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4. DESCENT CAPABILITY OF TWO-PROPELLER TILT-WING CONFIGURATIONS

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SUMMARY

The wing stall problem encountered with tilt-wing V/STOL designs during low-powered descent flight conditions has led to buffeting which adversely affects both performance and handling qualities. The results of tests conducted in the Langley full-scale wind tunnel with a large semi-span model of a two-propeller tilt-wing configuration have indicated that three important factors provide substantial improvement in the wing stall characteristics with consequent improvement in descent capability: down-at-center propeller rotation resulted in delayed inboard stalling and provided far better descent capability than the up-at-center rotation, moderate lowering of the propeller position relative to the wing chord provided further improvement in descent capability, and some flap deflection was absolutely essential in order to have any descent capability for low-powered flight conditions. Use of all three factors should provide good descent capability even without the complexity of other sophisticated stall control devices.

Author

4

INTRODUCTION

One of the main problems encountered with tilt-wing V/STOL designs has been wing stall during transition flight. This problem has been particularly true during the low-powered descent conditions. The wing stalling problem is serious because it has adverse effects on both performance and handling qualities as was experienced on the basic VZ-2 aircraft as discussed in references 1 to 4. Improvement of the VZ-2 wing stall characteristics was achieved by various modifications such as leading-edge slats and trailing-edge flaps but further improvement was considered very desirable. Subsequent research by NASA and private industry with small-scale models has defined the problem areas of the wing stalling phenomenon and more clearly indicated the effects of pertinent design variables. (For example, see refs. 5 to 9.)

DISCUSSION

Some of the factors affecting the onset of wing stalling for a two-propeller tilt-wing configuration are illustrated in figure 1. In the course of making a transition from forward flight to hover it is necessary, of course, for wing incidence to be varied from 0° to 90°. Without the effects of the propeller slipstream over the wing, complete stalling would result for the greater part of the wing incidence range. However, the propeller slipstream produces a chordwise flow component over the wing and, thus, tends to keep it from stalling in that area submerged in the slipstream. Two other areas are involved which are subject to stalling: one is inboard and one is outboard of the contracted propeller slipstream. The crosshatched area inboard of the propeller slipstream stalls at relatively low tilt angles because it is unprotected. The area at the wing tip outboard of the slipstream would also stall at low tilt angles except for the effect of the tip vortex due to lift which has a very strong influence on delaying tip stall. Under descent flight conditions the wing stalling problem is further aggravated because of one additional factor. As power is reduced to set up the descent condition, the propeller slipstream velocity is consequently decreased; therefore, the wing is subjected to substantially higher angles of attack than it would be for a corresponding level-flight case.

A photograph of a large-scale semispan tilt-wing model mounted for testing in the Langley full-scale tunnel is presented as figure 2. This model is being used to study the wing stalling problem on tilt-wing configurations as well as to provide quantitative design-type data on the effect of a number of configuration variables. The model has a boiler plate wing structure to support the propeller, various wing contours, and flap arrangements. Eventually the investigation will provide data for both two- and four-propeller configurations. The tufts which were used to detect local stalling are visible in the photograph.

The problem of predicting the descent capability of full-scale airplanes from wind-tunnel data requires careful interpretation because local stalling which could cause buffeting and adversely affect handling qualities does not always show up in the wind-tunnel force test polars. Therefore tuft photograph studies have to be used to detect such local stalling to correlate descent capability with force test data. For the velocities of interest in the descent flight region, separated flow on the aircraft fuselage or wing center section are unlikely to have appreciable buffeting effects because of the low energies involved, although some work has been directed toward minimizing the effects of these separated flow regions. When separated flow occurs within the propeller slipstream, however, severe buffeting might be expected because these disturbances are being felt at relatively high dynamic pressures. Therefore, the criterion for defining the maximum descent capability in these tests is taken as the largest descent angle that can be achieved without encountering flow separation on the wing anywhere within the propeller slipstream.

