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HOVER TESTS OF A MODEL H-FORCE ROTOR

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1. Abstract

The potential of using tip vanes at the ends of helicopter rotor blades to obtain a controllable H-force is considered. The addition of vanes placed perpendicular to the blade tips can be used to obtain an inplane force. By varying the angle of the vanes, a radial force can be created which can be controllable in azimuth position. Such a force could be used to provide translational motion of the rotor and aircraft without the requirement for rotor tilting. In addition, an H-force generated at high flight speed could be used as a propulsive force in a matter similar to a propeller. The force generated by the vanes could also affect the aircraft's stability characteristics. The H-force could also modify rotor performance in hovering since they could be thought to act as a virtual shroud.

Tests have been run with a model rotor which has a 6 foot diameter with a 3-inch chord blade. Test data are presented on the effects of various tip-vane configurations on the hovering Figure of Merit. The extreme sensitivity of the performance to vane arrangement is shown.

2. Introduction

The use of vanes located at the wing tips of fixed wing aircraft has been studied extensively since the early days of aviation and has recently received intensive study by Whitcomb of NASA (1). Actual production installation of such vanes in the form of winglets has occurred with the Learjet and the Lockheed L-1011. In these cases, the primary motivation was the attempt to obtain improved aerodynamic efficiency by achieving effective higher aspect ratios.

In the present work, the application of tip vanes to helicopter rotors has been motivated primarily because of considerations other than any effective aspect ratio gain. If tip vanes are suitably incorporated on rotor blade tips and are oscillated to vary their radially directed force, then they can provide a controllable in-plane or H-force(2). Such an H-force could be used as propulsive means for the helicopter,

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replacing a propeller as a means of providing additional forward thrust. In addition to its use as a high speed propulsive device, the controllable vanes could be used to provide an independent control to improve helicopter maneuverability at low speeds, such as in nap-of-the-earth flight.

3. Background

The initial concept of using oscillating tip vanes was first put forth by Pemberton Billings in a design concept proposed in 1934 for a side-by-side configuration helicopter(3). Although no actual aircraft was fabricated, the concept of using such tip vanes was clearly shown. The use of oscillating airfoils to provide lift and propulsion was under considerable study during that period for use in aircraft as cyclegyros and as replacements for the propellers for tugboats(4,5,6,7). Recent considerations of the use of tip vanes applied to rotors may be found in references 2 and 8.

In the previous reported study of the H-force rotor, the potential gain in helicopter speed is indicated through the presentation of the changes in angle-of-attack distribution on a rotor with the addition of auxiliary propulsion. As has been shown repeatedly in many prior studies, such auxiliary propulsion can reduce the angles of attack on the retreating side of the disk to a significant extent and thus increase the speed potential of the rotor.

4. Operation of the Tip Vanes

Figure 1 depicts a tip vane on a rotor. The vane is shown schematically in a vertical position located above the blade surface. The vane can pivot as shown. Figure 2 shows the coordinate geometry of a vane as viewed from above the rotor. During operation, it is necessary to both orient the vane along the resultant airstream, and to provide a suitable angle of attack around the azimuth to obtain the desired force variation. Several control laws have been considered, but since it is not the purpose of this paper to review the vane control, details may be found in reference 2.

One can also view the vanes located at the tips of a rotor as providing a virtual shroud. If one considers Kuechmann and Weber(9), it can be noted that an increase of over 50% in thrust can be achieved for a given power. If the view is taken that the control volume of fluid acted upon by the rotor sees a time averaged vane force similar to that of a shroud, then one could expect a significant modification to the flow field and the thrust of the rotor. To determine if shroud effects could be achieved and to determine the drag penalties in hover when using tip vanes, a series of model rotor tests were initiated using the model rotor hover stand at the Ohio State University.

Before the tests were actually started, it was learned that Van Holten had conducted analysis and tests of tip vane concepts aimed at improving wind turbine performance (10,11,12). In Van Holten's work, he predicted analytically that certain "T" shaped vanes could markedly alter the wake of an actuator disk in axial motion. He predicted a large wake expansion and a potentially large gain in static thrust performance. His work showed that the time-averaged results of rotating vanes would be essentially the same as for a stationary shroud.

As a result of the review of Van Holten's work, the model rotor tests planned were revised so that the tip configuration would resemble the configuration indicated in that work. The configuration chosen was a vane placed at the tip with half its span above and half its span below. In some configurations, the upper tip was canted inboard, and the angle of incidence was varied from nose inward to nose outward. The selection of angle of incidence was chosen based upon the tip vortex considerations of Whitcomb as well as Van Holten's work.

5. Experimental Arrangement

The tests were conducted on a helicopter rotor hover test stand that is driven by two 8 horsepower air motors. It is equipped with strain gauge flexures for measuring thrust and torque. Because of the need for very high accuracy and repeatability in these tests, the entire measurement system was reworked and recalibrated using dead weight tests. Thrust calibrations were made both with and without rotation. Rechecks of the calibration slopes are made repeatedly throughout the model tests. Rotor speed is measured by means of a magnetic pickup sensing a 56 toothed gear and a digital counter. Thrust and torque data are considered accurate to within ±2% and RPM to within ±1%. It must be noted that thrust measurements for a rotor normally are valid only for the particular hover stand used, and in no way can be considered as truly absolute values.

The rotor model tested had two blades with 3-inch chord and a diameter of 6 feet. The base rotor had tips that were simple rounded airfoil shapes. When any particular vane arrangement was tested, the plain rounded tip was removed and the vaned tip put in place. Every attempt was made to minimize any variations except for the changed tip. The airfoil used was NACA 0015.

The tip vanes were of two general types. The first one used a "T" configuration mounted at midspan to the blade tip. These vanes were 7 1/2 inches long with airfoil chord of 3 inches, an adjustable tab of aluminum 3/4 inch wide along the length of the vane, and had a base airfoil, NACA 0015.

The second tip vane used was of a semi-span type, 3-inch chord with no tab, and 3 1/2 inches long. It could be run in the upper or lower position. It was of the configuration shown in Figure 1.

The various actual configurations are shown schematically in Figure 3.

The rotors were run at a series of blade angles—0, 3, 6, 9, 12, and 15 degrees, at rotor speeds of 540, 560, and 580 RPM. Although it is recognized that the resulting Reynolds numbers are low, it is believed that the relative data between the various configurations will be meaningful.

In addition to the 3-inch chord rotor used in the tip vane tests, data will also be presented on a reference 4-inch chord, 6 foot diameter rotor which has been used to check the performance of the test stand.

The configurations initially tested used "T" shaped tip vanes. The configurations used followed the arrangements considered by Van Holten for wind turbines(10). The amount of tip slant and angle of incidence is shown for each test case indicated. All data are presented in the form of Figure of Merit versus CT/σ. Following the initial work with the "T" shaped vanes, tests were then run with the semi-span vanes located above and below the rotor.

6. Experimental Results

The initial data shown are for the reference rotor, 4-inch chord, 6 foot diameter untwisted, Figure 4. The performance of the model rotor used for tip variations is shown in Figure 5 where the Figure of Merit data are shown for the blades with a plain rounded tip. These data were re-run several times and were found to be quite repeatable. The reference rotor has a peak M=0.56 and the vaneless H-rotor has a peak of M=0.50. Such low values are the result of both these rotors being untwisted, operating at low N_r, with 0015 airfoils. Since the purpose of this work is to study changes, the absolute values are not considered to be critically important.

Test results of the "T" vane configuration with two blades are shown in Figures 6 through 13. Various amounts of tip slant and angle of incidence were used. The actual conditions are shown on each figure. As can be seen from the figures, drastic reductions in Figure of Merit occur in almost every case. Even the configurations wherein the tips are canted inward at the top, as suggested in the wind turbine work, show great reductions in performance. It is believed that significant flow separation occurs in the junction between the blade and the tip. It is apparent that the drag and lift losses are severe. At best, the drags caused by the "T" tip cause losses much greater than those predicted by the effect of tip drag on torque.

