciprocating, gas turbine, or jet-type engines.

Without question the value of an airplane increases directly with its top speed. For this reason high-speed design requirements

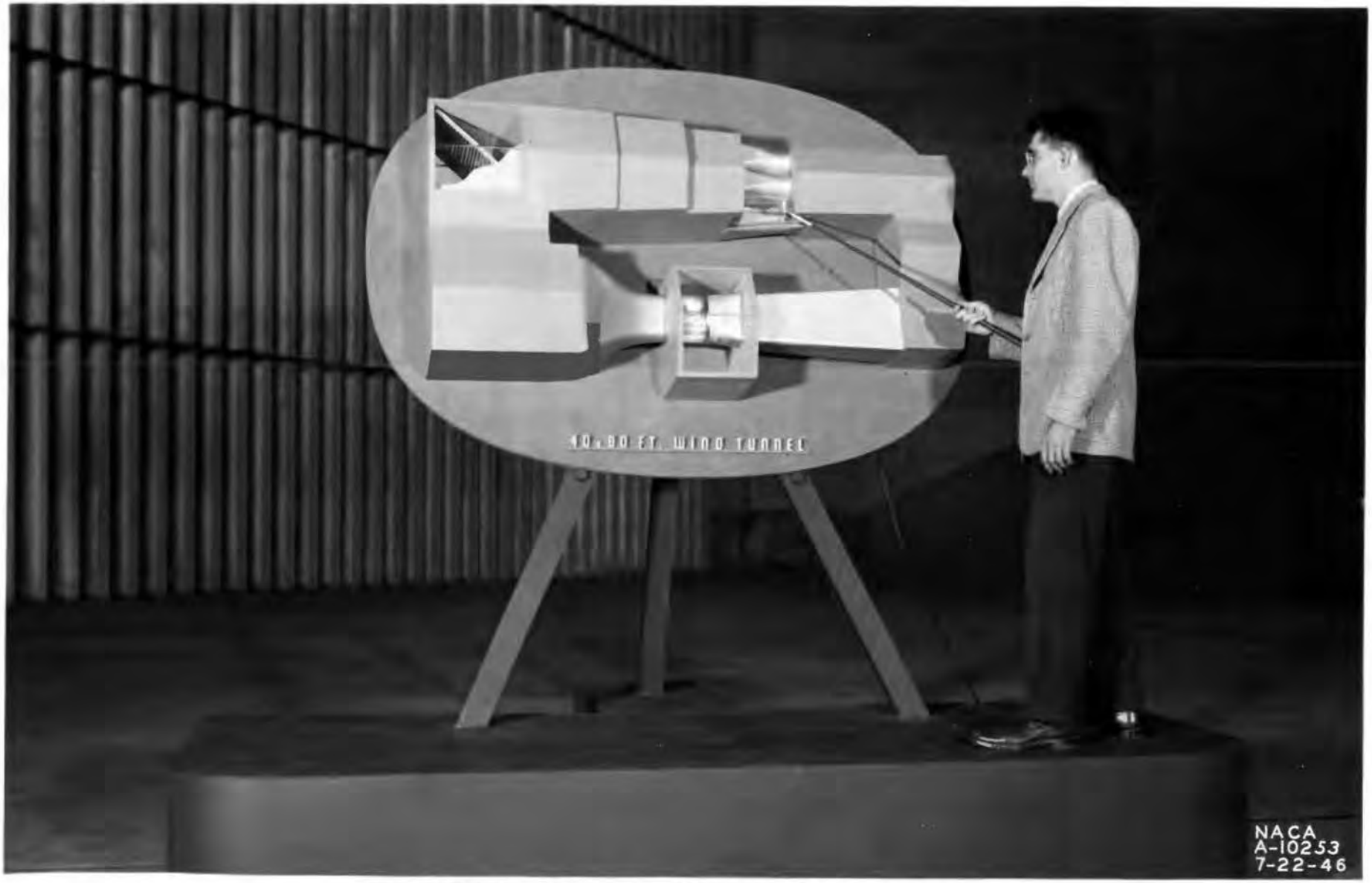
are dictating more and more the final form of airplanes. As the speeds become higher, these forms become increasingly unconventional. As might be expected, the unconventional airplanes show no tendency to act like conventional airplanes during slow speed flight. In fact, it now appears that the landing and take-off periods will be the most hazardous part of the flight of high-speed airplanes. Since high speed requirements preclude the use of ordinary means of easing take off and landing it becomes the problem of the low-speed tunnels to devise new means which will not conflict with high-speed requirements. It is in this field that the full-scale tunnel proves its worth.

