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FINAL REPORT

(NASA-CR-114626) FULL SCALE HOVER TEST OF A 25 FOOT TILT ROTOR (Bell Helicopter Co.) ~~125~~ 113 p HC $8.75 CSCL 01A

N73-25070

Unclas

G3/02 06854

FULL SCALE HOVER TEST
25-FOOT LOW DISC LOADING
TILT ROTOR

MODEL 300

REPORT 300-099-010

NASA CONTRACT NAS2-7308

BELL
HELICOPTER COMPANY
POST OFFICE BOX 482 · FORT WORTH, TEXAS 76101 A textron COMPANY

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TECHNICAL DATA

MODEL 300 No. of Pages 112

REPORT No. 300-099-010 DATE 5/16/73

TITLE FULL-SCALE HOVER TEST OF A 25-FOOT TILT ROTOR

PREPARED UNDER CONTRACT NAS 2-7308

BY S. Helf, E. Broman, S. Gatchel, B. Charles DATE 5/16/73

PROJECT ENGR. D. E. Broman DATE 5/16/73

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NOMENCLATURE

Symbol	Description
AFAPL	Air Force Aero Propulsion Laboratory
AFFDL	Air Force Flight Dynamics Laboratory
B	Rotor Blade Tip Loss Factor
b	Number of Blades of Rotor
c	Chord of Blade (feet)
C_D	Rotor Coefficient of Drag = $D/\rho\pi\Omega^2R^4$
C_L	Rotor Coefficient of Lift = $L/\rho\pi\Omega^2R^4$
C_P	Hover Power Coefficient = $550\,(HP)/\rho\pi R^2(\Omega R)^3$ (using test stand HP)
C_T	Hover Thrust Coefficient = $T/\rho\pi R^2(\Omega R)^2$
FM	Rotor Figure of Merit = $.707\,\frac{C_T{}^{3/2}}{C_P}$
HP	Rotor Horsepower
L	Rotor Lift (pounds)
M	Rotor Tip Mach Number
N	Rotor RPM in Horsepower Calculation from Oscillograph Data
Q	Rotor Torque Measured at the Mast (inch-pounds) from Oscillograph Data
R	Rotor Radius
RPM	Rotor Rotational Speed
T	Rotor Thrust Along the Mast Axis (pounds)
Δ	Delta - Indicating a Difference in Data

NOMENCLATURE (Continued)

Symbol	
Ω	Rotor Angular Velocity (rad/sec)
ΩR	Rotor Tip Speed (feet per second)
ρ	Air Density (slug/ft^3)
σ	Rotor Solidity = $\frac{bc}{\pi R}$ = .089 for Model 300
σ'	Air Density Ratio - Actual Air Density to Air Density at Sea Level Standard Day Conditions

I. SUMMARY

The Bell Model 300 tilt rotor, 25 feet in diameter, underwent a hover performance test under Government contract (Reference 1) in March 1973. The test was conducted on the Aero Propulsion Laboratory whirl stand at Wright-Patterson Air Force Base (Figures I-1 and I-2).

The maximum thrust over density ratio measured at the design tip speed of 740 feet per second was 10,016 pounds. This occurred when the power over density ratio was 1721 horsepower. At the hover overspeed rpm (ΩR = 786 feet per second), the thrust and power, over density ratio, were 11,008 pounds and 1866 horsepower.

During the test, the maximum measured thrust coefficient, C_T/σ, was 0.177, and the rotor figure of merit exceeded 0.81. Measured lifting efficiency was 8.35 pounds per horsepower at the thrust a 13,000-pound aircraft would require for hover at sea level on a standard day. No effect of compressibility on performance is discernible in the test results (the range of tip Mach numbers tested was 0.55 to 0.71).

The measured thrust exceeded the predicted maximum thrust by 8 percent, but an arbitrary increase in the tip loss factor, B, from 0.97 to 1.0 brings the calculated thrust into close agreement. This change in B makes computed power required higher than measured power required, but power measured on the whirl stand is somewhat optimistic because of the partial ground effect of the open-grid work platform below the rotor. The performance analysis which uses the tip loss factor of 1.0 seems to predict performance accurately, and the performance thus predicted is in very close agreement with the hover performance measured earlier in the 40- by 80-foot wind tunnel (Reference 2). The hover test in the wind tunnel seems to have represented out-of-ground-effect hover accurately, and to have been more conservative than the whirl test.

Neither blade loads nor control loads limited maximum thrust. Torque approached the static limit for the rotor, but all oscillatory loads were low.

A preliminary analysis of noise data made by the Air Force Flight Dynamics Laboratory indicates that the rotor noise on the test stand closely agrees with the noise measured in the wind tunnel. The noise levels predicted for the Model 301 tilt rotor research aircraft which uses the Model 300 tilt rotor should thus be accurate.

Hover performance is now well documented to show that the tilt rotor for the Model 301 aircraft will conservatively meet all hover requirements. Calculations with the tip loss factor B = 1.0 show the new hover ceiling to be 2200 feet higher or, for constant altitude, the maximum gross weight for hover is 850 pounds greater than predicted (increasing from 13,000 to 13,850 pounds).

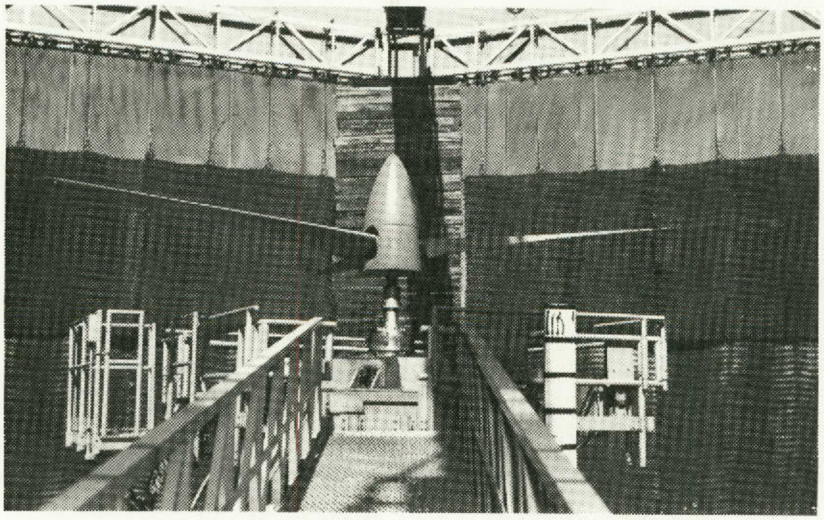

Figure I-1. 25-Foot Tilt Rotor on Whirl Stand

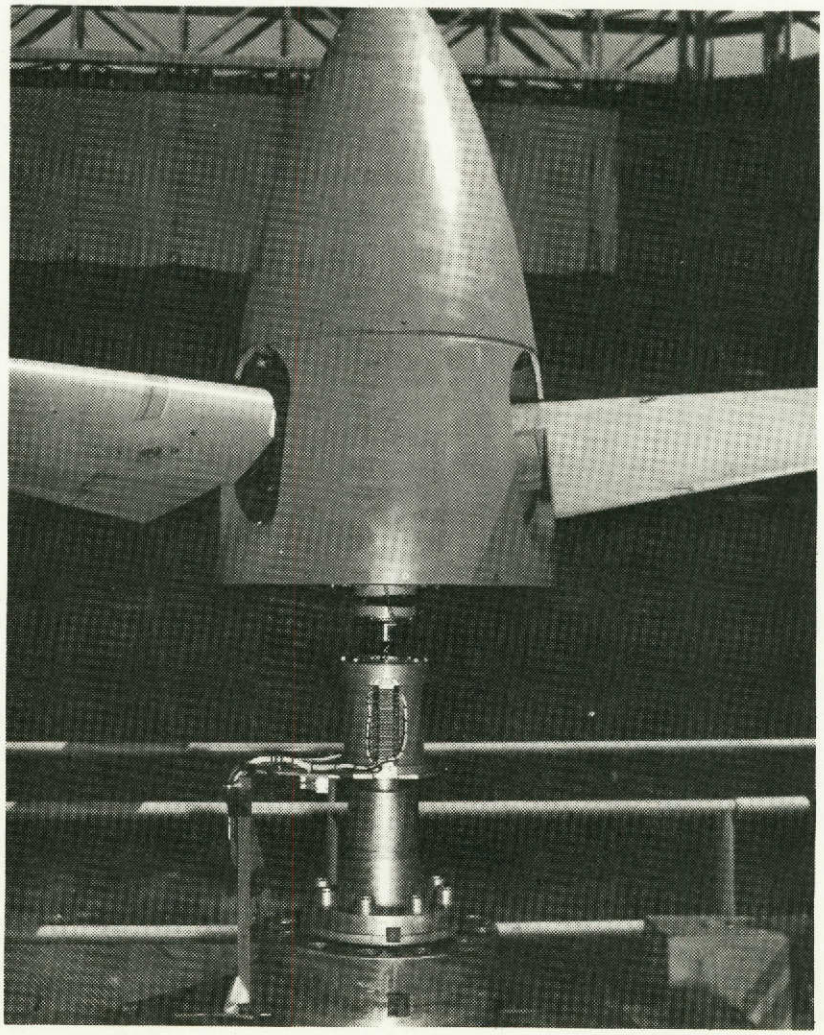

Figure I-2. 25-Foot Tilt Rotor Test Installation

II. BACKGROUND

Lack of success of the many VTOL configurations previously investigated was directly related to their inability to demonstrate a useful payload when hovering at hot-day and altitude conditions typical of those required for an operational VTOL. One of the obvious reasons for the lack of a useful payload was the failure to achieve the predicted performance goals for static thrust in hovering flight. It is, therefore, important in the future assessment of candidate VTOL types that the area of static thrust performance be carefully and accurately evaluated.

The tilt-rotor-type VTOL aircraft is one of the most promising configurations as a result of the good hovering payload (under operating temperatures and altitude conditions) that has been forecast for it. Although optimism in the performance forecast could be suspected, tests of the Bell 25-foot-diameter full-scale tilt rotor in the NASA-Ames Large-Scale Tunnel (under Army/NASA Contract NAS2-5386) in November 1970 showed lower power required than predicted and measured values of static thrust exceeded the maximum predicted static thrust by 15 percent. These static tests were performed under conditions which could possibly have provided some "ground effect" or other "wall effects" or allowed wake recirculation. See Figure II-1 for the wind-tunnel test installation.

The importance of an accurate assessment of static hover performance of the tilt rotor indicated the need for an independent check with a test specifically designed to represent the free hover condition. Additionally, the ability to accurately predict performance of a given VTOL propulsion system is needed if this type is to be considered for development to meet civil and/or military application requirements. It was to meet these needs that NASA-Ames contracted with Bell in November 1972 for the whirl-tower test of the full-scale 25-foot diameter tilt rotor.

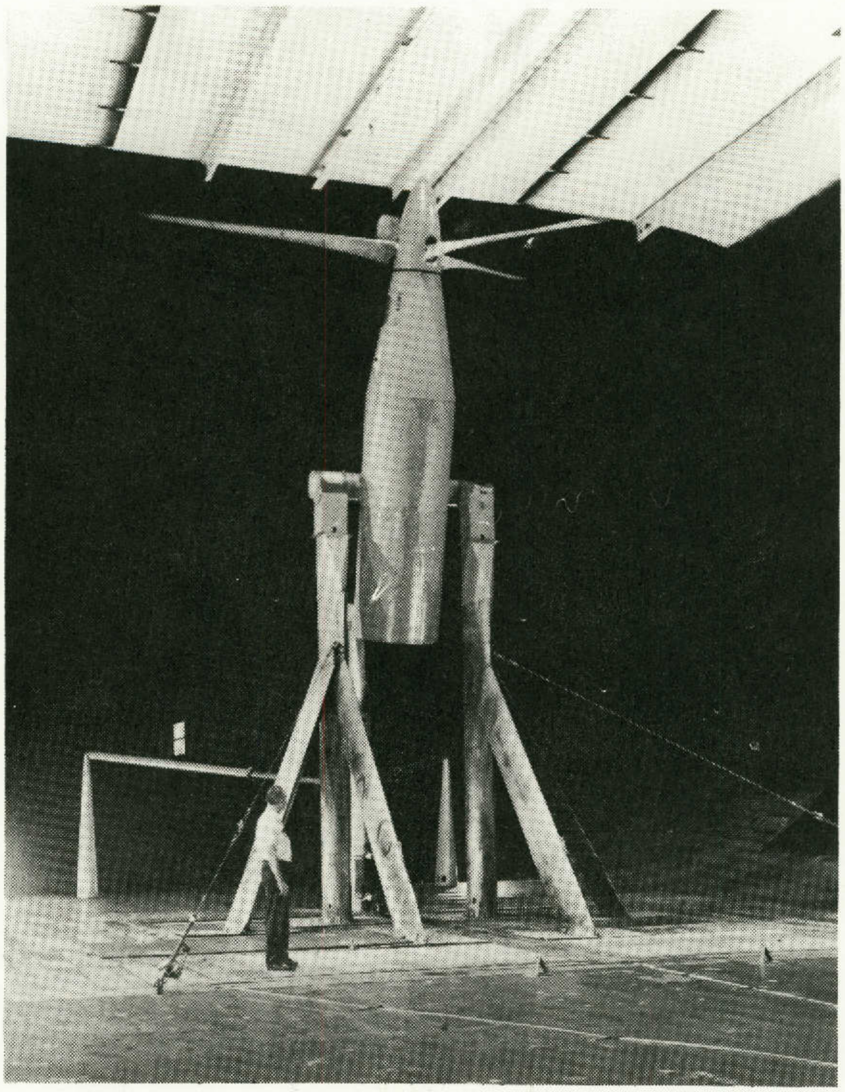

Figure II-1. 25-Foot Tilt Rotor in 40- X 80-Foot Wind Tunnel Performance Test, Nov. 1970.