Figures 14 through 16 indicate the results using a tip vane located above the blade tip. Figure 14 is the case of the vane at no angle and the results show a significant improvement over the "T" vanes, although it still falls far short of the same rotor without vanes. Figure 15 shows the case with the leading edge angled outboard at 3 degrees and some improvement can be seen. Figure 16 shows a case where the tip is angled inboard at 10 degrees. The results show poor performance. These three cases were two-bladed rotors. It was believed that much of the poor performance was due to boundary layer interactions. To attempt to minimize adverse pressure gradient effects, the tip vanes were then placed below the rotor.

Figures 17 through 20 illustrate the results with the two-bladed rotor with the tip vane in the down position. Examination of figure 17 reveals the interesting result that the Figure of Merit is greatly improved over the other configurations with tip vanes. It can be noted that this configuration is actually considerably better than the same rotor without tip vanes. The peak value of M is above 0.56, as compared to 0.50 for the vaneless case. It is apparent that not only is the viscous drag effect apparently reduced, but some form of thrust augmentation must occur. These data were re-run several times to verify the findings and the results were repeatable. Figures 18 through 20 show the results of changing the angle of incidence of the tip vane, and it can be seen that a reduction in performance results.

Following the tests with the two-bladed tip down rotor, the decision was made to run a series of model rotors with single blades. This would allow variations of blade tip shape to be made most readily. A suitable counterweight was incorporated. Figure 21 illustrates the results with a single blade with the plain rounded tip. It provides a reference. It can be seen that the peak Figure of Merit is reduced from a two-bladed value of $M=.5$ to a value below 0.4. Next the tip-down configuration was installed and tested as a single blade arrangement. The results are shown in Figure 22. It can be seen that a remarkable increase in Figure of Merit has occurred. Because of this unusual behavior, the tests have been repeated several times. A second set of results are shown in Figure 23.

Examination of Figures 22 and 23 reveal that the Figure of Merit has increased greatly. It is apparent that some form of "virtual shroud" action is taking place. Calculations reveal that the increase in performance is within the theoretical predictions as originally obtained from considerations of Kuechmann and Weber.

7. Conclusions

It is believed that tip vanes suitable for use as H-force generators can be developed which not only minimize hover losses, but can actually provide hovering performance gains. A word of caution is offered, however. Most of the data presented indicate that the phenomena involved are very sensitive to small changes in configuration. Slight changes could lead to significant reductions in performance rather than any gain.

8. References

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3. "Anon" The Pemberton Billing Durotofin The Aeroplane, Nov. 24, 1934, page 657-658.

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9. Credits

I would like to acknowledge the considerable effort that Mr. T. Parker, a graduate student in Mechanical Engineering, provided in the conduct of the tests reported in this paper.

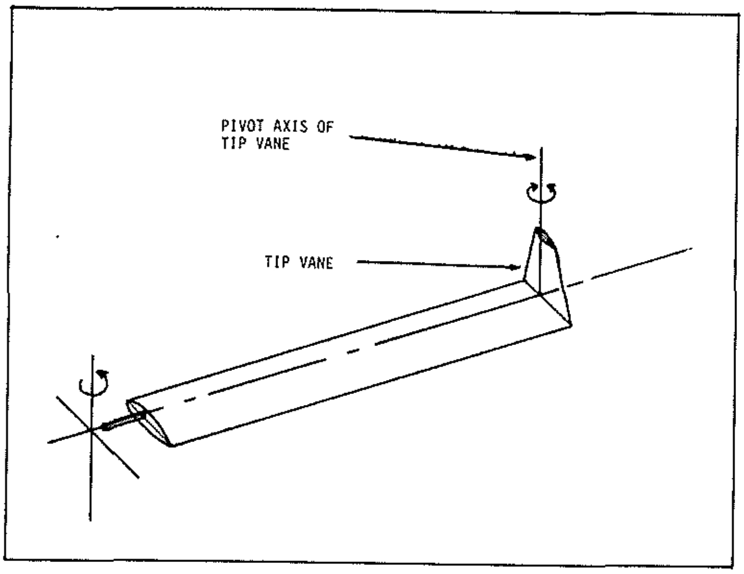

Figure 1. Arrangement of the Tip Vanes on a Rotor Blade.

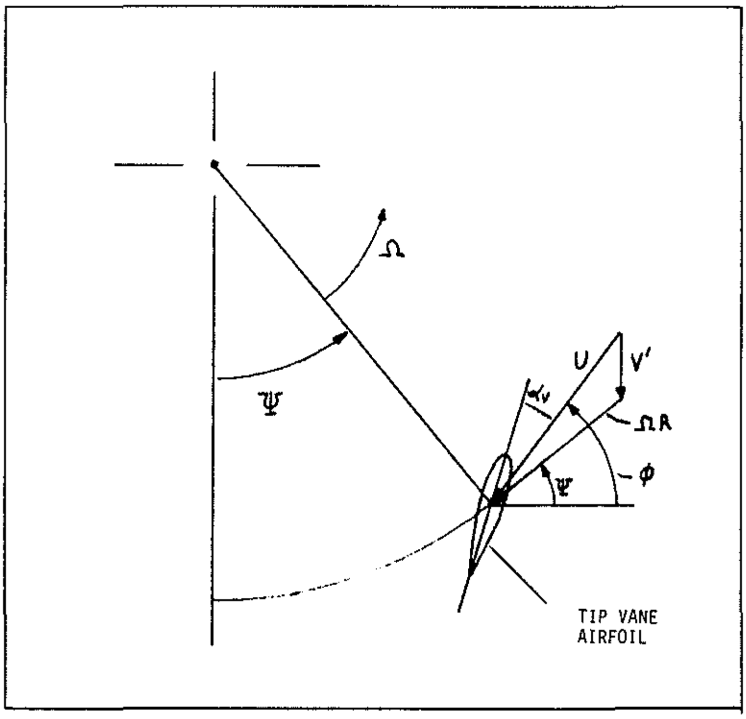

Figure 2. Flow Velocities and Angles at a Tip Vane Airfoil. Where:

V^1 - Resultant horizontal velocity along flight path
U - Resultant horizontal velocity at the vane airfoil
αv - Angle of attack of the vane
ψ - Rotor blade azimuthal position
ϕ - Geometric angle of the resultant velocity, V.