In the 40- by 80-foot wind tunnel the many factors controlling the low speed characteristics can be studied with sufficient accuracy on full-scale airplanes to be fairly certain that the airplane can safely take off and land. Without this ability an airplane is certainly worthless no matter what its top speed may be. The delicate balance which must be maintained between the many factors makes a full-scale study desirable if not imperative prior to flight tests. It is apparent then, that the full-scale tunnel is the place in which the answer can best be found to the vital question, will this airplane take off and land safely the first time it is flown?

All operations, including controlling the tunnel, adjusting the airplane and control surfaces to the desired position, controlling the airplane engine and recording the data are performed

from a control house located directly beneath the test section. Airplanes are prepared for investigation on the floor of the test chamber, the large structure surrounding the test section, and are then lifted approximately 110 feet into the air and lowered onto the supporting struts. Access to the normally closed test section is obtained by opening the two 60-ton main doors which form the upper half of the section. One of these doors has been partially opened to show their operation.

Before you leave here to walk through the tunnel may I say a word about the investigation now in progress (fig. 10 (b)). We are measuring the dynamic characteristics of highly sweptback wings. To do this we have found it necessary to design special test equipment. You will have an opportunity to examine this setup when you reach the test section. No formal discussion is planned but engineers will be on hand to answer your questions -- please do not hesitate to make good use of them. Thank you for your attention-- now if you will follow me we will proceed through the tunnel.



(a) Model of the 40- by 80-foot wind tunnel.

Figure 10.- Tour of 40- by 80-foot wind tunnel.

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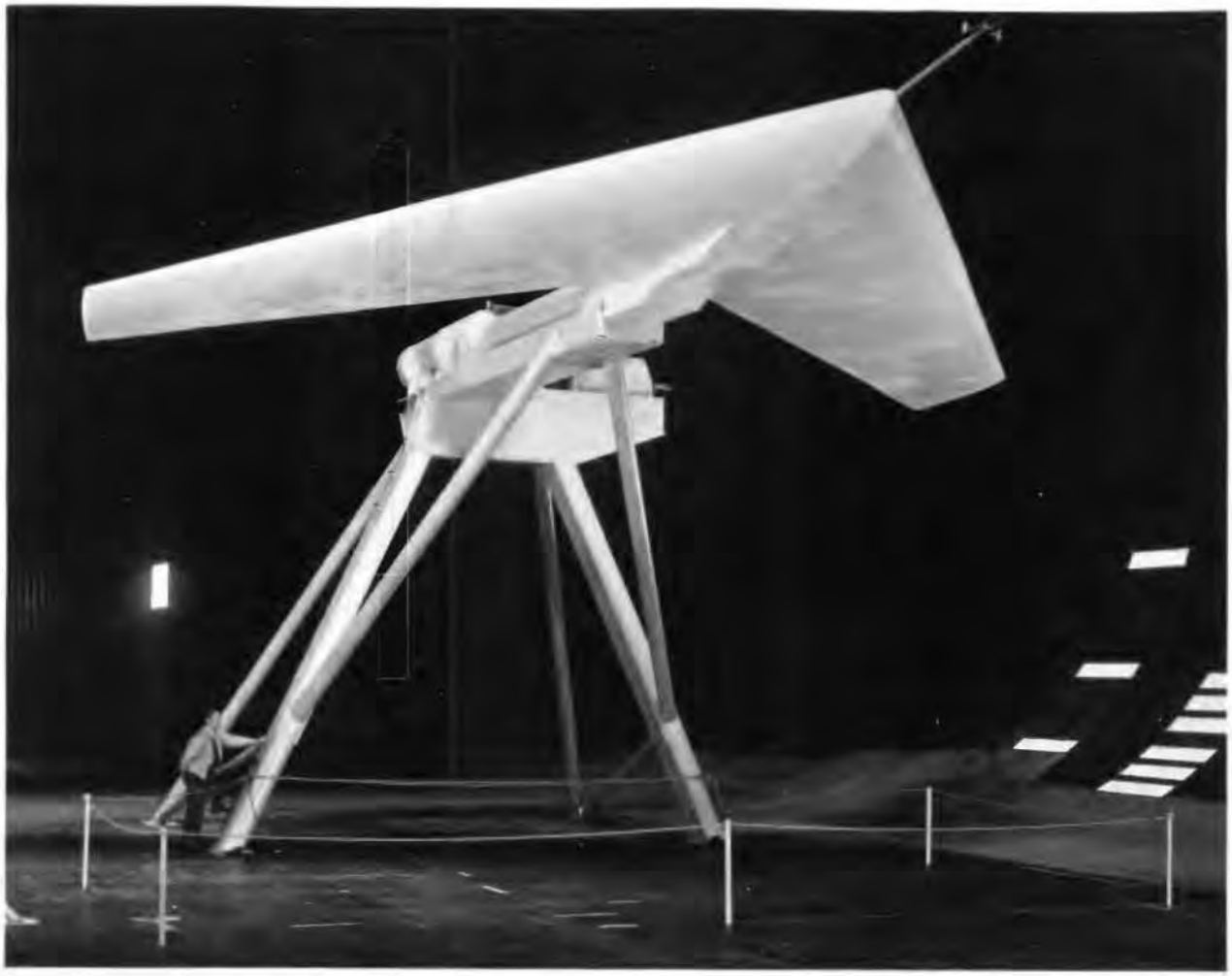