III. DESCRIPTION OF TEST HARDWARE

The test hardware consisted of the 25-foot Bell Model 300 tilt rotor mounted to the Wright-Patterson Air Force Base Aero Propulsion Laboratory Rotor Whirl Tower. Both the rotor and the test stand were instrumented for the test. See drawing 300-018-048 in Appendix for rotor configuration for this test.

A. 25-FOOT TILT ROTOR

The tilt rotor is a three-bladed semi-rigid rotor with a fully gimbaled hub for blade flapping freedom and is the same rotor as used in the wind-tunnel tests in 1970. (See Reference 2) The all-bonded blades are made with high-strength, heat-treated 17-7PH stainless steel. Blade pitch motion and retention are provided by needle bearings and wire straps. Stainless steel liners, bonded to the titanium yoke, prevent fretting. The stiff titanium yoke places all blade bending frequencies above rotor speed.

The geometry of the blades was developed with the help of two-dimensional tests in subsonic and transonic wind tunnels. The blades have an NACA 64-208 airfoil at the tip and a highly cambered, 28-percent thick section at the root. A combination of twist and camber was chosen to meet the aerodynamic requirements for both helicopter and airplane flight, and to permit the blade spar structure to have a uniform twist rate. The integral blade and grip eliminate the need for an aerodynamic cuff at the root of the blade. The basic chord of the blade is 14 inches. Chord, twist, lift coefficient and thickness distributions are shown in Figure III-1. Blade stiffness and mass distribution are shown in Reference 3, Figure III-2. The tilt rotor collective and cyclic natural frequencies are shown in Reference 2, Figures III-3 and III-4, respectively.

Collective pitch control is achieved with a rise and fall collective head above the hub. The same pitch links as used in the wind-tunnel tests of 1970 attach directly from the collective head to the pitch horns of each blade. The collective head is powered by a 28-volt DC electric motor with a gear head of 941:1 gear ratio and is mounted directly above the collective head. The electric motor gear head has a continuous operating torque of 100 inches-pounds and a stall torque of 500 inches-pounds which produce a collective head force of 500 pounds and 2500 pounds, respectively. The collective motor and gear head drive through an acme screw with a lead of .166 inch per rev and provide a collective rate of 8.5 degrees per minute or about 1/7 degree per second. The total collective travel was about 18 degrees of blade pitch.

Cyclic pitch was held to zero for this test by deleting the swashplate and by connecting the pitch links directly from collective head to the pitch horns of each blade.

To adapt the Model 300 tilt rotor to the test stand, a new mast with adapter flange was fabricated. See Drawing 300-018-043 in appendix. The test mast is identical to the aircraft mast in the vicinity of the hub but is stronger below the hub to the attachment flange because the mast is unsupported on the test stand whereas the aircraft mast is supported by bearings.

The Model 300 tilt rotor is faired with a fiberglass spinner with internal aluminum bulkheads.

Table III-1 provides a summary of pertinent descriptive data. Bell drawings 300-010-001 and 300-010-100 included in the appendix show some of the construction details of the tilt rotor.

B. AIR FORCE AERO PROPULSION LABORATORY ROTOR STAND

The test stand used for the test is located in area B of Wright Field and consists of a four-sided pyramid super structure mounted to four concrete platforms as shown in Figures III-2 and III-3.

The rotor is mounted on top of the AFAPL whirl stand 56 feet above the ground inside a 100-foot diameter cage with dimensions and features as shown in Figure III-4.

A 12- by 12-foot work platform is located 6 feet below the plane of the rotor. It has a 7- by 7-foot solid area with an open-grid walkway around it. The grid material on the walkway has an open area ratio of 0.76. This platform will cause some blockage to the rotor wake and may create a partial ground effect on the rotor. A 4-foot wide open-grid walkway extends from the south side of the work platform to the outer cage.

An anemometer mounted 4 feet above the top of the cage is used to measure wind velocity. The cage consisting of chain link fence has six layers in the plane of the rotor. This reduces the wind velocity at the rotor location.

The test stand is powered by a Westinghouse 15,000 horsepower synchronous ac electric motor. Ac power is generated by an alternator which is driven by an electric dc motor. In this manner, rpm is closely controlled by controlling the current to the dc motor. The alternator and dc motor are located in the adjacent power house and the ac synchronous motor is mounted inside the test stand just above the control room. The drive shaft is 10 inches in diameter with a flexure coupling 10 feet above the motor and an A.H. Emery pressure type thrust load cell and bearing 13 feet above the motor. The top of the drive shaft is 13 feet above the thrust load cell where an upper roller bearing and two Baldwin side force load cells are mounted to the test stand. This upper bearing and housing is held in position radially by four jack clamps which must be adjusted from .002 to .004 loose fit to allow for accurate thrust load readings from the thrust cell. The side force cells were not used for this test and were backed off and locked out of position.

The rotor mounting shaft pad is 12 inches in diameter and provides 8 mounting bolts of 1.00 inch diameter and 4 aligning face keys of 1.06 width and 4.81 long. The mounting bolts are special design with a portion of the shank necked down and polished to .56 diameter. The rotor drive shaft drives in either direction of rotation up to 600 rpm and the test stand power rating at the drive shaft is 4000 horsepower.

The test stand provides an overhead rail type hoist which allowed the fully assembled rotor to be lifted up for mounting on the stand. A closed circuit T.V. is provided to view the rotor from the control room. All test control read out equipment and monitors were provided in the control room in the base of the test stand. An elevator on the side of the test stand was used to transport personnel to the work platform.

C. INSTRUMENTATION

Rotor instrumentation was provided to monitor and record loads, frequencies and motions of the rotor during the test. Test stand instrumentation was provided to monitor and read thrust, power and rpm during the test.

1. Rotor Instrumentation

The rotor instrumentation is given in Table III-2. Nineteen channels of rotor strain gage and position data were measured and recorded during the tests. The rotor mast torque strain gage was accurately calibrated at Bell prior to shipment to the test site. Blade flapping, feathering and collective position was calibrated at the test stand prior to test. All other previously calibrated strain gages were rechecked to be reading the same voltage during laboratory checkout at Bell prior to shipping to the test site. All instrumentation remained on line and continued to function throughout the test.

2. Test Stand Instrumentation

Instrumentation provided by the Air Force Aero Propulsion Laboratory Rotor Whirl Tower for the Model 300 hover test is as follows:

Measurement	Operating Range	Monitor
Thrust	0 to 11,250 lb	Meter
Power[a]	0 to 2,000 hp	Meter

Measurement	Operating Range	Monitor
RPM[b]	0 to 600	Digital meter (at one second gate)
Wind speed	As required (knots)	Meter from anemometer
Wind direction	All directions	Meter from anemometer
Outside temperature	Ambient conditions (deg C)	Visual thermometer
Barometric press	Ambient conditions (in Hg)	Test stand barometer

[a]Horsepower is monitored in watts converted to horsepower with corrections for voltage and amps.

[b]Bell oscillograph also recorded rpm and mast torque.

The whirl stand was recalibrated just prior to the test and measurements of power, thrust, and rpm should each be within 1 percent of true value. All instruments carry U. S. Government calibration labels certifying calibration until July 1973.

Calibration of the Westinghouse 15,000 horsepower three-phase synchronous motor was performed in 100 rpm increments from 0 to 600 rpm. This determined the unloaded power for friction, winding and iron losses. Copper losses do not vary and are obtained from a curve supplied by Westinghouse. Power is obtained by subtracting these losses from the measured watts to the motor. The watt meter was adjusted to be within 1 percent of true value and calibrated against a watt meter calibrated by the U. S. Bureau of Standards.

Speed of the motor is measured by a digital counter measuring pulses from a 60 pole generator turning at shaft speed. The digital counter was calibrated and verified to be within 1 percent of true value by using a signal generator calibrated by the U. S. Bureau of Standards.

The A. H. Emery thrust measuring system was calibrated from 0 to 20,000 pounds by pulling on the top of the drive shaft with a hydraulic jack in series with a Baldwin precision load cell. The Baldwin load cell was calibrated by the U.S. Bureau of Standards. The rig thrust calibration factor was determined to be 0.985 which means that the thrust system was reading 0.985 of true thrust. Thrust readings were then divided by 0.985 to give true thrust.

TABLE III-1. TILT ROTOR DESCRIPTIVE DATA

Number of Blades per Proprotor	3	
Diameter	25.0 ft	
Disc Area per Proprotor	491 sq ft	
Blade Chord	14 in basic blade 17 in cuff root at 0.0875R Tapering to 14 in at 0.25R	
Blade Area (3 Blades)	43.75 sq ft	
Solidity	0.089	
Blade Airfoil Section Root (℄ Mast) Tip	 NACA 64-935 a = 0.3 NACA 64-208 a = 0.3	
Blade Twist (See Figure III-1 for Distribution)	-45.0 deg	
Hub Precone Angle	+2.5 deg	
δ_3	-15.0 deg	
Underslinging	0 deg	
Mast Moment Spring Rate (per Rotor)	2700 in lb/deg	
Flapping Design Clearance	±12.0 deg	
Blade Flapping Inertia (per Blade)	105 Slug ft^2	
Blade Lock Number	3.83	
	Tip Speed (fps)	 (rpm)
Hover Operating Overspeed	786	600
Helicopter	740	565
Conversion	700	534
Airplane	600	458

TABLE III-2. INSTRUMENTATION LIST - MODEL 300 WHIRL TOWER HOVER TEST

No.	Item or Name	Units	Operating Limit	100 Percent Display	Frequency Response	Readout		
						O-Graph	Scope	Meter
1	Red blade beam Sta. 22.8	in-lb	300,000 ±35,000	400,000	100	x		
2	Red blade beam Sta. 52.5	in-lb	130,000 ±17,500	150,000	100	x	x	
3	Red blade chord Sta. 52.5	in-lb	185,000 ±36,500	200,000	100	x	x	
4	Red blade torsion Sta. 52.5	in-lb	±3,000	±5,000	100	x		
5	Red blade spindle beam	in-lb	163,000 ±30,000	175,000	100	x		
6	Red blade spindle chord	in-lb	270,000 ±50,000	300,000	100	x	x	
7	Red pitch link axial	lb	500±345	800±345	100	x	x	
8	White pitch link axial	lb	500±345	800±345	100	x		
9	Collective tube axial	lb	1500±1035	2,500	100	x		x
10	Mast parallel bending	in-lb	50,000 ±50,000	50,000	100	x	x	
11	Mast perpendicular bending	in-lb	50,000 ±50,000	50,000	100		x	
12	Mast torsion	in-lb	217,000 ±10,000	250,000	100	x		x
13	Axial acceleration of slipring housing	g	3	5	60	x	x	
14	Side acceleration of slipring housing	g	3	5	60		x	
15	Side acceleration (90-degrees to above)	g	3	5	60		x	
16	Red blade feathering at tip	deg	-6 to +14	-10 to +20	50	x		
17	Red blade flapping	deg	±2	±5	50			x
18	Red blade azimuth	blip	one per rev		50	x		
19	Collective position	deg	-6 to 14	-10 to 20	50			x