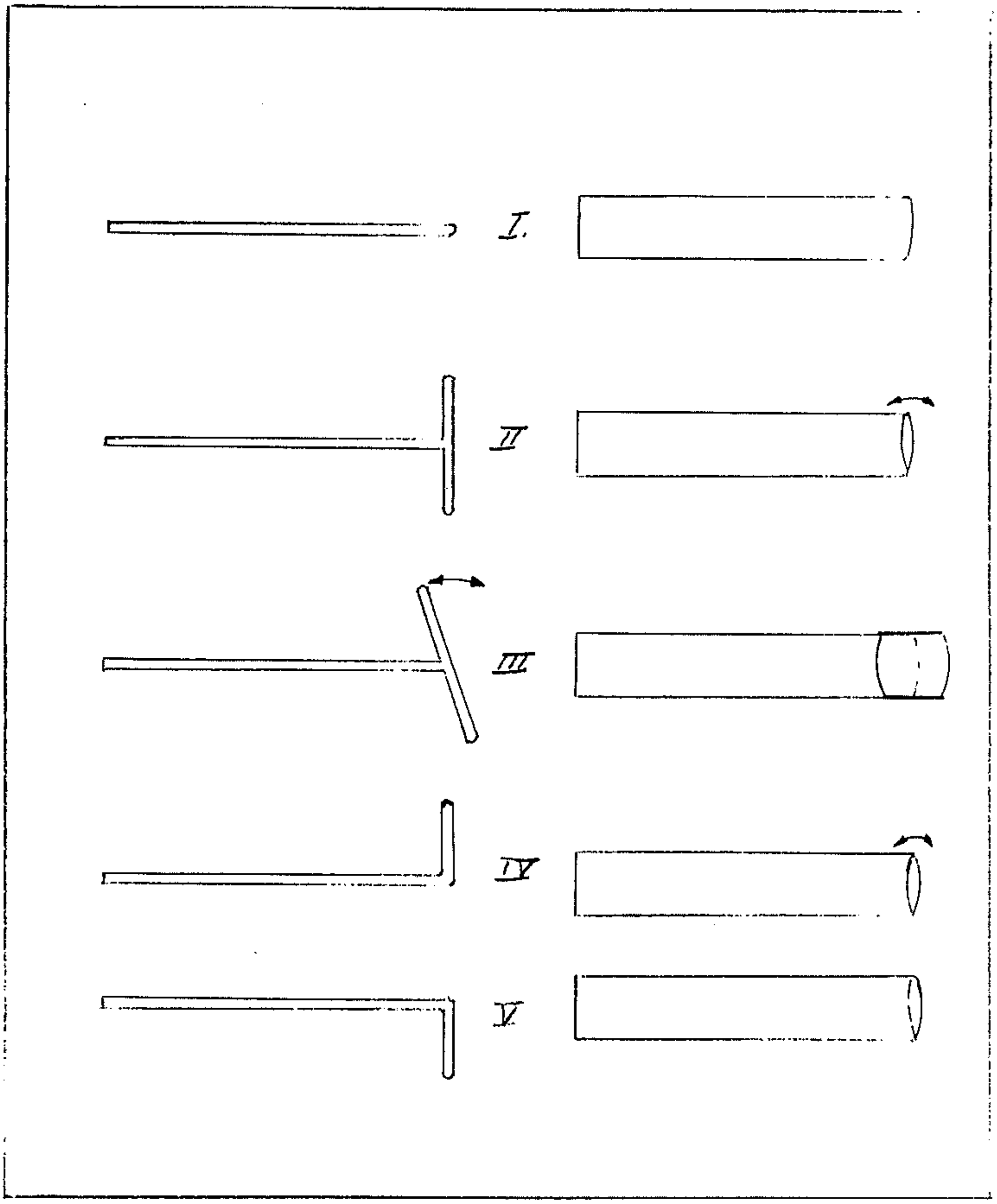

Figure 3. Arrangements of tip vanes on model rotor tips.