(b) Research set-up in 40- by 80-foot wind tunnel.

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(c) Typical set-ups in 40- by 80-foot wind tunnel.

Figure 10.- Concluded.

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40- BY 80-FOOT WIND TUNNEL TALKS

LOW-SPEED CHARACTERISTICS OF SWEPT WINGS

Gerald M. McCormack or Victor I. Stevens

You are familiar with the fact that as airplanes fly at speeds approaching the speed of sound, they are subjected to phenomena which have been labeled compressibility effects. In the talks at the 16-foot Tunnel and the Flight Research Section you (will) have heard some of the compressibility effects described. There are three main effects: an abrupt increase in the drag of the airplane which acts as a barrier to further increase in speed--an increasing tendency for the airplane to nose downward into an uncontrollable dive--and an extreme unsteadiness of airflow which causes the controls to flutter and the whole airplane to buffet. Methods for eliminating or postponing these effects have been the subject of increasingly concentrated research effort on the part of aerodynamists throughout the world. Perhaps the most spectacular result of this effort to date has been the discovery that the use of a high degree of sweep such as you see on this model is a powerful means of postponing the advent of the compressibility phenomena and their attendant defects. For example, if this airplane (fig. 11(b)) with straight wings suffers compressibility effects at 550 miles per hour, this one with 45° sweepback will not be subjected to them until a speed of 650 miles per hour is reached. The same is true for this airplane on which the wings have been swept forward.

However, such significant gains are not usually realized without penalties. The penalties in this case are the poor low-speed characteristics of swept wings. These poor low-speed characteristics present a serious problem for, although swept wing airplanes are primarily high speed aircraft (intended for flight in the high subsonic and transonic speed ranges), they still must be taken off, landed and flown safely at lower flight speeds just as the more conventional low-speed aircraft.

Due to the radical change in plan form, one might suspect that the low-speed stability and control problems of this swept wing airplane would differ considerably from those of this unswept wing airplane. The old rules of experience with which we could roughly proportion an airplane; for example, that the horizontal tail area should be approximately 20 percent of the wing area--that 60 percent span flaps and 40 percent span ailerons would give a satisfactory balance between landing speed and lateral control--and that approximately 3° of dihedral would give suitable handling characteristics--all must be re-evaluated for the swept wing configurations. Before this re-evaluation can be satisfactorily completed or even started, there must be compiled experimental data on swept wing configurations such as has been obtained in the course of the last twenty years on the unswept wing configurations. For the last six months the compilation of these data has been the main job of the 40- by 80-foot wind tunnel and it is anticipated that it will continue to be so for some time to come.

The research just completed took the form of an investigation of the characteristics of this series of wings (fig. 11(a)). These plan forms, as you can see, are those that would be obtained by rotating a

wing panel of these dimensions through a sweep range from 30° forward to 45° forward, to 30° back to 45° back. The wing you saw in the tunnel is the 45° swept back wing. We have investigated the characteristics of each of these wings with 60-percent-span flaps, full-span flaps and with 40-percent-span ailerons. Whereas the bulk of previous data on swept wings has been obtained at Reynold's numbers of 1/2 to 1 1/2 million, which is far below the normal flight conditions; the data for the present investigation were obtained at Reynold's numbers of 4 to 12 million which duplicates full scale flight conditions. As you will recall, Mr. Jones, in his talk given this morning in the auditorium, pointed out that importance of so matching flight Reynold's number.