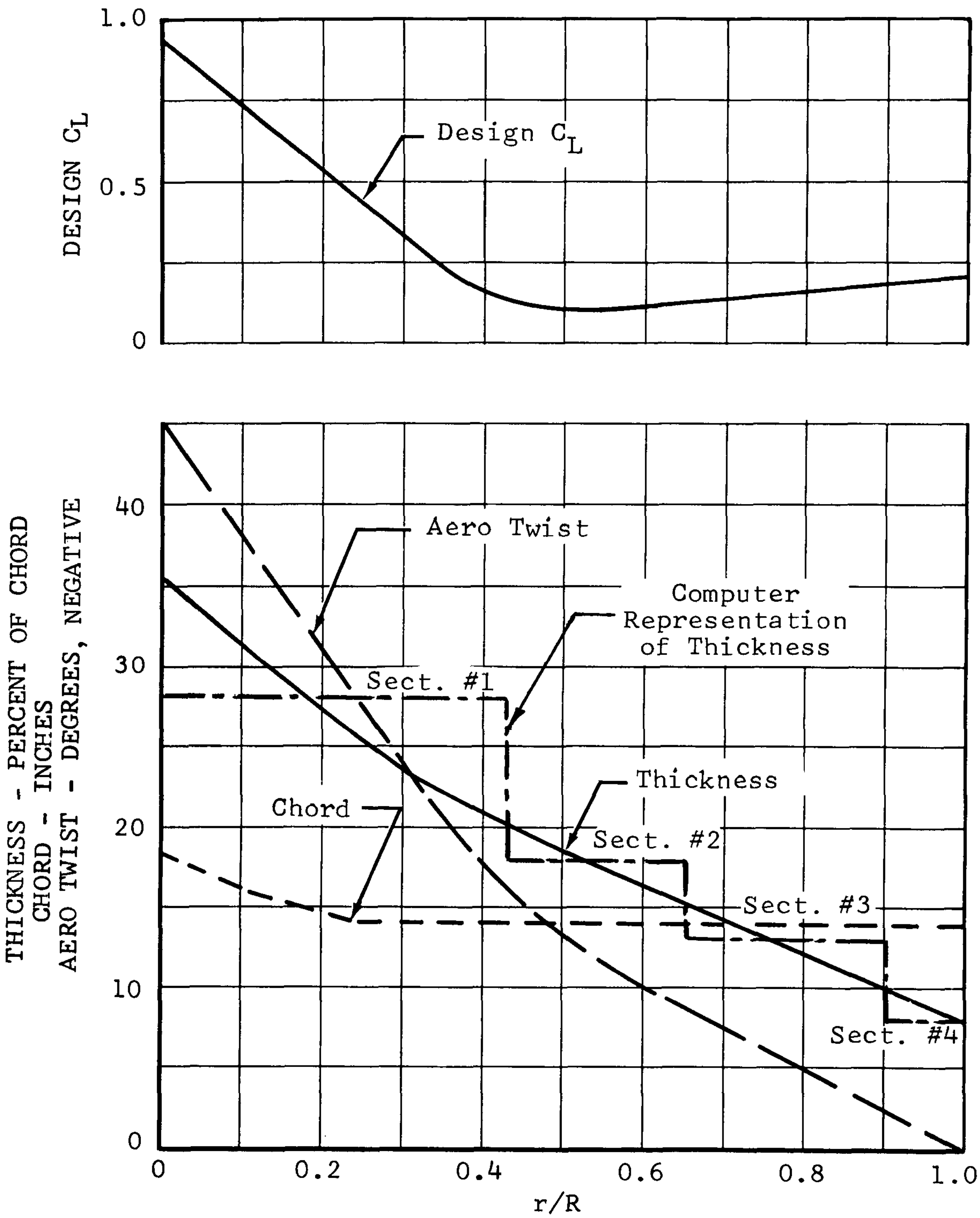

Figure III-1. 25-Foot Tilt Rotor Parameters.

Figure III-2. AFAPL Rotor Test Stand Work Platform.

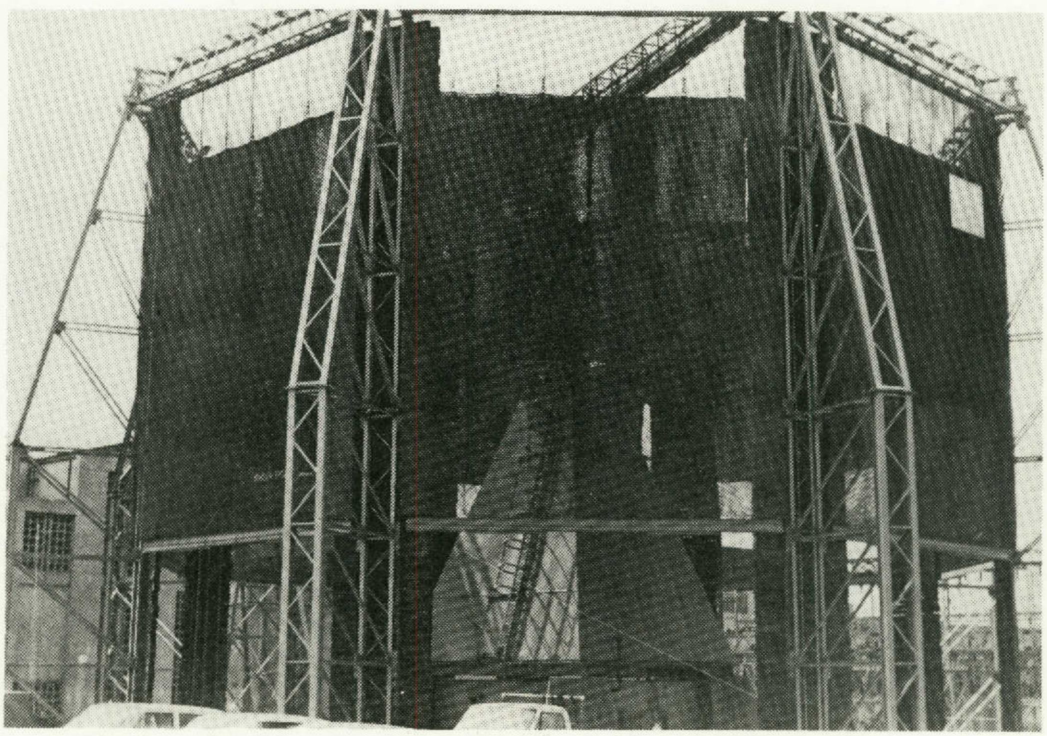

Figure III-3. AFAPL Rotor Test Stand.

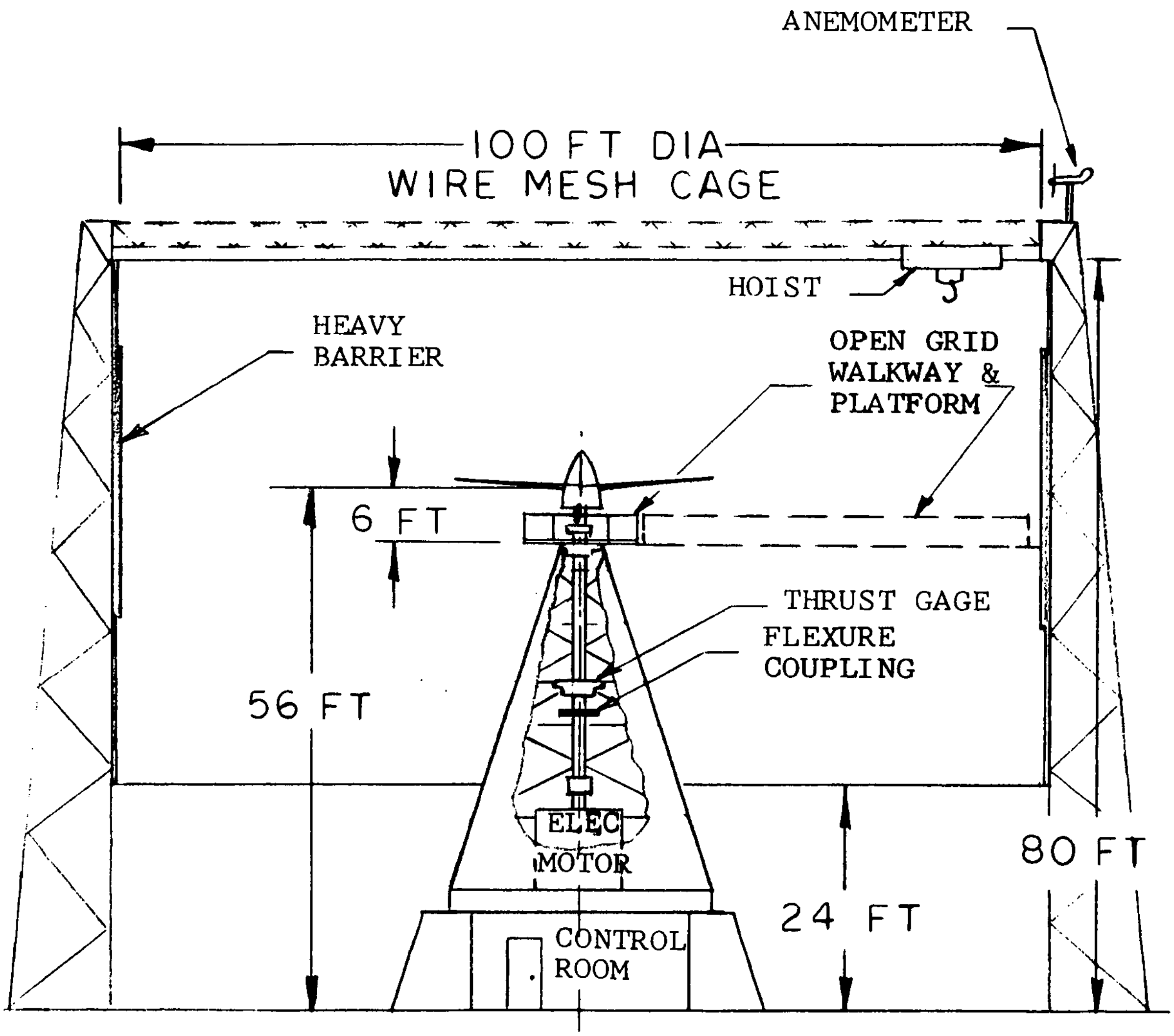

Figure III-4. 25-Foot Tilt Rotor on the Whirl Stand

IV. PERFORMANCE DATA

A. TEST PROCEDURE

The test was conducted with the rotor mounted vertically on the test stand with the rotor hub about 6 feet above the 12 x 12 foot work platform and about 56 feet above the ground. (See Figure III-4) The direction of rotation for the test was counter clockwise looking down on the rotor.

All instrumentation given in the previous section was operating and zeros were taken along with measurement of full throw travels prior to and immediately following each run. The temperature was read on an outside thermometer graduated in centigrade. Barometric pressure was read on a calibrated and corrected mercury barometer at the test site. Temperature and barometric pressure was read at the start of each run and checked again at the end of the run. Wind velocity and direction was monitored remotely in the Control Room from an anemometer mounted 4 feet above the protective cage. In addition a hand held wind velocity gage was used to check wind velocity at the rotor plane. This was found to be about half of the anemometer reading and is the basis for the wind velocity shown on the data figures and Tables.

The test run log is shown in Table IV-1. The test was conducted in 7 data runs with an initial shakedown run prior to run 1 and an additional run at the conclusion of the test to check the affect of the driveshaft bearing clamps tight at the upper end of the test stand driveshaft. Run 5 was basically a rotor load check run and therefore was not properly zeroed for thrust measurement. All other runs are considered good data runs. The test procedure for each run was to hold rpm constant and to vary collective pitch from the minimum of -3.7 deg up to a value corresponding the limit mast torque which usually occurred at 12 to 14 deg of pitch at the blade tip. The rpm range used for the test was 458, 534, 565 and 600 with tip speeds of 600, 700, 740 and 786 feet per second respectively. The total number of valid data points is 72 and the total run time is 5 hours-18 minutes. The blade tip Mach number range versus outside temperature covered by the test is shown in Figure IV-1.

Rotor flapping was monitored throughout the test and also recorded on the latter runs. Flapping generally did not exceed ±1/2 deg except during occasional wind gusts the flapping would go to ±1 1/2 deg.

Comparison of power measured by the test stand to the power determined by the torque strain gage on the mast is shown in Figure IV-2. Additional tabulated data of power measurements from mast torque and test stand is given in the Appendix, Tables I and II.

As seen in Figure IV-2, power from the two methods is generally within less than 1 percent and the maximum discrepancy is 3 percent. Correlation between measured performance and theory and data scatter for test runs at 600 and 740 feet per second is shown in the Appendix, Tables III through VI.

B. TEST RESULTS

Test results are plotted in Figure IV-3 in terms of horsepower over density ratio versus thrust over density ratio for the four test tip speeds. All of the data points are shown in a non-dimensional plot of power versus thrust coefficient in Figure IV-4. It is seen that the data from all four test RPM's fall together and that there is no discernible effect of tip speed for the tested tip Mach number range from .55 to .71.

Test results from the hover test of the 25-foot diameter rotor in the Ames 40 x 80 foot wind tunnel are compared in Figure IV-4 with the whirl tower results. The whirl tower data substantiates the performance measured in the wind tunnel, in fact it indicates slightly better performance; in that for the same thrust coefficient, the power is approximately 5 to 8 percent less.

Figure IV-5 shows the lifting efficiency of the rotor in terms of pounds of lift per horsepower for the design tip speed of 740 ft/second. Lifting efficiency exceeds 10 pounds per horsepower and is 8.3 pounds per horsepower at a thrust corresponding to an aircraft gross weight of 13,000 pounds. As shown in Figure IV-6, figure of merit exceeded .81 for the low wind data points.

C. PERFORMANCE PREDICTION METHOD

Tilt rotor performance is calculated using theory and a computer program developed for helicopter rotors. The analysis combines blade element and momentum theory based on the method of NACA TN3747.

The mathematical model has been extended to eliminate small angle assumptions and include aerodynamic refinements such as the inplane component of induced velocity. In addition, the calculated induced velocity has been increased seven percent based on results of correlation studies with the measured performance of many helicopters.