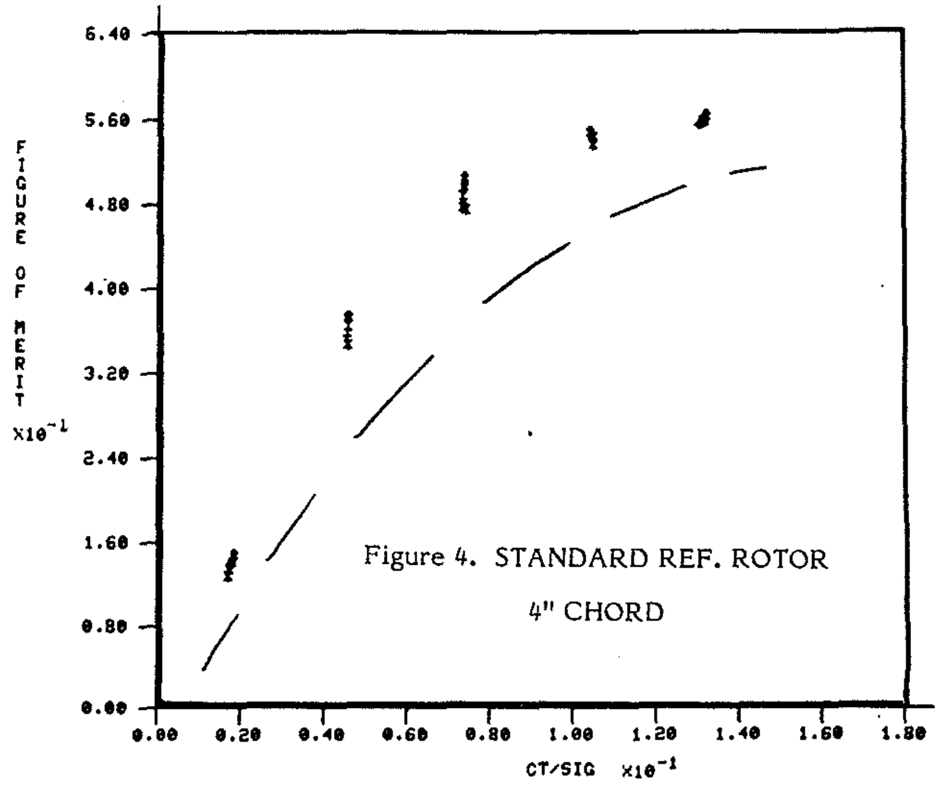

Figure 4. STANDARD REF. ROTOR
4" CHORD

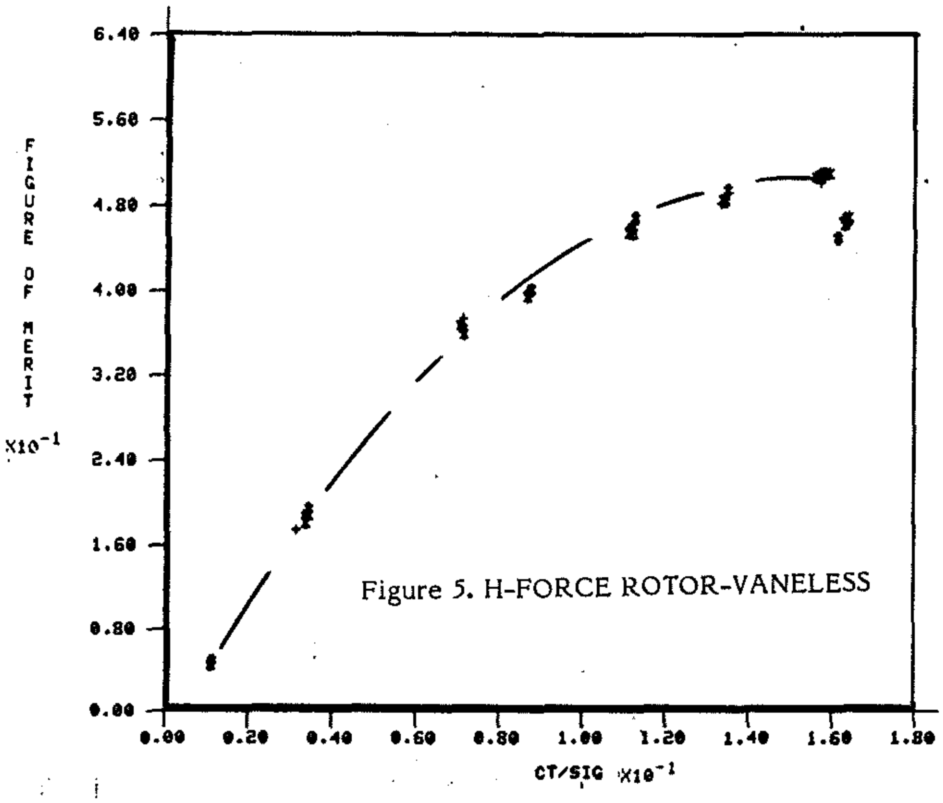

Figure 5. H-FORCE ROTOR-VANELESS

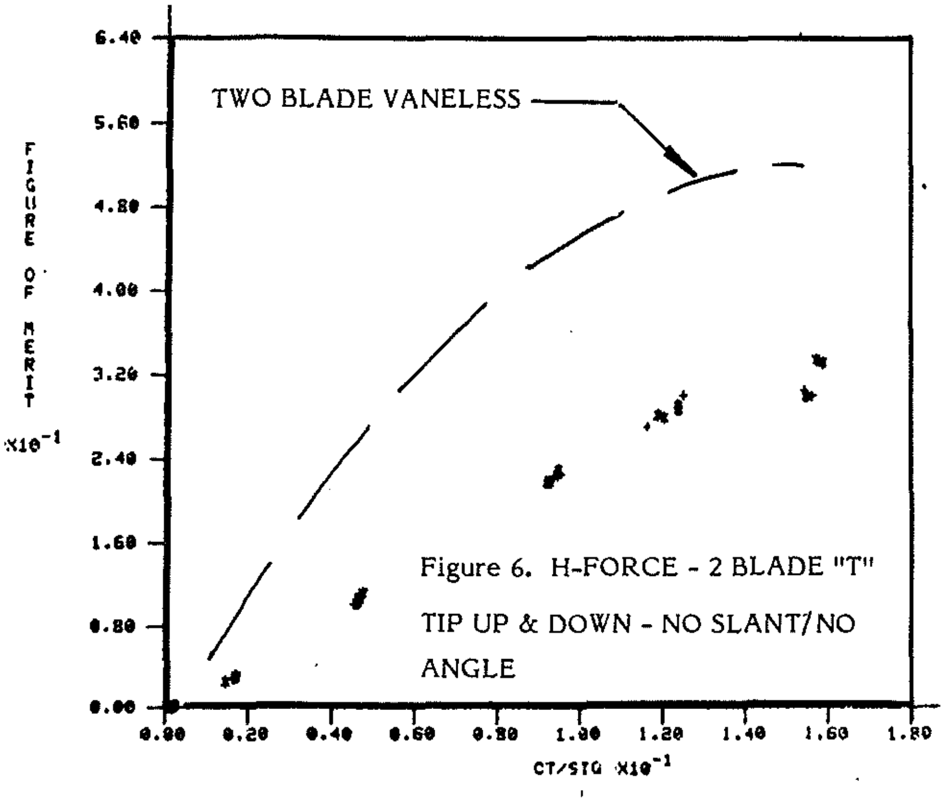

Figure 6. H-FORCE - 2 BLADE "T" TIP UP & DOWN - NO SLANT/NO ANGLE

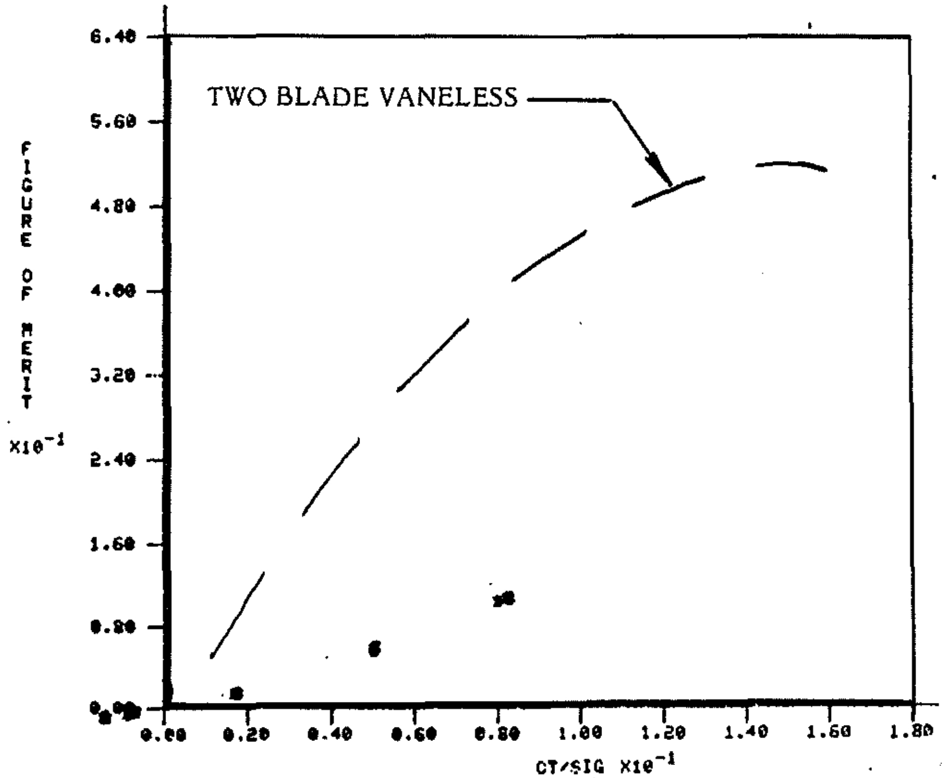

Figure 7. 2 BLADE "T" TIP UP & DOWN, TOP SLANT IN 11 DEG NO ANGLE

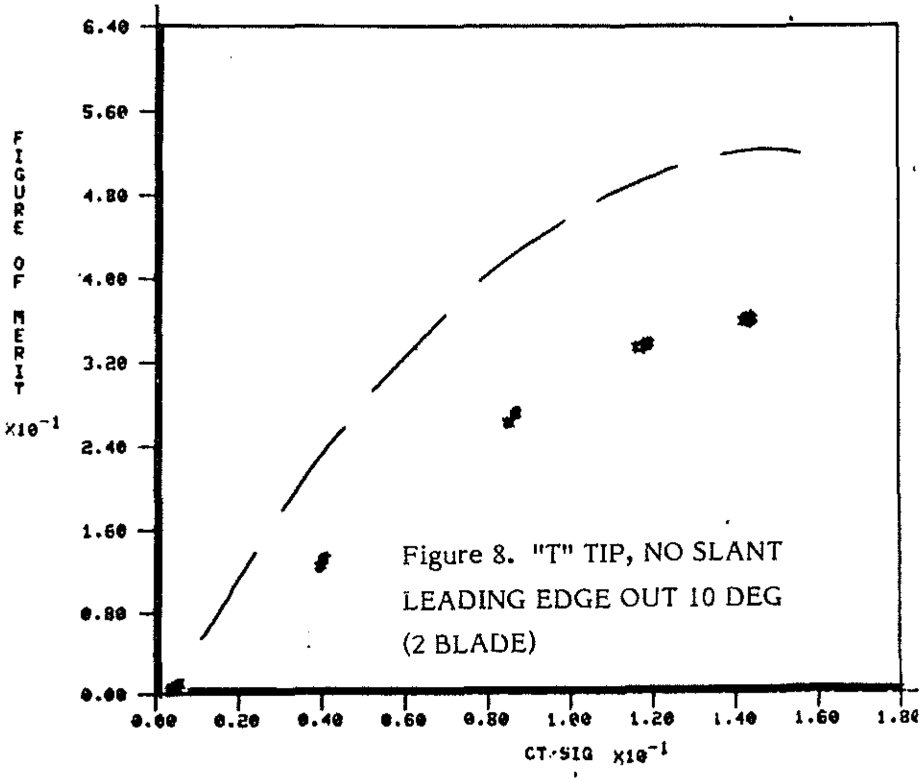

Figure 8. "T" TIP, NO SLANT LEADING EDGE OUT 10 DEG (2 BLADE)