I would like to show you the results of our recent investigation and interpret the results for you into the characteristics of a sweptback-wing airplane as compared to an unswept-wing airplane. Before starting, however, I would like to warn you not to look upon this as an investigation completed but merely the first exploratory results of a job which promises to grow bigger as we learn more of the problems which confront us.

Perhaps the most disturbing effect observed in these results was the influence of sweep on the maximum lift--maximum lift being a deciding factor for landing and take-off performance. This chart (fig 11(c)) shows the effect of sweep on maximum lift. This is the maximum lift obtainable on the plain wing and this is the maximum obtainable on the same wing with 60-percent-span flaps. The plain wing loses a considerable amount of lift as the wing is swept.

Furthermore the amount of lift we can obtain by the use of flaps decreases rapidly as the wing is swept. Thus you can see our 45° sweptback wing pays a penalty on two counts, a loss in lift of the plain wing and a loss in lift obtainable by deflecting flaps.

The consequences of this loss in lift in terms of the take-off distance and landing speed of our two airplanes is shown on this chart (fig. 11 (d)). As you can see, our sweptback wing airplane is handicapped 15 percent on take-off run--it should be remembered that considerable trouble is experienced in designing current high performance airplanes to take off from the size fields normally available.

The unswept wing airplane lands at 100 miles per hour, which at present is considered a maximum safe landing speed. In contrast, the sweptback wing requires 120 miles per hour (fig. 11 (d)), an increase of 20 percent. To look at the same problem from another angle--if the unswept wing airplane lands at 100 miles per hour with a weight of 10,000 pounds, then in order to land swept wing airplanes at 100 miles per hour, its weight would have to be reduced to 7,000 pounds, a sacrifice of 3,000 pounds of pay load.

It is apparent from these comparisons that considerable effort will have to be expended to find means for increasing the maximum lift obtainable on swept wings if we are to consider the characteristics possessed by our current high-performance fighters as a reasonable minimum. There is reason to believe that we can decrease the loss in lift due to sweep by the selection of proper plan form. Just what the optimum plan form is for each sweep angle must await settlement by further research.

Perhaps the complications associated with use of full-span flaps, will have to be tolerated in order to achieve this goal. The effect of full-span flaps is shown by this curve. Notice that on a swept-back wing little is gained in going from partial to full-span flaps, but on the sweptforward wing the gain is significant although short of what we desire (fig. 11 (e)).

Other possibilities include slots to delay the stall over the critical portion of the wing, a more refined design of slotted flaps, or the use of boundary layer control which heretofore in conventional wings has not been considered worth the complication it entails. As yet we do not have the experimental data to determine the comparative merits of these various expedients but such data will be the object of our research during the coming year.

The next characteristic of swept wings worthy of examination is the aileron control which is the ability of the ailerons to roll or bank the airplane. The realization of adequate aileron control is made difficult on two counts. In the first place, the aileron effectiveness, or the rolling force produced by the ailerons decreases with sweep, and in the second place the demands placed upon aileron control increases with sweep.

To deal with the first of these, the loss in aileron effectiveness, this chart (fig. 11 (e)) shows for low-speed flight the variation of aileron effectiveness with sweep. We have assigned 100 percent effectiveness to the conventional 40 percent span aileron on the straight wing. Note the loss in effectiveness with sweep. The trend of this curve serves to illustrate one of the benefits of sweepforward.

Observe that with 45° sweepback the effectiveness has dropped to 1/4 of its former value, while with 45° sweepforward the effectiveness has dropped to only half. However, since the aileron effectiveness is appreciably reduced by either sweepforward or sweepback, we can conclude that if we are to maintain aileron effectiveness on swept wings, equal to that on unswept wings, the ailerons will have to be considerably bigger than those we are used to now. Perhaps full-span ailerons or the use of flaps as ailerons will be the answer--but this will have to be determined by future investigations.

And now for the second of the aileron problems--the increased demands placed upon aileron control by sweep. This problem is the result of what is called dihedral effect. As you know, an airplane when sideslipped has an inherent tendency to roll. This tendency can be increased by building dihedral into the wing, and hence the tendency to roll when sideslipped is called dihedral effect.