The effects of stall, compressibility, and reverse flow are included by entering tables of the airfoil's two-dimensional lift and drag coefficients. The tables cover the range of Mach numbers up to 1.0 and angles of attack from 0 to ±180 degrees. Each blade may be divided into spanwise segments with the blade twist and planform varying linearly within each segment. The rotor equations of motion are solved by numerical integration. Bell computer program ARST01, the latest version of F35 with improved iteration loops, is used to make the calculations. A seeming limitation of this performance method (F35) is the assumption of an induced velocity based on simple momentum theory. Comparison with other performance prediction methods, however, shows that this is not objectionable. Bell has a computer program (BRAM) which incorporates free trailing tip vortex, and a program (AR0601), which has a semifree wake. Neither of these programs predicts significantly different performance than F35 and both require much more computer time. In hover, the 7 percent empirical corrections incorporated in F35 to account for the higher order wake effects and other factors influencing hover performance, results in good correlation with helicopter flight test data. With the free wake representation, some empirical corrections are also required to achieve the same degree of correlation. At the present state of the art, the use of sophisticated wake representations does not offer increased accuracy.

In 1970, when the 25-foot-diameter tilt rotor was tested in the Ames 40-x 80-foot tunnel, it reached thrust values 15 percent higher than the maximum thrust predicted by computer program F35. In correlation studies following the test (Reference 2) it was found that to predict as much thrust as measured it was necessary to

(1) Increase the tip loss factor B from a value of about .95 computed by the equation

$$B = 1 - \frac{\sqrt{2C_T}}{b}$$

to a value of .97 and

(2) Increase C_L max for some of the airfoil section data and

(3) Make C_L constant above C_L max for some of the airfoil section data.

Figure IV-2 through IV-5 of Reference 2 show the modifications made to the measured two-dimensional airfoil section data.

D. CORRELATION OF TEST WITH THEORY

Figure IV-7 and IV-8 shows how the above theory, (B = .97 etc) which was used for the pretest predicting, correlates with the whirl stand performance. It is seen that still the measured thrust exceeded the predicted maximum thrust by 8 percent.

Predicted performance is shown in the Test Plan and Predictions report (Reference 4).

Performance has been recalculated with the following additional modification to the performance method:

(1) The tip loss factor increased from .97 to 1.0 and

(2) C_L held constant above C_L Max in the section data for all airfoil at all Mach numbers and

(3) C_L max increased for the 18 percent airfoil at .5 Mach number to be consistent with what was done before for the other Mach numbers and airfoils.

Airfoil section data from the two-dimensional test data (Reference 5 and 6) are illustrated in Figures IV-9 through IV-12. The airfoil section data used in the computer program for each of the four blade segments is tabulated in Tables IV-2 through IV-9. The computer division of the blade into four segments is illustrated in Figure III-1.

Figure IV-13 through IV-22 show how the theory as modified by the second change (B = 1.0 etc), correlates with the whirl stand performance. It is seen that the theory now correctly predicts the thrust, but over predicts the power. Tables III and IV in the Appendix show the difference between test and theory at selected data points.

The discrepancy between the performance theory and the measured data is believed to be caused by three factors:

(1) While the rotor plane is some 56 feet (h/D = 2.25) above the ground there is still some ground effect from the work platform on the whirl tower that was discussed in Section III.

(2) Although, the use of a tip loss factor in helicopter performance calculation has been standard practice for many years and has been reasonably reliable, more refined analysis may be required to predict maximum thrust. For example several investigators (References 7, 8, 9) have found that square tipped wings and rotor blades develop considerable lift at their tip and that the assumption of zero lift outboard of some blade station is unrealistic. In fact, there is evidence (Reference 8) that the presence of the tip vortex can create much higher lift at the tip than would be calculated by classical wake theory and strip analysis. This additional lift is equivalent to the vortex in induced lift at the lateral edges of low aspect ratio wings. Bell has been studying under contract (Reference 10) with NASA the rotor wake and its interaction with various tip shapes on model rotors and has developed a rotor wake analytical model. However, there is at present no way to rigorously account

for the vortex generated lift on hovering rotors. Simplified approaches to quantifying tip vortex lift indicate that the assumption of zero tip loss may not be far from reality. The increase in pressure associated with vortex lift should also increase the power above that calculated by simple momentum theory and strip analysis.

(3) Although, the airfoil section data was based on careful two-dimensional testing at full scale Reynolds and Mach numbers there may be radial boundary layer flow which alleviates stall and increases the maximum lift coefficient.

The performance prediction method (B = 1.0, etc.) has been empirically developed on the basis of the whirl stand performance test which is somewhat optimistic because of a partial ground effect. Even so, the modifications of the theory have been logical and the resulting predicted performance is as accurate as possible at this time, and is in close agreement with the wind-tunnel test as shown in Figures IV-15, IV-17, IV-23 and IV-24. It appears that the wind-tunnel test was an accurate representative of out-of-ground effect hover and was more conservative than the whirl test.

E. AIRCRAFT HOVER CEILING

Hover ceilings of the Model 301 tilt rotor research aircraft (which uses the Bell Model 300 rotor) based on the measured whirl stand performance are shown in Figure IV-25. Included for comparison are predicted hover ceilings in Figures IV-26 and IV-27 based on a tip loss of B = .97 from Reference 11 and predicted hover ceilings based on B = 1.0. The prediction using B = 1.0 which is more conservative than test data, shows an increase in standard day hover ceiling of 2200 feet at constant gross weight or at a constant altitude an increase of 850 pounds of gross weight with respect to pretest predictions. The hover ceilings are based on an airframe download of 7 percent of thrust.

F. CONCLUSIONS AND RECOMMENDATIONS

1. Thrust measured on the whirl stand exceeded the maximum thrust predicted prior to the test by 8 percent.
2. Whirl stand power is optimistic in comparison to theory modified to correlate with thrust and in comparison with hover performance measured in the wind tunnel.
3. The modified theory is in good agreement with the wind-tunnel test.
4. The wind-tunnel test was representative of out-of-ground-effect hover and more conservative than the whirl test.

5. Future research on hover performance should include flow visualization of stall and tip vortex phenomenon which could include a tuft survey, a limited amount of hot-wire x-probes to determine spanwise flow velocities, and flow visualization using evaporative film techniques.

TABLE IV-1. HOVER TEST RUN LOG

RUN	NUMBER OF DATA POINTS	RPM	TIP SPEED (fps)	TIP COLLECTIVE PITCH (deg)	TEMP (DEG C.)	BAROMETER (IN Hg)	WIND VELOCITY AT ROTOR (KTS)	TIP MACH NUMBER	RUN TIME (MINUTES)	RUN ACCUM. TIME (HRS-MIN)
Initial Shakedown Run	11*	0 to 456	-	-2 to +8	+5	29.19	0-5	-	51	51
1	13	458^{+1}_{-2}	600	-3.7 to +14	+5	29.08 to 29.19	0 to 4	.546	37	1:28
2	12	534^{+3}_{-1}	700	-3.7 to +13	+5	29.06	0-5	.637	24	1:52
3	13	565^{+2}_{-0}	740	-3.7 to +12.5	0	29.19	0-5	.680	39	2:31
4	1	564	739	+7	+5	29.19	0-6	.674	10	2:41
5	9*	300-565	-	-3.7 to +8	+5	29.42	0-2	-	25	3:06
6	6	458^{+0}_{-2}	600	-3.7 to 12	+2	29.55	0-2	.550	86	4:32
	11	565^{+4}_{-1}	740	-3.7 to +12	+4	29.55	0-2	.678		
7	16	600^{+1}_{-2}	786	-3.7 to +11	+6	29.54	0-2	.715	36	5:08
Tight Shaft Run	2	565	740	+6, +8	+8	29.54	0-2	-	10	5:18

*Thrust readings not valid since no zero reading taken prior to test.

TABLE IV-2. LIFT COEFFICIENTS, 7.5- TO 42.5-PERCENT BLADE RADIUS, COMPUTER INPUT DATA

ANGLES OF ATTACK	MACH NUMBERS 0.	0.30000	0.75000	0.80000
-180.0	0.00300	0.	0.	0.
-170.0	0.50000	0.31000	0.22000	0.16000
-165.0	0.49000	0.27000	0.19000	0.15000
-160.0	0.28000	0.22000	0.16000	0.12000
-150.0	0.13000	0.12000	0.09000	0.07000
-145.0	0.35000	0.18000	0.14000	0.10000
-140.0	0.52000	0.24000	0.18000	0.14000
-130.0	0.53000	0.36000	0.26000	0.20000
-120.0	0.38000	0.24000	0.18000	0.14000
-100.0	0.	0.	0.	0.
-90.0	-0.26000	-0.16000	-0.13000	-0.10000
-80.0	-0.50000	-0.31000	-0.25000	-0.20000
-60.0	-0.94000	-0.61000	-0.49000	-0.40000
-50.0	-1.00000	-0.75000	-0.61000	-0.49000
-40.0	-0.90000	-0.65000	-0.53000	-0.43000
-30.0	-0.62000	-0.54000	-0.44000	-0.37000
-25.0	-0.74000	-0.57000	-0.45000	-0.36000
-20.0	-0.86000	-0.59000	-0.48000	-0.36000
-12.0	-0.60000	-0.54000	-0.34000	-0.23000
-10.0	-0.55000	-0.50000	-0.27500	-0.19000
-8.0	-0.49000	-0.44500	-0.21500	-0.15000
-6.0	-0.32500	-0.29000	-0.15000	-0.11500
-4.0	-0.15000	-0.13000	-0.05500	-0.05000
-2.0	0.03800	0.04000	0.03000	0.01500
0.	0.26000	0.20000	0.12000	0.08000
2.0	0.42000	0.36500	0.20500	0.14000
4.0	0.64000	0.52500	0.29000	0.20500
8.0	0.93500	0.93500	0.40500	0.26000
10.0	1.01000	1.01000	0.43500	0.28500
12.0	1.10500	1.10500	0.46000	0.31000
16.0	1.12000	1.12000	0.46000	0.30000
18.0	1.12500	1.12500	0.46000	0.29000
20.0	1.12500	1.12500	0.46000	0.28000
22.0	1.12500	1.12500	0.44000	0.28000
25.0	1.12500	1.12500	0.43000	0.26000
30.0	1.12500	1.12500	0.40000	0.25000
40.0	1.12500	1.12500	0.56000	0.43000
50.0	1.00000	0.87000	0.74000	0.60000
180.0	0.	0.	0.	0.

TABLE IV-3. DRAG COEFFICIENTS, 7.5- TO 42.5-PERCENT BLADE RADIUS, COMPUTER INPUT DATA

ANGLES OF ATTACK	MACH NUMBERS 0.	0.65000	0.75000	0.80000
-180.0	0.03000	0.08000	0.21000	0.34000
-160.0	0.30000	0.35000	0.71000	1.00000
-150.0	0.45000	0.87000	1.07000	1.38000
-145.0	0.68000	1.03000	1.23000	1.58000
-140.0	0.95000	1.17000	1.41000	1.77000
-130.0	1.20000	1.50000	1.76000	2.14000
-120.0	1.51000	1.81000	2.10000	2.50000
-100.0	2.00000	2.20000	2.50000	2.50000
-90.0	2.04000	2.26000	2.50000	2.50000
-80.0	1.86000	2.25000	2.50000	2.50000
-60.0	1.47000	1.95000	2.50000	2.50000
-50.0	1.22000	1.71000	2.30000	2.50000
-40.0	0.86000	1.28000	1.80000	2.50000
-30.0	0.38000	0.86000	1.26000	1.99000
-25.0	0.27000	0.66000	1.00000	1.69000
-20.0	0.17000	0.45000	0.74000	1.40000
-12.0	0.03800	0.11300	0.34300	0.92000
-10.0	0.02300	0.06000	0.27800	0.82000
-8.0	0.01700	0.04300	0.20600	0.70000
-6.0	0.01400	0.03000	0.16800	0.58000
-4.0	0.01400	0.03000	0.13900	0.44000
-2.0	0.01400	0.03000	0.12000	0.40000
0.	0.01400	0.03000	0.12000	0.40000
2.0	0.01400	0.03000	0.12000	0.40000
4.0	0.01400	0.03000	0.13500	0.45000
8.0	0.02600	0.02600	0.20000	0.69000
10.0	0.03400	0.03400	0.28000	0.80000
12.0	0.04200	0.04200	0.37000	0.92000
16.0	0.10000	0.10000	0.56000	1.15000
18.0	0.13300	0.13300	0.66000	1.28000
20.0	0.17400	0.17400	0.75000	1.40000
22.0	0.21000	0.21000	0.85000	1.50000
25.0	0.26000	0.26000	0.99000	1.69000
40.0	0.70000	0.70000	1.68000	2.50000
50.0	1.10000	1.10000	2.14000	2.50000
180.0	0.	0.	0.	0.