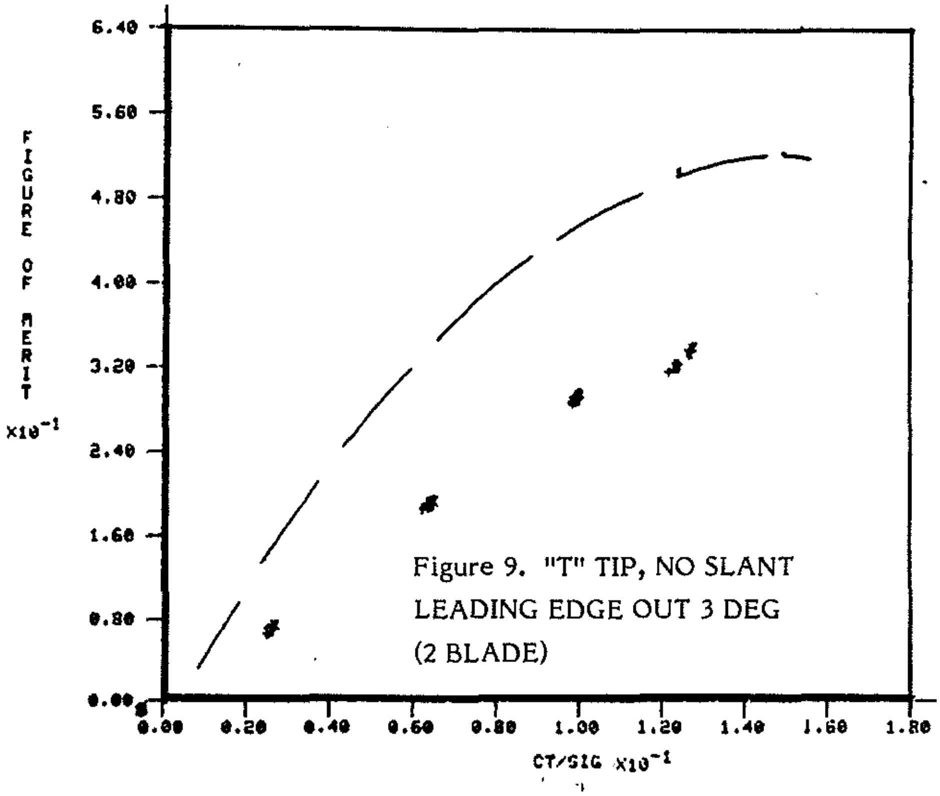

Figure 9. "T" TIP, NO SLANT LEADING EDGE OUT 3 DEG (2 BLADE)

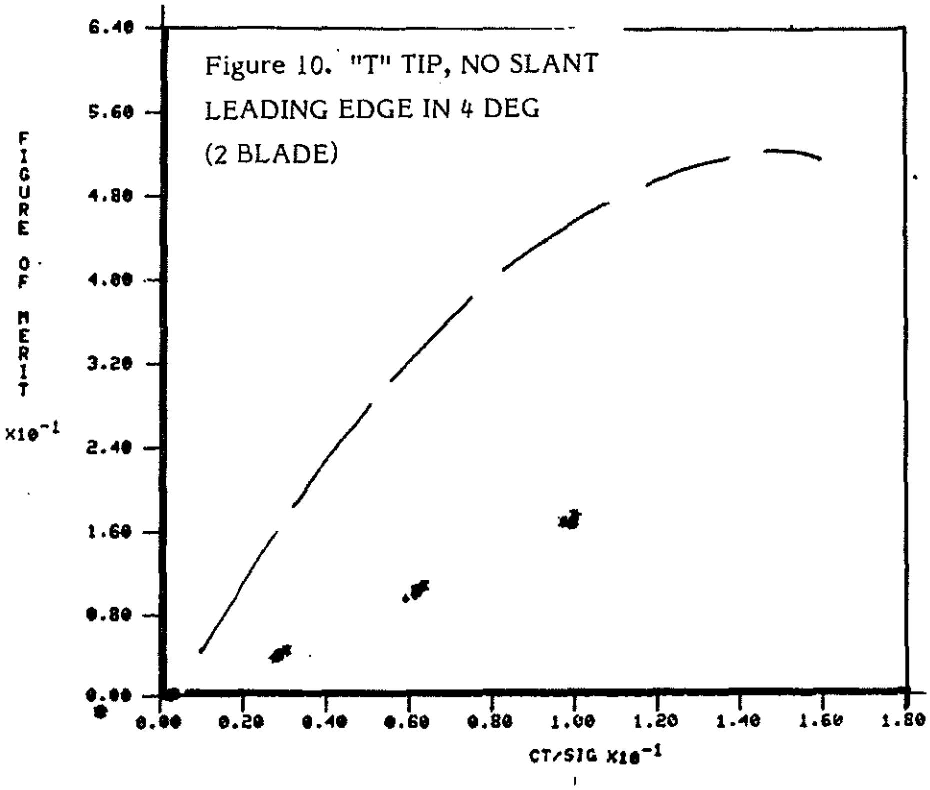

Figure 10. "T" TIP, NO SLANT
LEADING EDGE IN 4 DEG
(2 BLADE)