Sweeping the wing plan form greatly increases this basic dihedral effect in low-speed flight. For example, this airplane (fig. 11 (a)) will have the same tendency to roll when sideslipped as this one with abnormally high dihedral. For a practical illustration--assume that sideslip is encountered in the landing approach--due to dihedral effect there will be a tendency for the leading wing to rise and the pilot must counteract this tendency to roll by deflecting the ailerons. This chart (fig. 11 (f)) shows how sweep affects the amount of aileron deflection required to balance the roll caused by 5° of sideslip. It will require 13° of aileron deflection on this airplane in contrast to 5° on this one. These data are based on the optimistic assumption of equally effective ailerons on both airplanes. But as shown on the

previous chart, the effectiveness decreased with sweep. If this decrease is taken into account, the curve takes this form. The curve is terminated here, since 20° is the maximum effective deflection of ailerons. This means that with normal 40-percent-span ailerons, it will not be possible to maintain rolling control on our 45° sweptback wing if as little as 5° sideslip is encountered in the landing approach. The advantage of sweepforward in this regard shows up once again on this curve as a decrease in required aileron deflection.

Not only must the ailerons be able to maintain the wings in a level or banked attitude, but they must also be capable of rolling the airplane as in a maneuver. In performance of this function the ailerons must produce a rolling force to overcome the inherent damping or resistance to rolling of the wing. On a swept wing the ailerons are aided by the fact that the damping of a swept wing is less than that of an unswept wing. We have measured the damping of the swept wings using the test setup in the tunnel. Typical results are shown in this chart (fig. 11 (g)). This axis is damping, the resistance to rolling is positive in this direction--the wing is stable and resists any roll-negative in this direction--the wing is unstable and tries to roll itself. This axis is speed-decreasing in this direction so that this is the high-speed region and this the stalled region.

Let us first focus our attention on the damping characteristics in the high-speed flight. We can see that the damping of the 45° sweptback wing is about 2/3 that of the straight wings. This reduction is nearly enough to compensate for the reduction in aileron

effectiveness in high speed flight, so that the ailerons on a swept wing should be able to produce about the same rate of roll as the ailerons on an unswept wing.

Looking now at the characteristics in low-speed flight, we find that as stall is approached the damping of the straight wing gradually reduces and finally reverses direction so that the wing is unstable and tries to roll itself. This phenomenon is called auto-rotation. We are familiar with its consequences--the well-known spin. As shown on this chart, our data on swept wings are incomplete in the stalled region but preliminary analysis of the data thus far obtained indicate that the sweptback wings should have somewhat less tendency to spin than straight wings. As this investigation proceeds we will obtain data which define these characteristics accurately for both sweptback and sweptforward wings.

To summarize--it is a known fact that significant gains in maximum speed can be realized by sweeping the wing plan form. However, any airplane, in order to be practical, must take off and land safely; therefore the poor low-speed characteristics of swept wings present major problems. Today we have discussed the most serious of these fundamental problems.

1.) The take-off run must be reduced

2.) The landing speed must be reduced

3.) The aileron control in low speed flight must be improved

Other problems may arise as the investigation proceeds. The development of means to combat these problems will be to a large

extent the job of this tunnel during the coming year. When you come back to us on the annual inspection next year, you will be able to judge how effectively we have done this job by the degree of positiveness with which we can give you the answers.

And now I would like to present Mr. Anderson (or Wick) who will talk to you about another phase of the research conducted in the 40-by 80-foot wind tunnel during the past year---Mr. Anderson (or Wick)---

PROPELLER BLADE TWIST

Adrien E. Anderson or Bradord H. Wick

A portion of the work in this tunnel during the past year has been devoted to the study of full-scale propeller operation. You may ask: why worry about propellers when the emphasis today is on the jet and rocket-propelled transonic and supersonic airplanes of the future? The answer is that, even in the future, the majority of airplanes will travel at subsonic speeds where the propeller is the most efficient form of propulsion. At the present time, the propeller is unexcelled for speeds up to 500 miles per hour. With the advent of the gas turbine, the future holds the promise of even higher speeds for propeller-driven aircraft.

It is not amiss, therefore, that we bring to your attention today a factor that deserves consideration not only in the development of future propellers but also in the improvement of present propellers. This factor, propeller blade distortion, came to our attention during a compressibility investigation of a propeller being used on a Navy torpedo-bomber. Subsequent study of propeller blade distortion showed that it ranked in importance with compressibility in knocking down the thrust output of propellers at moderately high flight speeds.