A number of wing and flap designs for two-propeller configurations have been investigated at Langley with the large-scale model shown in figure 2 (refs. 10 to 13), and the work accomplished to date is summarized in table I. Experience has shown that tilt-wing designs tend to have more wing area than is required for cruise because of the problem of trying to keep the wing from stalling in the transition range. When the model of the present investigation was designed, it was thought that a ratio of wing chord c to propeller diameter D of at least 0.6 would be required to obtain adequate descent capability and the program was designed around that ratio. The model was tested first with a ratio of wing chord to propeller diameter of 0.6 with Fowler flaps in one series of tests (ref. 10) and with single-slotted flaps in another series of tests (refs. 11 and 12). The results of these tests were good enough to justify a reduction in wing size so that the next series of tests were conducted with a ratio of wing chord to propeller diameter of 0.5 with both double- and single-slotted flaps. The results of tests with double-slotted flaps are presented in reference 13. These results are also encouraging and therefore the next tests in this continuing series will be made with an even smaller wing having a ratio of wing chord to propeller diameter of only 0.4 with a single-slotted flap. The rest of this paper deals with the low-speed performance that has been achieved in this investigation in terms of descent capability for the $c/D = 0.5$ wing with a single-slotted flap, and the effects of the design variables given at the bottom of table I are illustrated.

The effect of propeller rotation is illustrated in figure 3 where stall boundaries are presented in terms of flight-path angle γ plotted against thrust coefficient $C_{T,s}$ for both modes of rotation, up at center and down at center. These are the stall boundaries that were obtained from the tuft studies according to the criterion previously established. Positive values of γ indicate climb conditions, whereas negative values represent descent conditions. For combinations of $C_{T,s}$ and γ above a boundary the conditions are satisfactory, whereas for combinations below a boundary, local stalling has occurred. A value of $C_{T,s}$ of 1.0 corresponds to the condition of zero velocity or hovering flight, whereas values of 0.6 to 0.9 correspond to flight in the transition range which is the real region of interest for the descent flight conditions. The data show that wing stall can be experienced even in the climb condition for the up-at-center propeller rotation over the transition flight range. The reason for this stalling is illustrated by the sketch in the upper right of figure 3. With up-at-center propeller rotation, the flow from the propeller is such that the area inboard of the nacelle is subjected to higher angle of attack, thereby increasing stall in this region, while at the same time the area at the wing tip (already protected by the tip vortex) gets further protection as a result of the lower angles of attack induced by the slipstream rotation. With down-at-center propeller rotation, a marked improvement in descent capability is achieved in the transition range of thrust coefficients because of delayed inboard stalling. The reason for this reduced stalling is illustrated by the sketch in the lower right of figure 3 where for down-at-center propeller rotation the flow from the propeller is in the proper direction to reduce the stalling tendency inboard of the nacelle, whereas the strong wing-tip vortex still tends to keep the area outboard of the nacelle from stalling. These, and other similar results, indicate that down-at-center propeller rotation should be used unless there are otherwise good reasons for not using it. Direction of propeller rotation might become a trade-off factor when considering cruise performance, for example.

The effect of propeller position in relation to the wing is illustrated in figure 4. Small-scale work by the Vertol Division of the Boeing Company (refs. 8 and 9) has indicated an important effect of propeller position which led to the study of the propeller positions indicated in this figure, which are referred to as the high, mid, and low positions - 2.5 percent propeller diameter above the wing chord line and 5 and 10 percent below the wing chord line. These positions were all roughly 22 percent propeller diameter ahead of the wing leading edge which approximated the better locations indicated from the small-scale tests. The descent boundaries shown here are for the basic wing with flap deflected 20° and with down-at-center rotation. The descent boundary for the mid propeller position is the same as that for the down-at-center rotation in figure 3. The results show a progressive improvement in descent capability throughout the thrust coefficient range with lowering of the propeller position.

The effect of flap deflection is illustrated in figure 5 where results are presented for various flap deflections δ_f with the propeller position and direction of rotation that were shown to be most favorable - low position and down-at-center rotation. The most notable point is that some flap deflection is absolutely necessary in order to have descent capability for other than the higher thrust coefficients as indicated by the fact that there is no descent capability for much of the thrust coefficient range for the zero-flap-deflection boundary. Flap deflection of 20° provides very good descent capability even without other stall control devices.

The investigation included a number of other stall control devices such as inboard fences and leading-edge slats as illustrated in figure 6. These are the logical "fixes" to try to improve the disturbed flow inboard of the nacelle, especially to prevent the stalled flow on the wing center section from spreading and triggering stall of the area inside the propeller slipstream. Results indicated, however, that these devices gave second-order effects compared to the three major factors discussed previously - that is, propeller rotation, propeller position, and flap deflection. In general, the main effect of this increased sophistication was to provide increased lift capability with only a slight improvement in the descent capability.