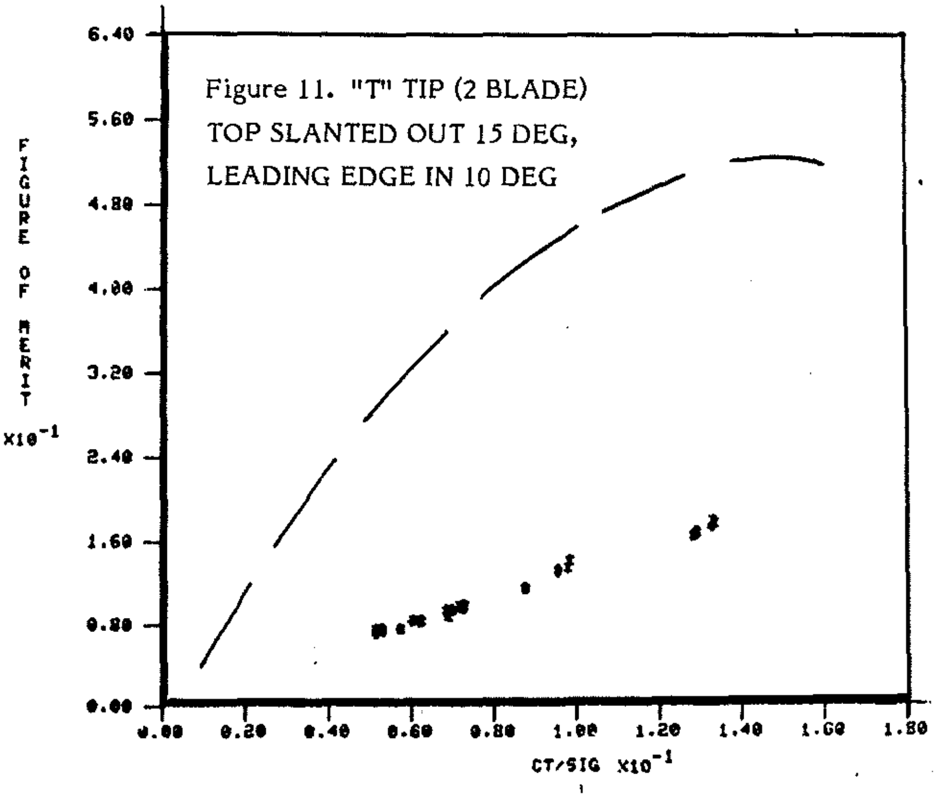

Figure 11. "T" TIP (2 BLADE)
TOP SLANTED OUT 15 DEG,
LEADING EDGE IN 10 DEG

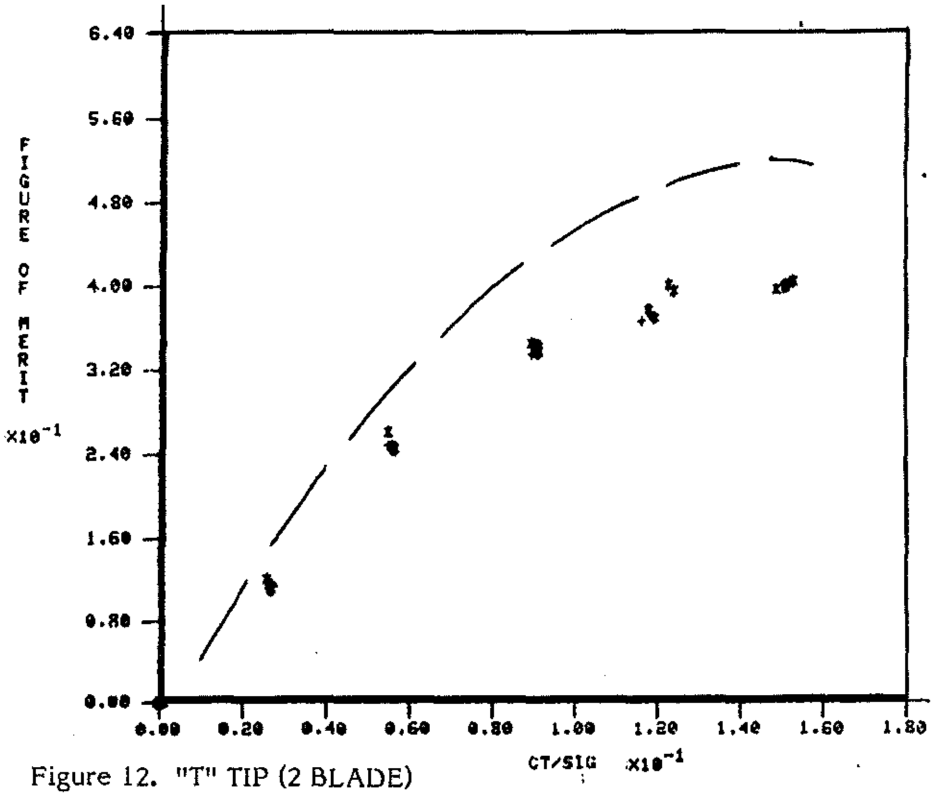

Figure 12. "T" TIP (2 BLADE)
TOP SLANTED OUT 15 DEG,
LEADING EDGE OUT 7 DEG

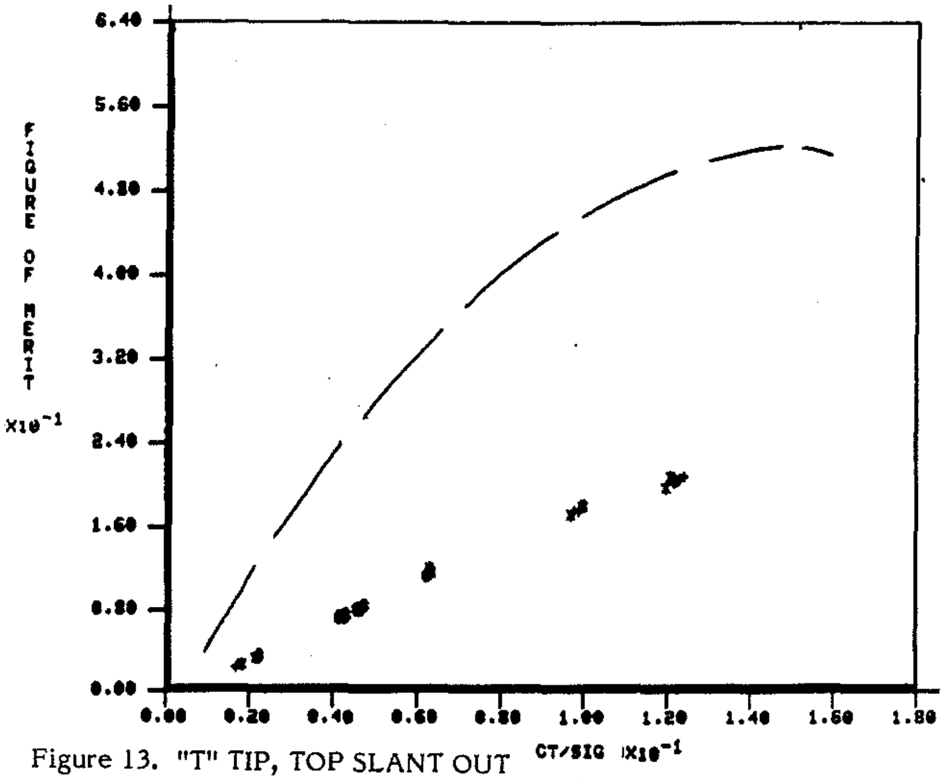

Figure 13. "T" TIP, TOP SLANT OUT
15 DEG, LEADING EDGE ANGLE IN
5 DEG (2 BLADE)