For a better understanding of what we mean by propeller blade distortion, consider this propeller blade. A propeller has this twisted shape built into it so that each section along the blade may operate at its optimum condition. The problem that arises is,

that the forces acting along the blade of a rotating propeller tend to distort this twisted design shape, causing the blade sections to operate at less than optimum conditions. There are two kinds of forces involved: aerodynamic forces, which tend to bend the blades forward and to untwist them, and the centrifugal forces which oppose but are not able to reverse this movement. The resultant distortion is composed, therefore, of a forward bending and an untwisting of the blades. It is this twisting distortion, that caused the blade sections to no longer operate at optimum conditions.

In order to determine the actual amount of twisting distortion, we made use of small 1/4 inch square mirrors glued along the back of one of the propeller blades. We hope, by means of this model (fig. 11 (a)), to give you a demonstration of the method used. A light source was placed down near the floor of the tunnel and directed toward the mirrors which reflected it to one of the windows on the opposite side of the tunnel. In this model we have again reflected the light so that you may see the light spot on the ground-glass panel. Let me explain that as the propeller blade twists the light travels across the window, in this case the glass panel, the magnitude and direction depending on the amount and direction of the blade twist. If, when the propeller is rotating, we measure the amount of deflection of the light beam from its static position, we are able to determine the amount of twist of the propeller blade. There doesn't appear to be much twist here, but for the actual propeller 1° of twist caused a light movement of roughly 30 inches.

We found that as we increased the propeller speed, the blade would tend to untwist itself proportionately along the blade, untwisting, in some cases, as much as 1 1/2° at the tip.

Now let us see what effect propeller blade twist has upon performance. On this chart (fig. 11 (h)) we have attempted to represent graphically the relative performance of a Navy torpedo-bomber operating at normal power with three different propeller conditions. The performance characteristics considered are: climb and high speed. Looking first at the high-speed performance, we find that the airplane operating with the actual propeller, which suffers from the effects of both twist and compressibility, has a top speed of 330 miles per hour. If the propeller were affected only by compressibility, i.e., if the effects of the blade twist were eliminated, the speed would be increased 12 miles per hour. And thirdly, if we eliminate both twist and compressibility the speed is upped an additional 17 miles per hour. So we can see that the speed loss due to blade twist is nearly as great as that due to compressibility, 70 percent in fact.

Similar conditions prevail for rate of climb. As shown here (fig. 11 (h)), the effect of blade twist is again equal to about 70 percent of the effect of compressibility.

If other propellers of recent design are suffering blade-twist losses comparable to those for this propeller, it is certainly apparent that the problem of eliminating or reducing these blade-distortion losses demands equally as much attention as the compressibility problem. As we go to airplanes of higher speeds, the performance

losses due to blade distortion may be expected to increase proportionately with the top speed of the airplane. With the introduction of turbine drives, and still higher forward speeds, propeller designers are considering the use of sweptback propeller blades to delay the detrimental effects of compressibility. But sweptback propeller blades will inherently suffer greater blade distortion than ordinary blades. Therefore, if we are to obtain the maximum advantage of sweptback blades, means must be found for counteracting the effects of blade distortion.

How can we counteract these effects? The obvious answer is to predistort the blades; in other words, build into the blade design the amount of twist necessary to counteract the anticipated distortion at the desired operating condition. The difficulty in applying this solution is in knowing how much predistortion is required.

This, then, is the problem we face in eliminating the propeller blade-distortion losses for present-day propellers, and in preventing these losses for future designs. To solve this problem, further experimental and theoretical investigations are necessary. The performance results which we have presented, indicate that the dividends will be well worth the investment.

(a) General view.

Figure 11.- Forty- by eighty-foot wind tunnel talks.