CONCLUDING REMARKS

Good descent capability is possible for a wing of relatively low ratio of chord to propeller diameter, even without other stall control devices, providing that a low propeller position in combination with down-at-center propeller rotation is used. Improved lift capability and somewhat improved descent capability may be achieved through the use of leading-edge and other stall control devices. The practicability of further reduction of wing size in combination with relatively simple flaps is indicated.

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TABLE I

CONFIGURATIONS TESTED

FLAP TYPE	WING CHORD/PROPELLER DIAMETER			
	c/D = 0.7	c/D = 0.6	c/D = 0.5	c/D = 0.4
SINGLE SLOTTED		√	√	
DOUBLE SLOTTED			√	
FOWLER		√		

1. PROPELLER ROTATION
2. PROPELLER POSITION
3. FLAP DEFLECTION
4. LEADING-EDGE SLATS
5. UPPER-SURFACE FENCES

FACTORS AFFECTING WING STALL
TWO-PROPELLER CONFIGURATION

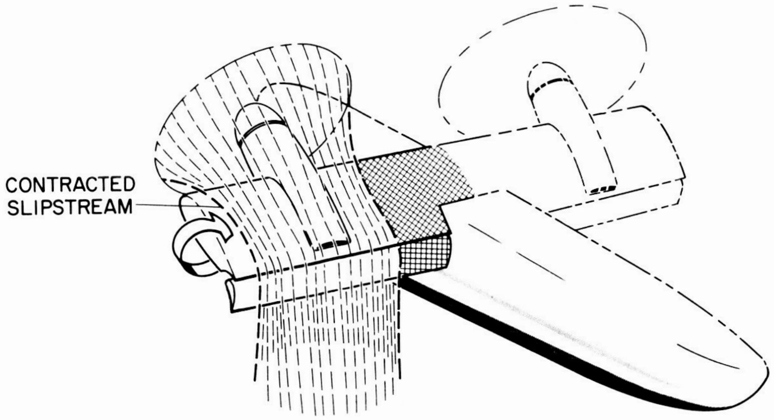

Figure 1

LARGE-SCALE TILT-WING MODEL

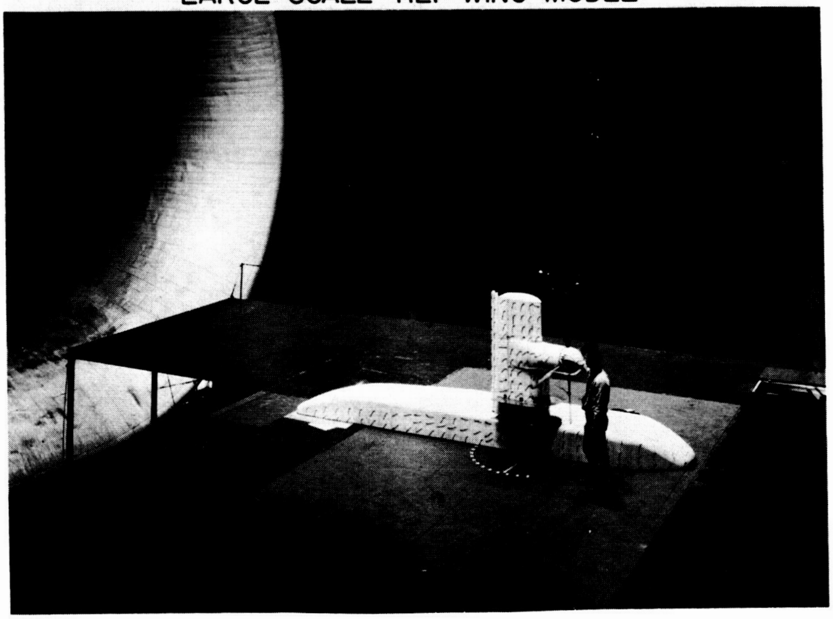

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Figure 2

EFFECT OF PROPELLER ROTATION

MID PROPELLER POSITION; $\delta_f = 20°$

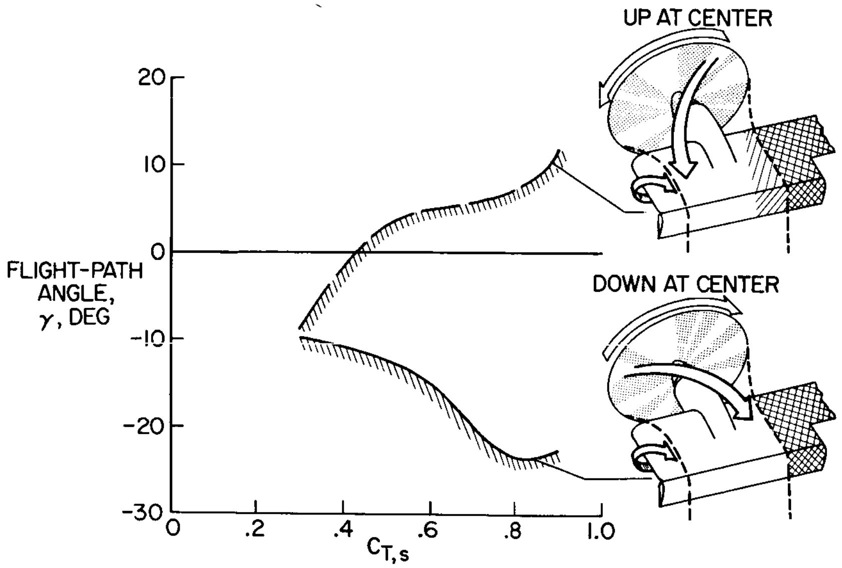

Figure 3

EFFECT OF PROPELLER POSITION

DOWN-AT-CENTER ROTATION; $\delta_f = 20°$

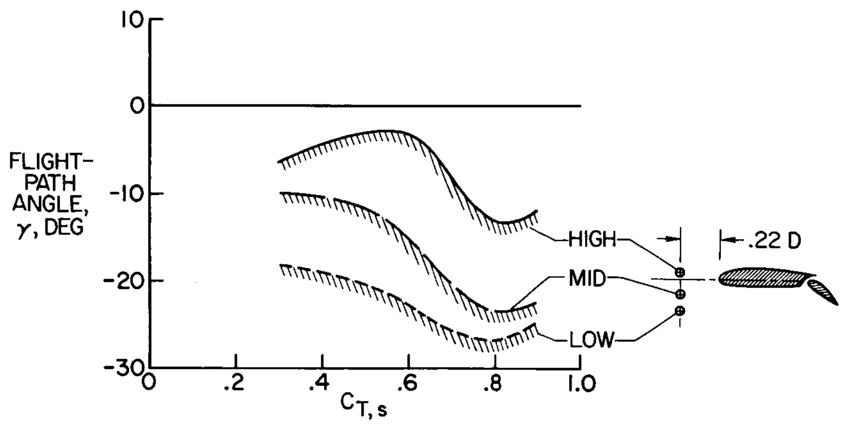

Figure 4

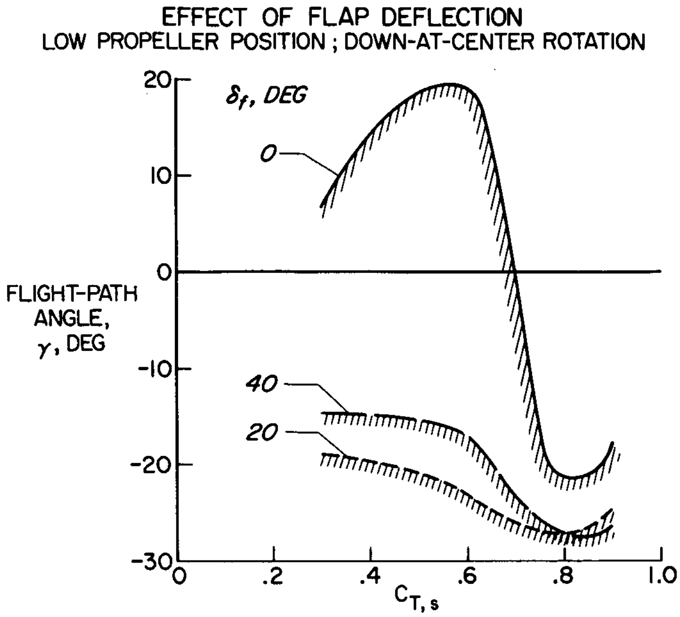

Figure 5

FENCES AND LEADING-EDGE SLATS

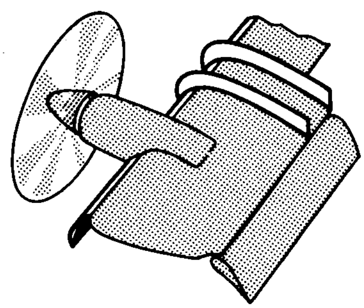

Figure 6