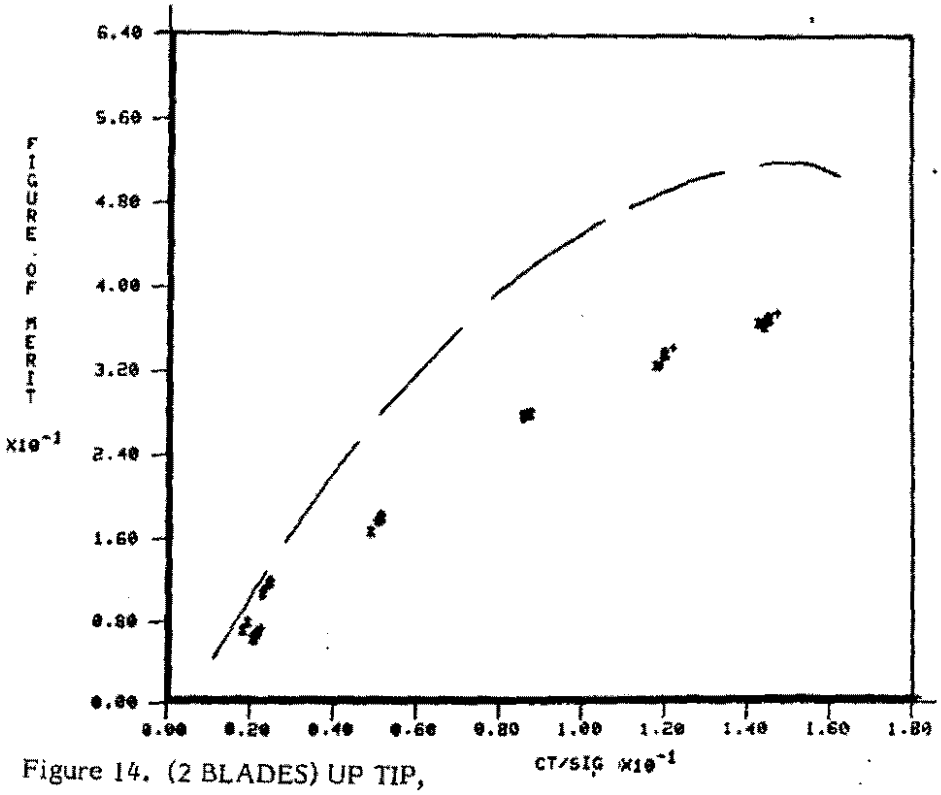

Figure 14. (2 BLADES) UP TIP,
NO SLANT, LEADING EDGE 0 DEG

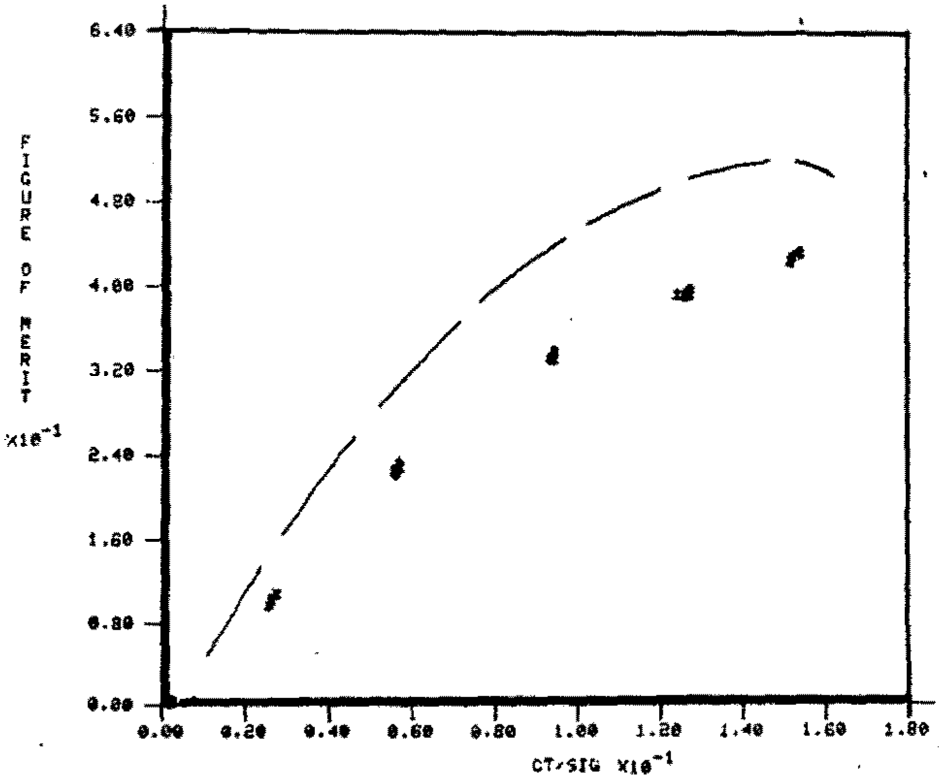

Figure 15. (2 BLADES) UP TIP,
NO SLANT, LEADING-EDGE OUT
3 DEG

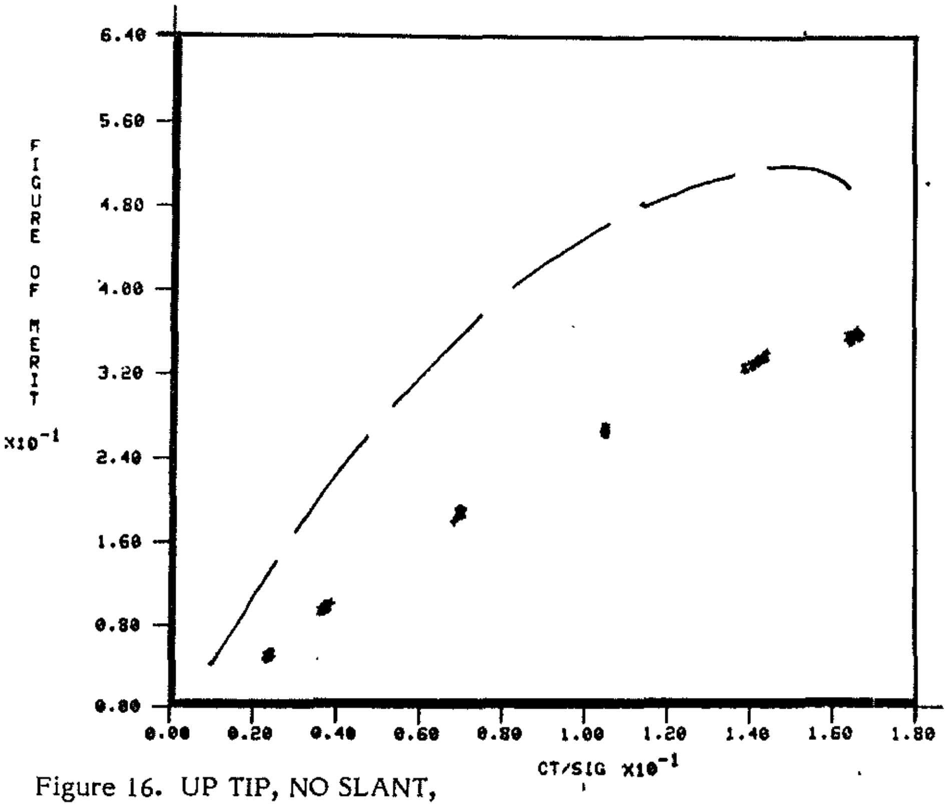

Figure 16. UP TIP, NO SLANT,
LEADING EDGE IN 10 DEG
(2 BLADE)