TABLE IV-4. LIFT COEFFICIENTS, 42.5- TO 65-PERCENT BLADE RADIUS, COMPUTER INPUT DATA

ANGLES OF ATTACK	MACH NUMBERS 0.	0.26000	0.30000	0.40000	0.50000	0.61000	0.66000	0.71000	1.00000
-180.0	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000
-8.0	-0.85800	-0.85800	-0.86000	-0.87500	-0.86500	-0.85500	-0.78000	-0.60000	-0.18000
-6.0	-0.62500	-0.62500	-0.62500	-0.64500	-0.64000	-0.63500	-0.57000	-0.45000	-0.15000
-4.0	-0.39500	-0.39500	-0.39500	-0.40500	-0.40300	-0.40000	-0.35500	-0.29000	-0.11500
-2.0	-0.17000	-0.17000	-0.16500	-0.17000	-0.18000	-0.19000	-0.15000	-0.13000	-0.06000
0.	0.05000	0.05000	0.05000	0.05000	0.04500	0.04000	0.03500	0.03000	0.01500
2.0	0.27000	0.27000	0.27000	0.26500	0.27000	0.25500	0.22000	0.19000	0.09000
4.0	0.48500	0.48500	0.48000	0.49500	0.48300	0.47000	0.41000	0.35000	0.16500
6.0	0.69000	0.69000	0.68500	0.70500	0.69000	0.67500	0.61000	0.51000	0.19000
8.0	0.89000	0.89000	0.88500	0.91000	0.90300	0.89500	0.80000	0.67000	0.21000
10.0	1.08000	1.08000	1.06500	1.12000	1.06800	1.01500	0.90500	0.75000	0.23000
12.0	1.16500	1.16500	1.17500	1.20000	1.13800	1.07500	0.96000	0.80000	0.26000
14.0	1.16500	1.16500	1.17500	1.20000	1.13800	1.07500	0.99500	0.80000	0.28000
20.0	1.16500	1.16500	1.17500	1.20000	1.13800	1.07500	0.99500	0.80000	0.35000
50.0	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000
130.0	-0.80000	-0.80000	-0.80000	-0.80000	-0.80000	-0.80000	-0.80000	-0.80000	-0.80000
180.0	0.	0.	0.	0.	0.	0.	0.	0.	0.

TABLE IV-5. DRAG COEFFICIENTS, 42.5- TO 65-PERCENT BLADE RADIUS, COMPUTER INPUT DATA

ANGLES OF ATTACK	MACH NUMBERS 0.	0.26000	0.30000	0.40000	0.50000	0.61000	0.66000	0.71000	1.00000
-180.0	5.42100	5.42100	5.42100	5.42100	5.42100	5.42100	5.42100	5.42100	5.42100
-8.0	0.01400	0.01400	0.01400	0.01400	0.01700	0.02200	0.02500	0.06100	0.44000
-6.0	0.01000	0.01000	0.01000	0.01000	0.01100	0.01200	0.01000	0.03000	0.35500
-4.0	0.00900	0.00900	0.00900	0.00900	0.00900	0.01000	0.00800	0.02300	0.31200
-2.0	0.00700	0.00700	0.00700	0.00700	0.00700	0.00700	0.00700	0.01500	0.30000
0.	0.00700	0.00700	0.00700	0.00700	0.00700	0.00700	0.00700	0.01500	0.30000
2.0	0.00700	0.00700	0.00700	0.00700	0.00700	0.00700	0.00700	0.01800	0.30100
4.0	0.00800	0.00800	0.00700	0.00700	0.00800	0.00700	0.00800	0.02900	0.32300
6.0	0.01000	0.01000	0.00900	0.00800	0.01400	0.00700	0.00700	0.04700	0.34600
8.0	0.01400	0.01400	0.01300	0.01100	0.01500	0.01400	0.03700	0.12500	0.41000
10.0	0.02100	0.02100	0.02000	0.02100	0.05400	0.03300	0.08200	0.28200	0.47600
12.0	0.07200	0.07200	0.06600	0.05000	0.08300	0.06800	0.19000	0.35000	0.54000
14.0	0.10100	0.10100	0.10400	0.09200	0.12400	0.21200	0.25000	0.41700	0.59000
16.0	0.12600	0.12600	0.14000	0.12500	0.21600	0.30800	0.34400	0.48400	0.63000
18.0	0.18100	0.18100	0.21500	0.17500	0.30300	0.40600	0.44200	0.52800	0.80000
90.0	0.21300	0.30700	0.34400	0.37800	1.60000	2.05000	2.05000	2.05000	2.05000
180.0	0.30400	0.40600	0.44100	0.47500	1.80000	2.60000	2.60000	2.60000	2.60000

TABLE IV-6. LIFT COEFFICIENTS, 65- TO 90-PERCENT BLADE RADIUS COMPUTER INPUT DATA

ANGLES OF ATTACK	MACH NUMBERS 0.	0.30000	0.40000	0.50000	0.60000	0.66000	0.71000	0.76000	0.82000	0.85000	1.00000
-180.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
-10.0	-0.76700	-0.76700	-0.74100	-0.70600	-0.49500	-0.88000	-0.87000	-0.80000	-0.73000	-0.49000	-0.37000
-9.0	-0.75000	-0.75000	-0.72000	-0.70500	-0.64000	-0.86500	-0.85000	-0.80000	-0.73000	-0.52000	-0.38500
-8.0	-0.70800	-0.70800	-0.70800	-0.70000	-0.72000	-0.83300	-0.81800	-0.77200	-0.71000	-0.55000	-0.40000
-7.0	-0.65000	-0.65000	-0.65000	-0.69000	-0.70000	-0.76500	-0.74000	-0.68000	-0.65500	-0.49500	-0.38500
-6.0	-0.55900	-0.55900	-0.58900	-0.58700	-0.62600	-0.65600	-0.65900	-0.59500	-0.58500	-0.44000	-0.36000
-5.0	-0.45000	-0.45000	-0.47000	-0.50000	-0.54000	-0.54000	-0.55000	-0.51000	-0.48000	-0.37000	-0.33500
-4.0	-0.34300	-0.34300	-0.35700	-0.38000	-0.40500	-0.41400	-0.42500	-0.39600	-0.37500	-0.31000	-0.28000
-3.0	-0.25000	-0.25000	-0.24000	-0.27000	-0.27000	-0.28000	-0.30000	-0.28000	-0.26500	-0.24000	-0.20000
-2.0	-0.12300	-0.12300	-0.12500	-0.13200	-0.14600	-0.15500	-0.14000	-0.14400	-0.16000	-0.15500	-0.12000
-1.0	-0.03000	-0.03000	-0.01000	-0.03000	-0.03100	-0.03200	-0.10000	-0.04000	-0.06000	-0.06000	-0.04000
0.	0.07800	0.07800	0.08500	0.08900	0.09300	0.09900	0.09900	0.07200	0.05900	0.05000	0.04000
1.0	0.18000	0.18000	0.21000	0.21300	0.23300	0.24000	0.23000	0.20500	0.18000	0.13000	0.12000
2.0	0.30900	0.30900	0.31800	0.33800	0.36300	0.36500	0.36200	0.31500	0.27000	0.22800	0.20000
3.0	0.40000	0.40000	0.43900	0.46700	0.50200	0.50000	0.51000	0.42500	0.38000	0.31500	0.27500
4.0	0.52300	0.52300	0.55100	0.58300	0.62700	0.62300	0.62000	0.53700	0.48500	0.41000	0.35500
5.0	0.62000	0.62000	0.66500	0.68000	0.73500	0.73000	0.70000	0.62000	0.59500	0.50000	0.43500
6.0	0.73500	0.73500	0.78100	0.82500	0.88300	0.87400	0.79700	0.70900	0.66000	0.60000	0.51500
7.0	0.83000	0.83000	0.88500	0.92000	0.96000	0.94000	0.87200	0.76000	0.74000	0.69000	0.58000
8.0	0.95600	0.95600	1.00000	1.02000	1.05400	1.00500	0.94800	0.82000	0.81000	0.78000	0.59000
9.0	1.05000	1.05000	1.11000	1.11400	1.11000	1.05000	1.01000	0.85900	0.88000	0.88000	0.60500
10.0	1.15900	1.15900	1.17800	1.17500	1.14700	1.08500	1.05700	0.89900	0.93000	0.96000	0.62000
11.0	1.23600	1.23600	1.20000	1.20000	1.14700	1.08500	1.10500	0.89900	1.01000	1.03000	0.63000
12.0	1.25400	1.25400	1.20000	1.20000	1.14700	1.08500	1.14200	0.89900	1.01000	1.03000	0.63000
13.0	1.25400	1.25400	1.20000	1.20000	1.14700	1.08500	1.14200	0.89900	1.01000	1.03000	0.63000
14.0	1.25400	1.25400	1.20000	1.20000	1.14700	1.08500	1.14200	0.89900	1.01000	1.03000	0.63000
15.0	1.25400	1.25400	1.20000	1.20000	1.14700	1.08500	1.14200	0.89900	1.01000	1.03000	0.63000
16.0	1.25400	1.25400	1.20000	1.20000	1.14700	1.08500	1.14200	0.89900	1.01000	1.03000	0.63000
17.0	1.25400	1.25400	1.20000	1.20000	1.14700	1.08500	1.14200	0.89900	1.01000	1.03000	0.63000
18.0	1.25400	1.25400	1.20000	1.20000	1.14700	1.08500	1.14200	0.89900	1.01000	1.03000	0.63000
19.0	1.25400	1.25400	1.20000	1.20000	1.14700	1.08500	1.14200	0.89900	1.01000	1.03000	0.72000
20.0	1.25400	1.25400	1.20000	1.20000	1.14700	1.08500	1.14200	0.89900	1.01000	1.03000	0.78000
180.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.

TABLE IV-7. DRAG COEFFICIENTS, 65- TO 90-PERCENT BLADE RADIUS, COMPUTER INPUT DATA

ANGLES OF ATTACK	MACH NUMBERS 0.	0.30000	0.40000	0.50000	0.60000	0.66000	0.71000	0.76000	0.82000	0.85000	1.00000
-180.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
-10.0	0.13200	0.13200	0.13200	0.13500	0.15300	0.18400	0.23100	0.28200	0.33000	0.37000	0.
-9.0	0.10100	0.10100	0.10000	0.10500	0.11200	0.12800	0.17300	0.23200	0.28100	0.31700	0.
-8.0	0.05900	0.05900	0.06800	0.08000	0.05800	0.06600	0.09800	0.14300	0.23000	0.25900	0.
-7.0	0.03200	0.03200	0.04000	0.05300	0.05000	0.04700	0.07000	0.10700	0.19600	0.23200	0.
-6.0	0.01000	0.01000	0.01200	0.02100	0.02200	0.02800	0.04100	0.06600	0.17000	0.20800	0.45500
-5.0	0.01000	0.01000	0.01000	0.01600	0.01300	0.01300	0.01400	0.03700	0.13500	0.19300	0.38800
-4.0	0.01000	0.01000	0.00900	0.00900	0.00800	0.01000	0.01100	0.01400	0.11800	0.17700	0.33700
-3.0	0.00900	0.00900	0.00800	0.00800	0.00700	0.00900	0.00900	0.01000	0.10500	0.16300	0.32300
-2.0	0.00800	0.00800	0.00800	0.00800	0.00700	0.00800	0.00800	0.00900	0.09700	0.14900	0.30800
-1.0	0.00700	0.00700	0.00700	0.00700	0.00600	0.00600	0.00700	0.01000	0.09500	0.14900	0.30000
0.	0.00600	0.00600	0.00600	0.00600	0.00600	0.00600	0.00600	0.01300	0.09100	0.14900	0.30000
1.0	0.00600	0.00600	0.00600	0.00600	0.00600	0.00700	0.00700	0.01900	0.10800	0.16000	0.30300
2.0	0.00600	0.00600	0.00600	0.00600	0.00700	0.00600	0.00800	0.03500	0.12800	0.17500	0.30600
3.0	0.00800	0.00800	0.00600	0.00600	0.00600	0.00600	0.01000	0.05800	0.15200	0.19500	0.31400
4.0	0.00900	0.00900	0.00700	0.00700	0.00800	0.00700	0.01600	0.06000	0.17500	0.21800	0.32300
5.0	0.01000	0.01000	0.00800	0.00800	0.01000	0.01000	0.02300	0.08500	0.19800	0.23500	0.33900
6.0	0.01000	0.01000	0.00800	0.00900	0.01100	0.01300	0.03500	0.09500	0.21500	0.25300	0.36000
7.0	0.01100	0.01100	0.01000	0.01000	0.01900	0.02000	0.05900	0.13900	0.23800	0.27500	0.38200
8.0	0.01300	0.01300	0.01200	0.01500	0.02700	0.03500	0.08800	0.16800	0.26100	0.29900	0.41000
9.0	0.01400	0.01400	0.01300	0.01900	0.04800	0.06400	0.13100	0.20000	0.28700	0.31600	0.43600
10.0	0.01700	0.01700	0.01800	0.03500	0.05600	0.09300	0.16100	0.23000	0.30500	0.33900	0.46000
11.0	0.02300	0.02300	0.03600	0.06000	0.12300	0.13500	0.20500	0.25000	0.32100	0.35300	0.
12.0	0.03400	0.03400	0.11000	0.09800	0.16800	0.18700	0.22400	0.26800	0.33700	0.36700	0.
13.0	0.13700	0.13700	0.13200	0.13600	0.20000	0.19500	0.24400	0.28700	0.35300	0.38200	0.
14.0	0.21100	0.21100	0.18600	0.19100	0.22900	0.23500	0.26600	0.30500	0.37000	0.39700	0.
15.0	0.23000	0.23000	0.21100	0.21800	0.25200	0.25900	0.28600	0.32400	0.38800	0.41300	0.
16.0	0.24800	0.24800	0.24500	0.24300	0.27600	0.28200	0.30800	0.34300	0.40300	0.42800	0.
17.0	0.27300	0.27300	0.25300	0.26600	0.29800	0.30700	0.32900	0.36100	0.42000	0.44300	0.
18.0	0.28500	0.28500	0.27500	0.29000	0.32100	0.33000	0.35000	0.38000	0.43500	0.45800	0.
19.0	0.29800	0.29800	0.29700	0.31200	0.33100	0.34900	0.36700	0.39600	0.45100	0.46900	0.
20.0	0.32000	0.32000	0.31800	0.33200	0.35600	0.36800	0.38400	0.41200	0.46400	0.48100	0.
180.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.