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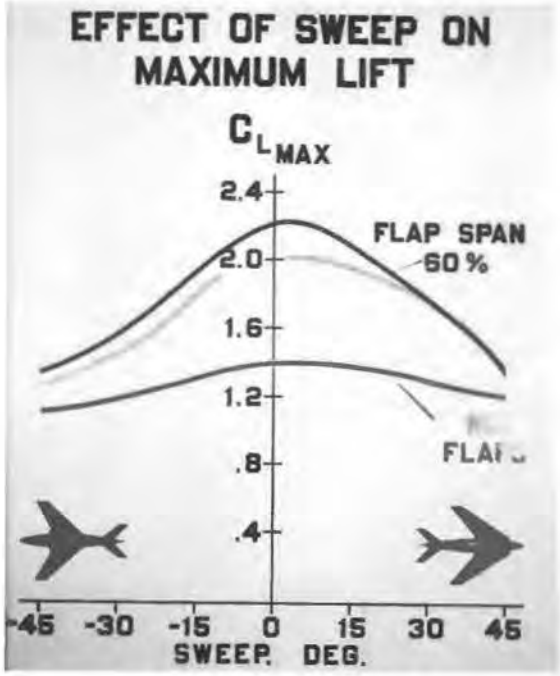
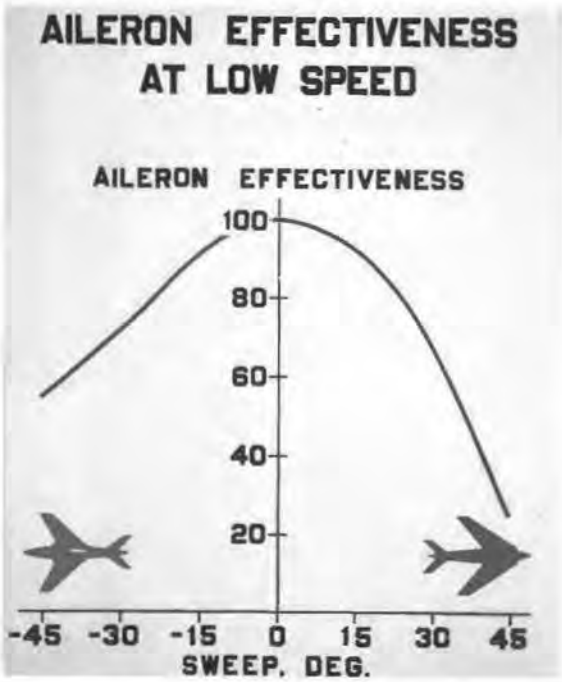
(b) First chart.



(c) Second chart.

(d) Third chart.



(e) Fourth chart.

Figure 11.- Continued.

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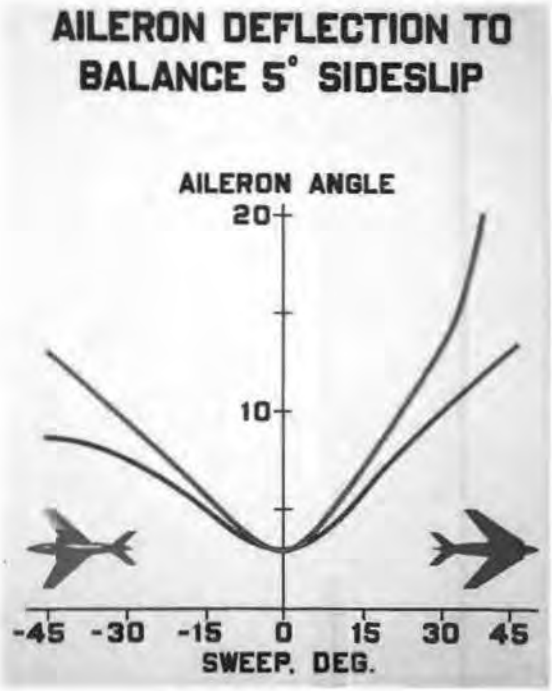
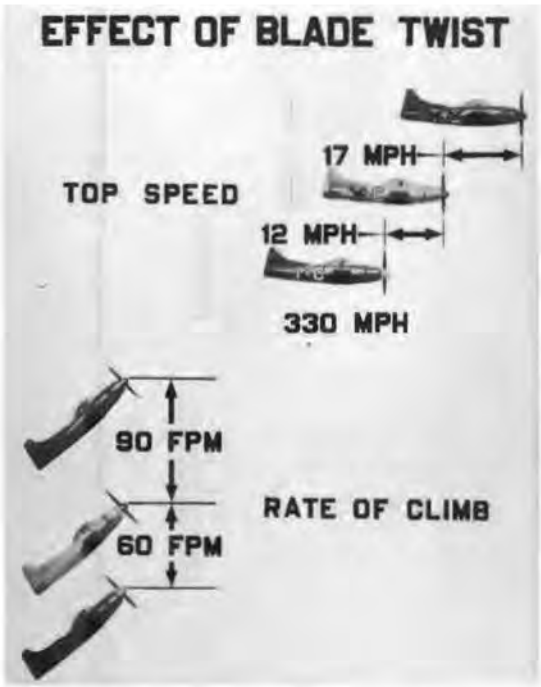


(f) Fifth chart.