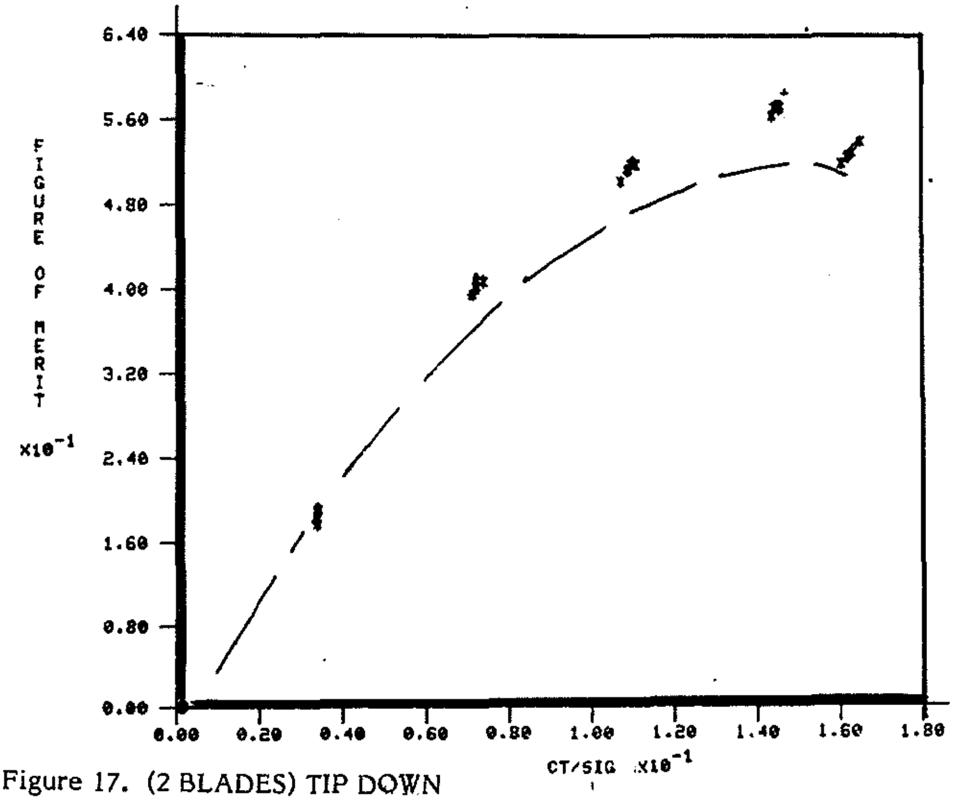

Figure 17. (2 BLADES) TIP DOWN
NO SLANT, LEADING EDGE 0 DEG

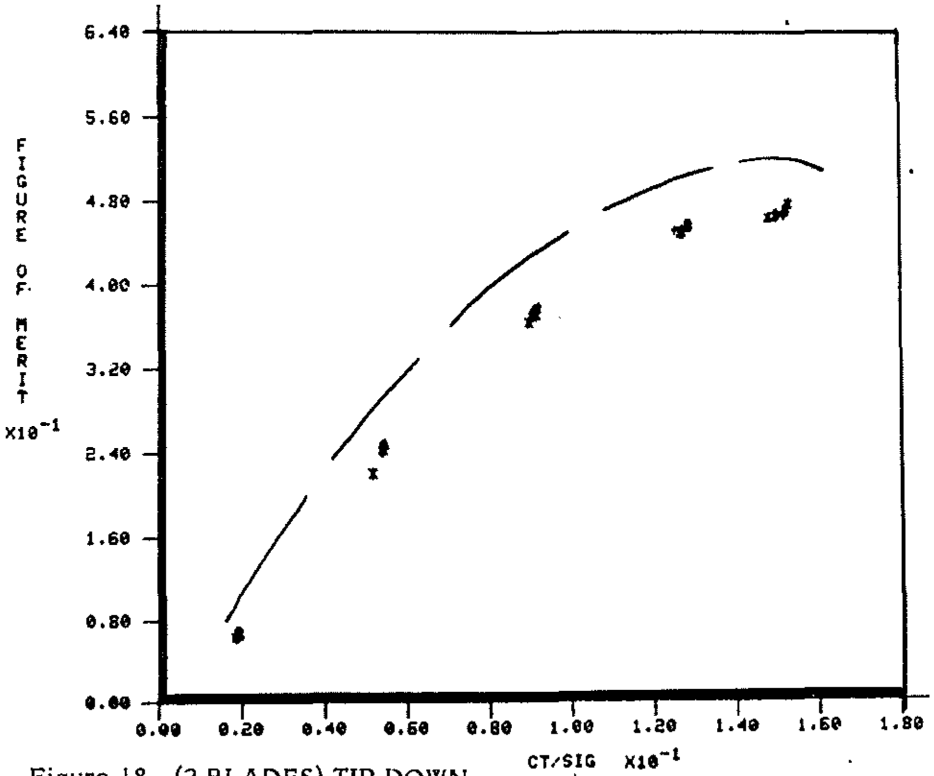

Figure 18. (2 BLADES) TIP DOWN
NO SLANT, LEADING EDGE IN
3 DEG

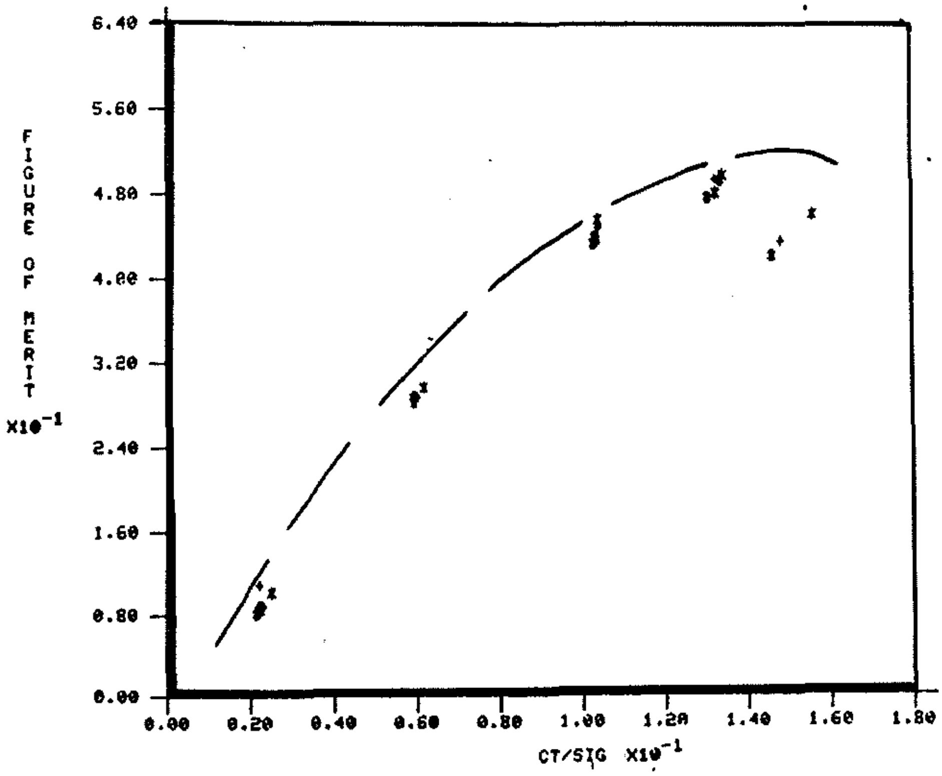

Figure 19. (2 BLADES) TIP DOWN
NO SLANT, LEADING EDGE IN 3 DEG
TAB IN 10 DEG

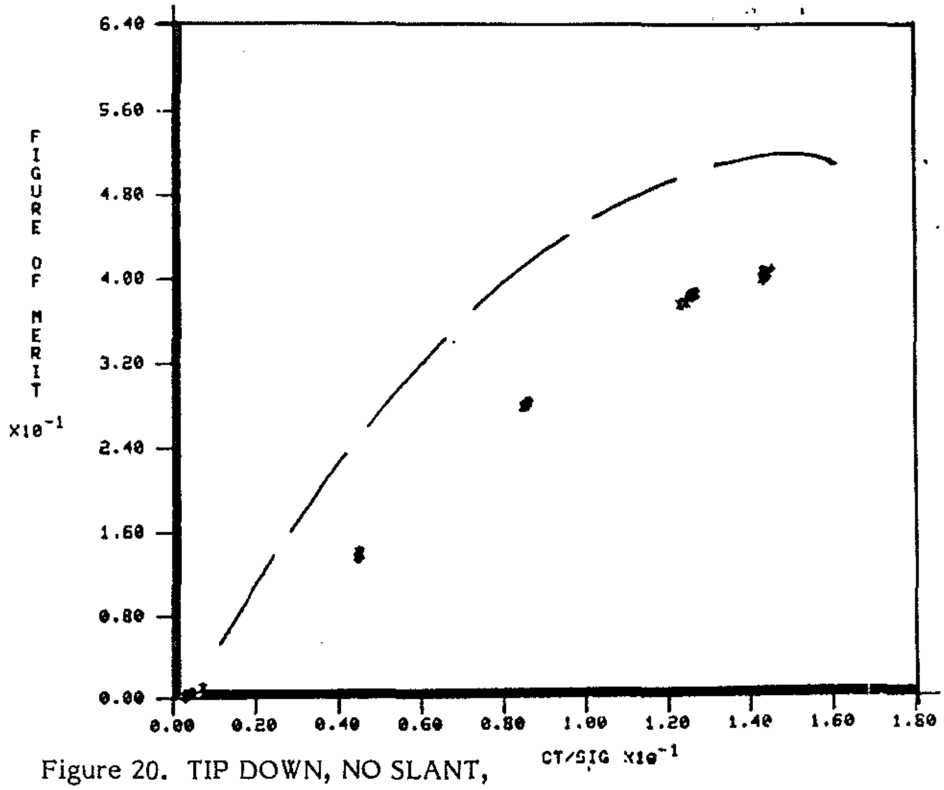

Figure 20. TIP DOWN, NO SLANT, LEADING EDGE 0 DEG, TAB OUT 10 DEG (2 BLADE)

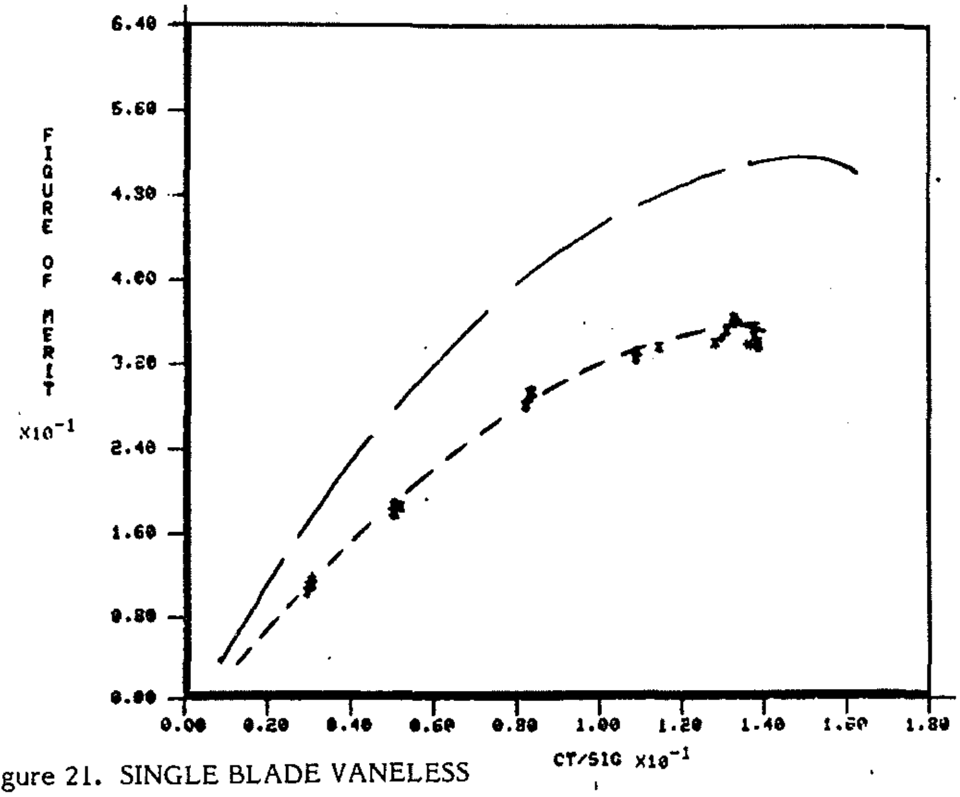

Figure 21. SINGLE BLADE VANELESS H-ROTOR
3" CHORD, NO TWIST