TABLE IV-8. LIFT COEFFICIENTS, 90- TO 100-PERCENT BLADE RADIUS, COMPUTER INPUT DATA

ANGLES OF ATTACK	MACH NUMBERS 0.	0.30000	0.40000	0.50000	0.60000	0.66000	0.71000	0.76000	0.81000	0.85000	1.00000
-180.0	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000
-6.0	-0.54100	-0.54100	-0.55400	-0.57800	-0.61200	-0.70100	-0.76000	-0.79000	-0.68000	-0.57500	-0.57500
-5.0	-0.43400	-0.43400	-0.44800	-0.47300	-0.51300	-0.57000	-0.63000	-0.68000	-0.56000	-0.51000	-0.51000
-4.0	-0.34000	-0.34000	-0.35200	-0.36800	-0.40100	-0.42900	-0.48200	-0.53000	-0.44000	-0.43500	-0.43500
-3.0	-0.25000	-0.25000	-0.25500	-0.26000	-0.27600	-0.28000	-0.29000	-0.36000	-0.29000	-0.29500	-0.29500
-2.0	-0.11600	-0.11600	-0.12000	-0.12900	-0.14500	-0.15400	-0.13000	-0.19300	-0.12100	-0.11500	-0.11500
-1.0	-0.01200	-0.01200	-0.01100	-0.01500	-0.02000	-0.02000	0.02000	-0.01600	0.00100	0.02500	0.02500
0.	0.09100	0.09100	0.09500	0.10100	0.11100	0.11800	0.17000	0.15000	0.21700	0.18500	0.18500
1.0	0.20700	0.20700	0.21600	0.22300	0.25500	0.28000	0.32000	0.33500	0.36000	0.34500	0.34500
2.0	0.32300	0.32300	0.33400	0.35700	0.38900	0.41600	0.46100	0.49000	0.51000	0.49000	0.49000
3.0	0.42000	0.42000	0.43000	0.48000	0.52000	0.56500	0.61000	0.62500	0.65000	0.59500	0.59500
4.0	0.54500	0.54500	0.56900	0.62000	0.66500	0.71200	0.76700	0.77400	0.76500	0.66000	0.66000
5.0	0.66000	0.66000	0.67000	0.75000	0.78000	0.84000	0.89000	0.87500	0.84000	0.71500	0.71500
6.0	0.77200	0.77200	0.79400	0.81000	0.91600	0.97000	0.98700	0.95600	0.91000	0.74000	0.74000
7.0	0.87800	0.87800	0.88700	0.92800	1.04100	1.07500	1.06000	0.99000	0.94500	0.76000	0.76000
8.0	0.95000	0.95000	1.00100	1.04000	1.14800	1.15000	1.12600	1.02000	0.90000	0.78000	0.78000
9.0	0.98800	0.98800	1.11000	1.14000	1.21000	1.19900	1.17800	1.05500	0.92000	0.78000	0.78000
10.0	1.00900	1.00900	1.17200	1.18600	1.23300	1.19900	1.21800	1.05500	0.87000	0.78000	0.78000
11.0	1.01600	1.01600	1.20000	1.20000	1.23300	1.19900	1.25400	1.05500	0.87000	0.78000	0.78000
12.0	1.01600	1.01600	1.20000	1.20000	1.23300	1.19900	1.25400	1.05500	0.87000	0.78000	0.78000
13.0	1.01600	1.01600	1.20000	1.20000	1.23300	1.19900	1.25400	1.05500	0.87000	0.78000	0.78000
14.0	1.01600	1.01600	1.20000	1.20000	1.23300	1.19900	1.25400	1.05500	0.87000	0.78000	0.78000
50.0	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000
130.0	-0.80000	-0.80000	-0.80000	-0.80000	-0.80000	-0.80000	-0.80000	-0.80000	-0.80000	-0.80000	-0.80000
180.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.

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TABLE IV-9. DRAG COEFFICIENTS, 90- TO 100-PERCENT BLADE RADIUS, COMPUTER INPUT DATA

ANGLES OF ATTACK	MACH NUMBERS 0.	0.30000	0.40000	0.50000	0.60000	0.66000	0.71000	0.76000	0.81000	0.85000	1.00000
-180.0	5.00000	5.00000	5.00000	5.00000	5.00000	5.00000	5.00000	5.00000	5.00000	5.00000	5.00000
-10.0	0.10600	0.10600	0.11800	0.15400	0.17400	0.19000	0.20400	0.23300	0.27000	0.33000	0.56000
-5.0	0.02500	0.02500	0.02300	0.03600	0.03300	0.03600	0.05000	0.07300	0.09400	0.12500	0.32500
-4.0	0.00900	0.00900	0.00900	0.01600	0.01900	0.02000	0.02600	0.03700	0.06700	0.10400	0.30300
-3.0	0.00700	0.00700	0.00800	0.01100	0.01000	0.01100	0.01200	0.02700	0.03900	0.07700	0.23500
-2.0	0.00700	0.00700	0.00700	0.00800	0.00800	0.00800	0.00900	0.00900	0.01500	0.04900	0.23500
-1.0	0.00700	0.00700	0.00700	0.00700	0.00600	0.00600	0.00700	0.00800	0.01200	0.04900	0.23500
0.	0.00600	0.00600	0.00600	0.00600	0.00600	0.00600	0.00600	0.00600	0.02100	0.04900	0.23500
1.0	0.00600	0.00600	0.00600	0.00600	0.00600	0.00600	0.00600	0.00900	0.03800	0.07200	0.23700
2.0	0.00600	0.00600	0.00600	0.00600	0.00600	0.00600	0.00600	0.01600	0.05600	0.09500	0.24600
3.0	0.00700	0.00700	0.00600	0.00600	0.00600	0.00700	0.00700	0.02900	0.08000	0.12100	0.25000
4.0	0.00800	0.00800	0.00600	0.00600	0.00800	0.00900	0.01100	0.05000	0.10500	0.14700	0.26100
5.0	0.00800	0.00800	0.00600	0.00600	0.01500	0.01700	0.02500	0.07200	0.12800	0.16700	0.27100
6.0	0.00900	0.00900	0.00700	0.00800	0.01900	0.02800	0.04900	0.09800	0.14900	0.18600	0.28400
7.0	0.01100	0.01100	0.00800	0.01100	0.04000	0.04400	0.07800	0.12400	0.17500	0.21000	0.30800
8.0	0.01500	0.01500	0.01000	0.01300	0.06100	0.07400	0.11500	0.15500	0.20300	0.23600	0.33200
9.0	0.06700	0.06700	0.02300	0.03000	0.09800	0.10400	0.14300	0.18000	0.22500	0.26200	0.35700
10.0	0.10700	0.10700	0.05200	0.05600	0.10800	0.14100	0.17000	0.21400	0.25300	0.28700	0.38100
11.0	0.14700	0.14700	0.07600	0.09000	0.15300	0.17000	0.20100	0.24100	0.27900	0.31200	0.40500
12.0	0.18100	0.18100	0.11700	0.12300	0.19100	0.20800	0.24300	0.26600	0.30500	0.33700	0.43000
13.0	0.20200	0.20200	0.15200	0.15400	0.22400	0.24100	0.26500	0.29100	0.33000	0.36200	0.45300
14.0	0.22700	0.22700	0.18100	0.18400	0.25000	0.26700	0.28600	0.31900	0.35500	0.38700	0.47700
15.0	0.24000	0.24000	0.20300	0.20400	0.27100	0.28900	0.31400	0.34300	0.38100	0.41200	0.48000
90.0	2.60000	2.60000	2.60000	2.60000	2.60000	2.60000	2.60000	2.60000	2.60000	2.60000	2.60000
180.0	0.01500	0.01500	0.01500	0.01500	0.01500	0.01500	0.01500	0.02000	0.04000	0.08000	0.30000

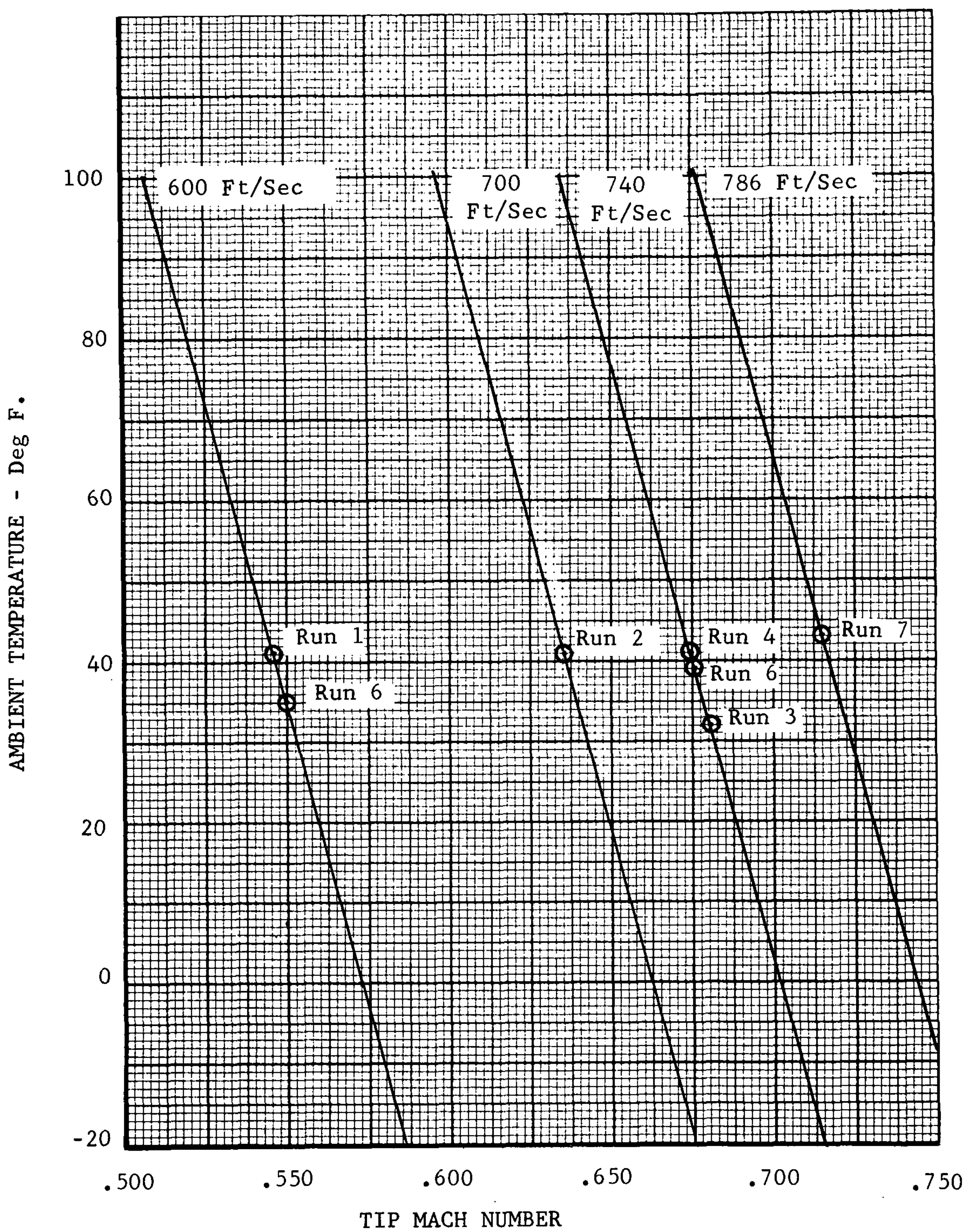

Figure IV-1. Tip Mach Number Variation With Temperature.