(g) Sixth chart.



(h) Seventh chart.

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Figure 11.- Concluded.

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Figure 12.- Model motors.

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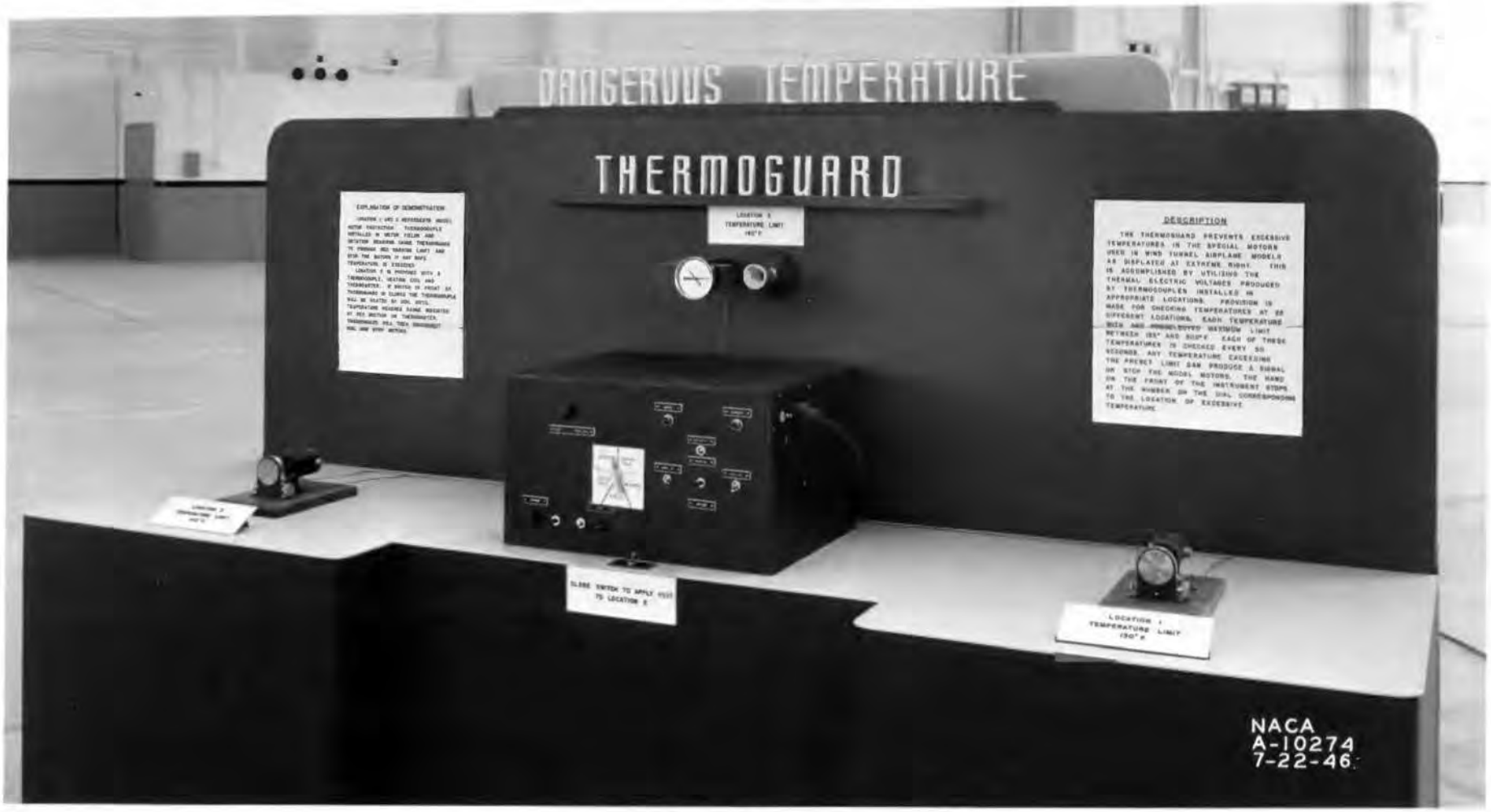

(a) Thermoguard.

Figure 13.- Instrument display.

(b) Optical deflection recorder.

(c) Heat flow meter.

Figure 13.- Continued.

(d) Strain gages.

(e) Airspeed cell, recording accelerometer, gyro inclinometer, trailing airspeed head.

Figure 13.- Concluded.

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