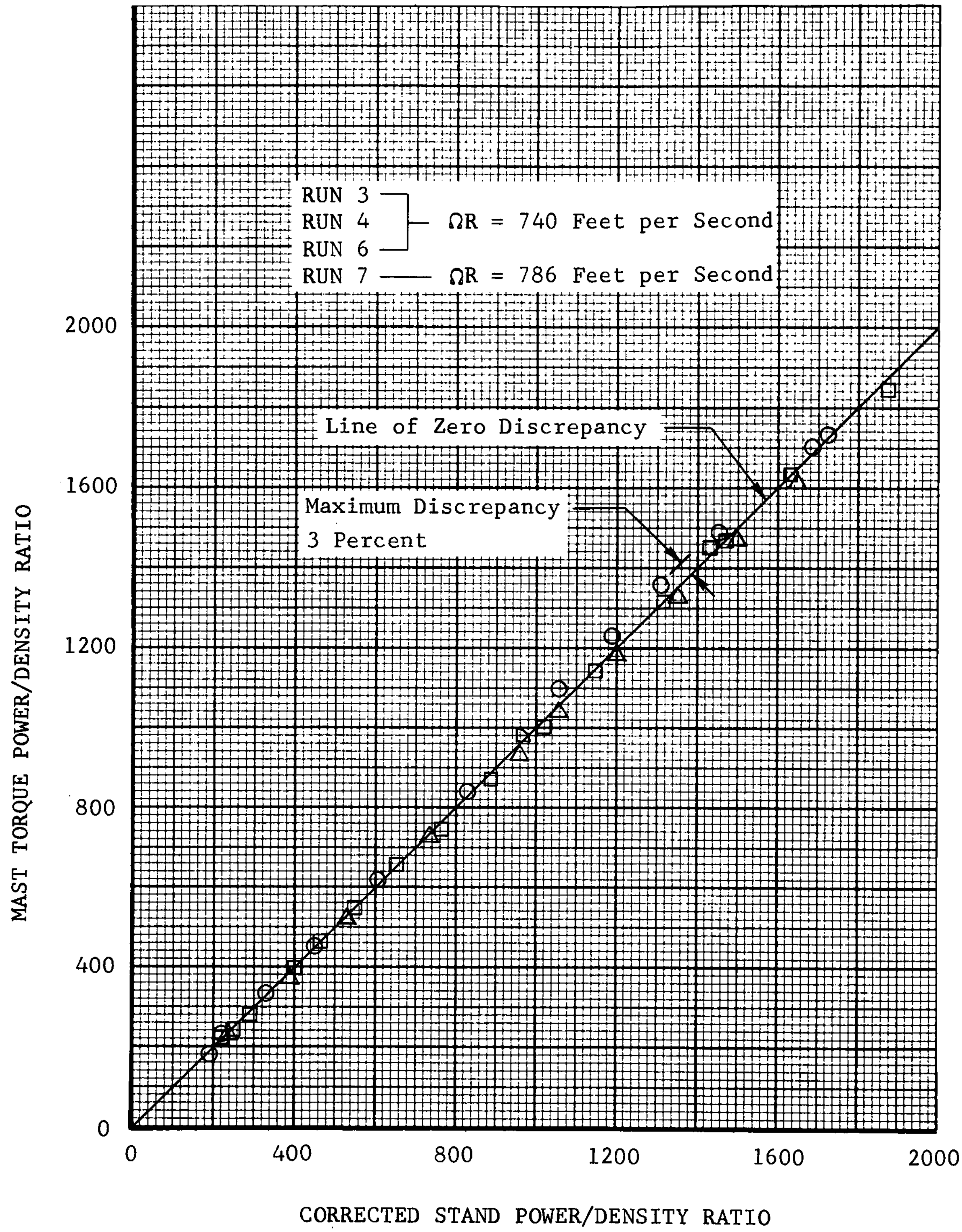

Figure IV-2. Comparison of Mast Torque Power to Corrected Test Stand Power.

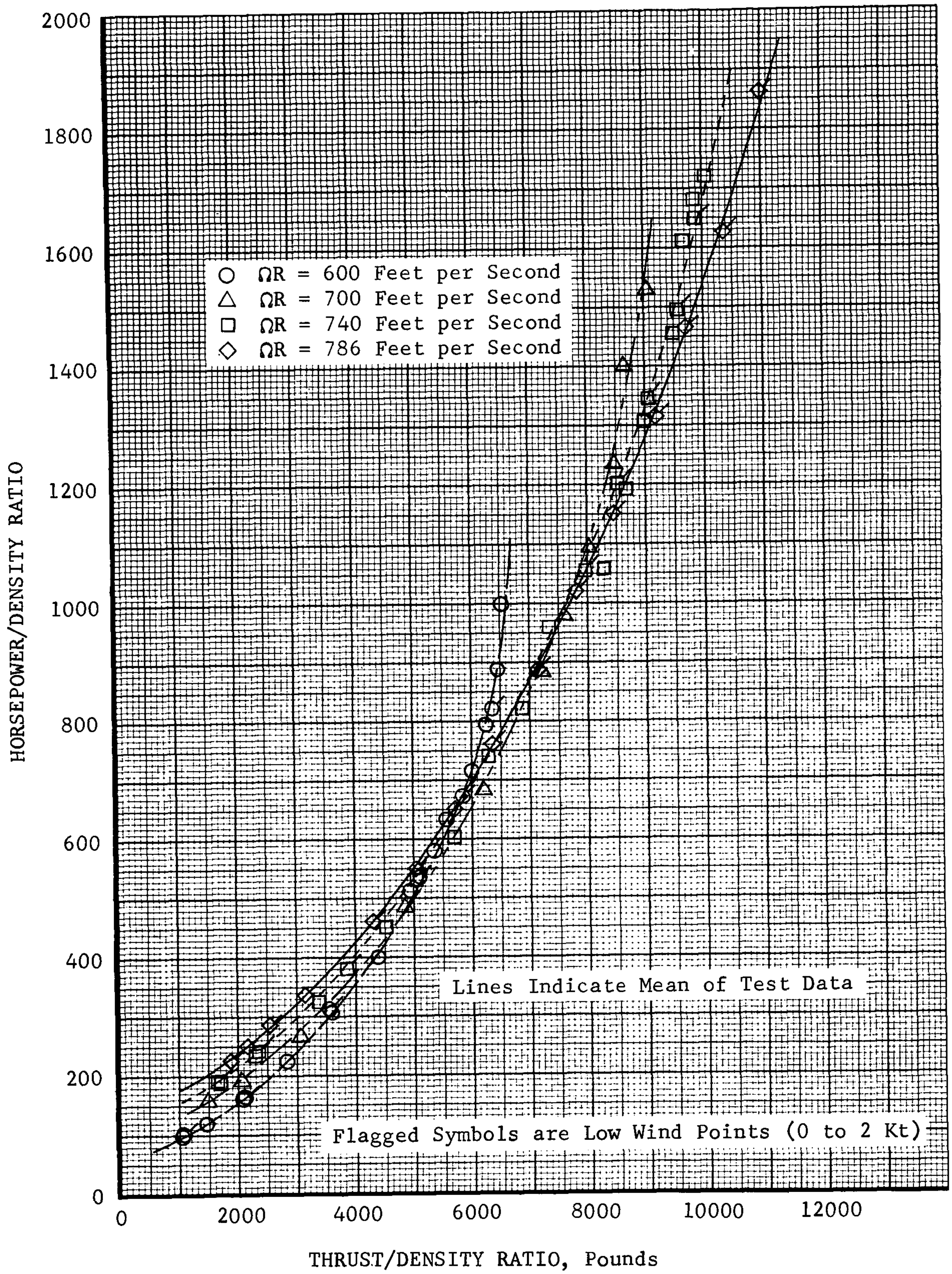

Figure IV-3. Dimensional Hover Power Required.

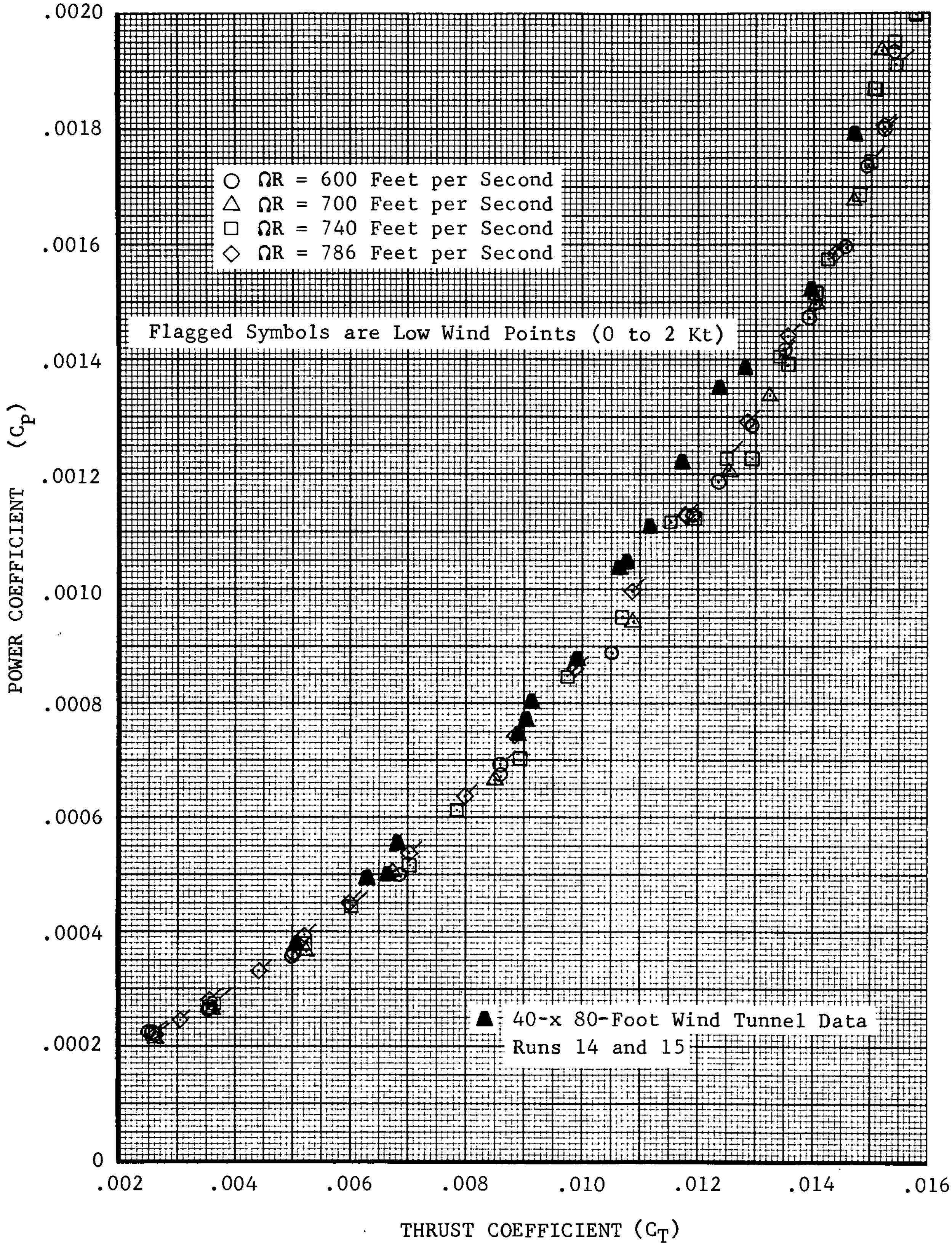

Figure IV-4. Nondimensional Hover Power Required.

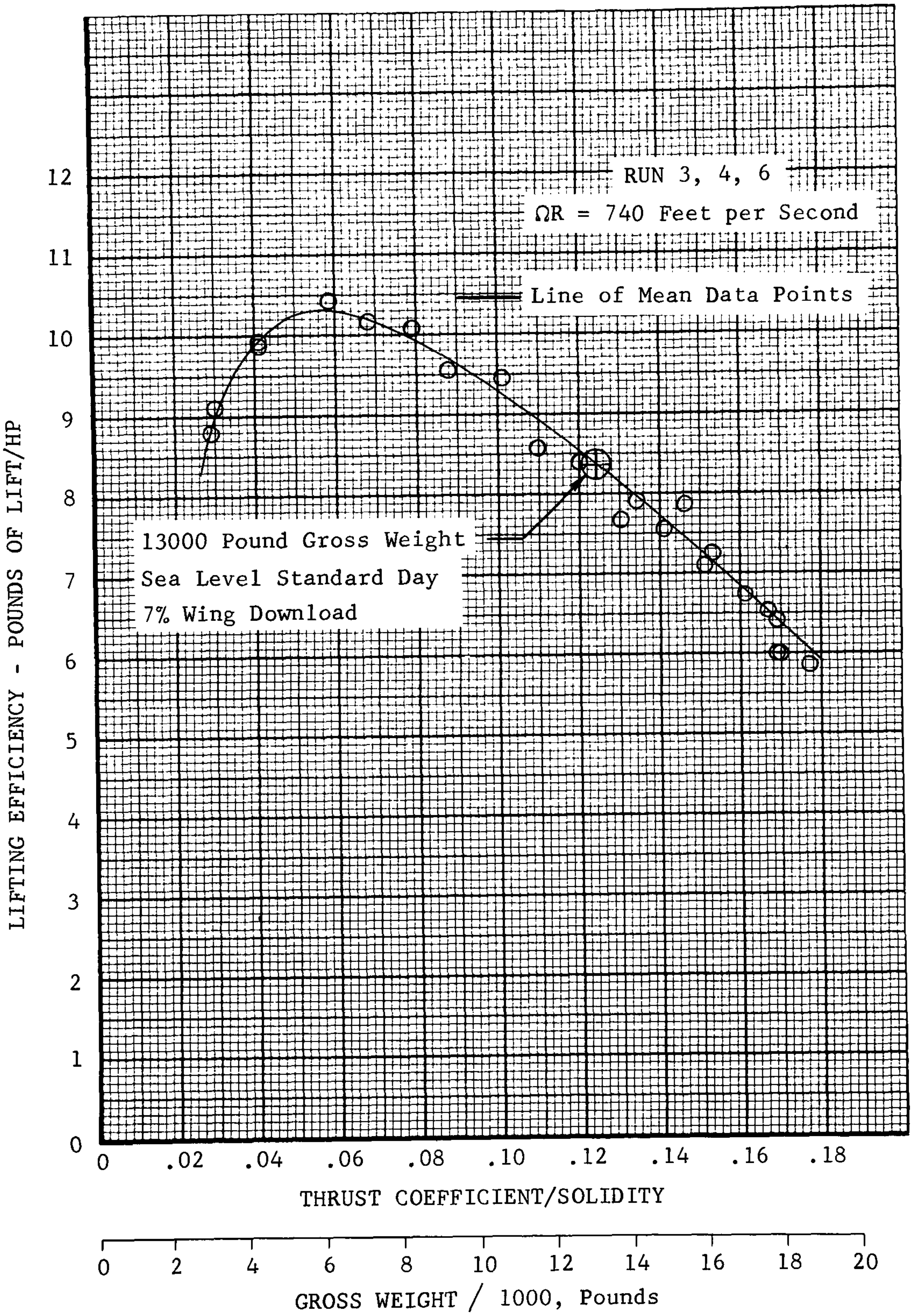

Figure IV-5. Tilt Rotor Lifting Efficiency For The Tilt Rotor Aircraft.

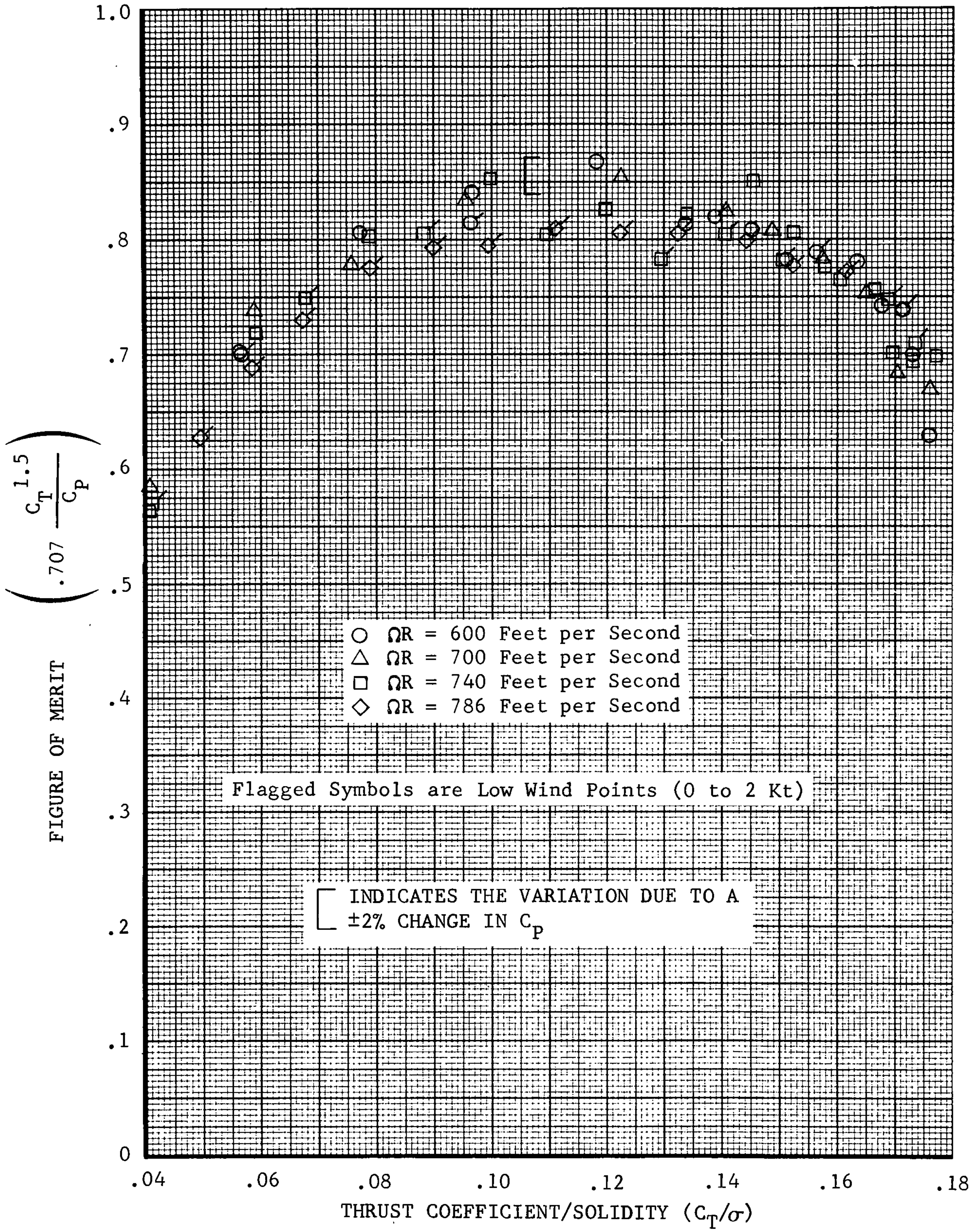

Figure IV-6. Tilt Rotor Figure of Merit Versus Thrust Coefficient/Solidity From All Data Points.

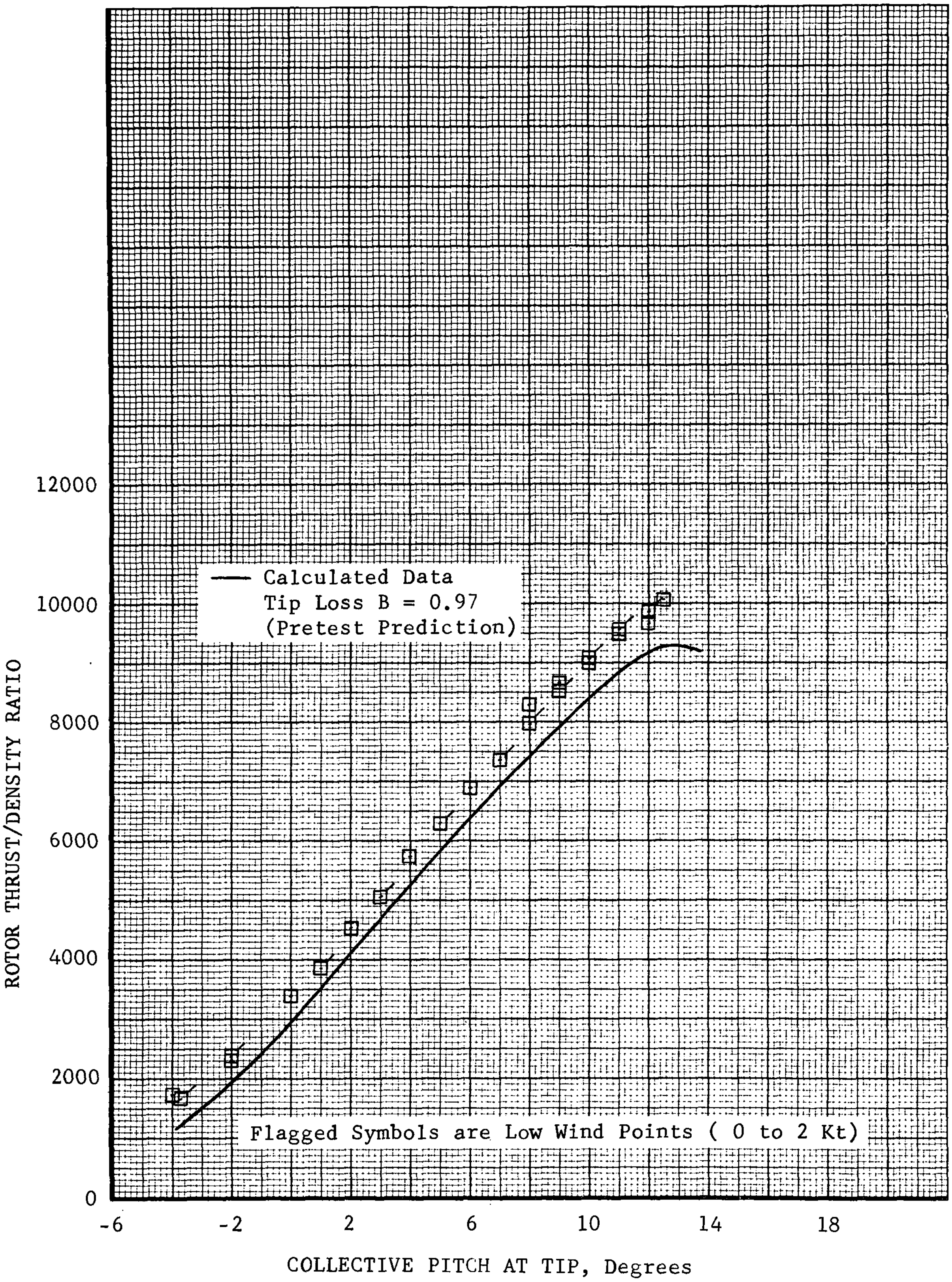

Figure IV-7. Correlation of Pretest Predicted Hover Thrust to Test Data at ΩR = 740 Feet Per Second.

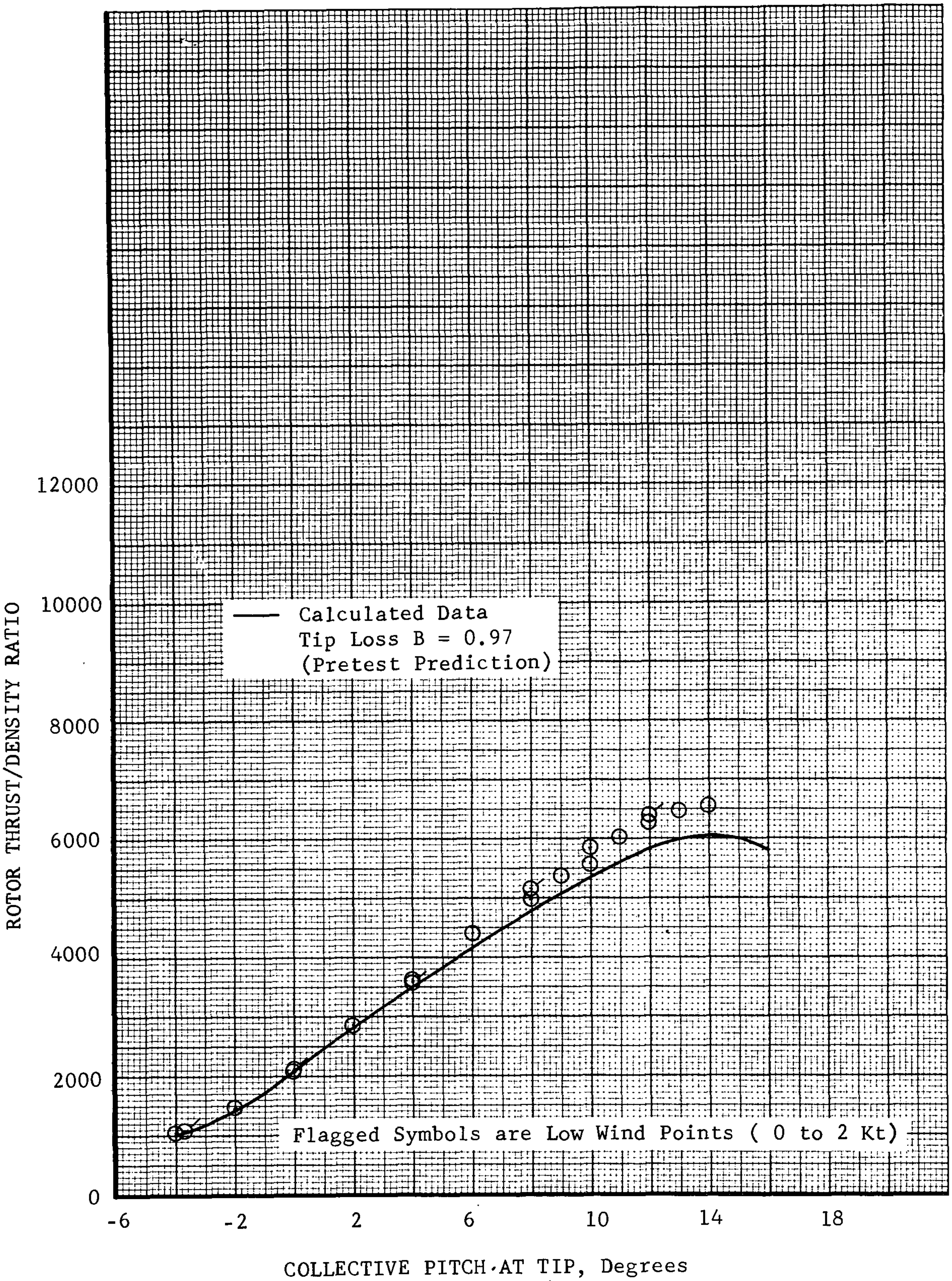

Figure IV-8. Correlation of Pretest Predicted Hover Thrust to Test Data at ΩR = 600 Feet Per Second.

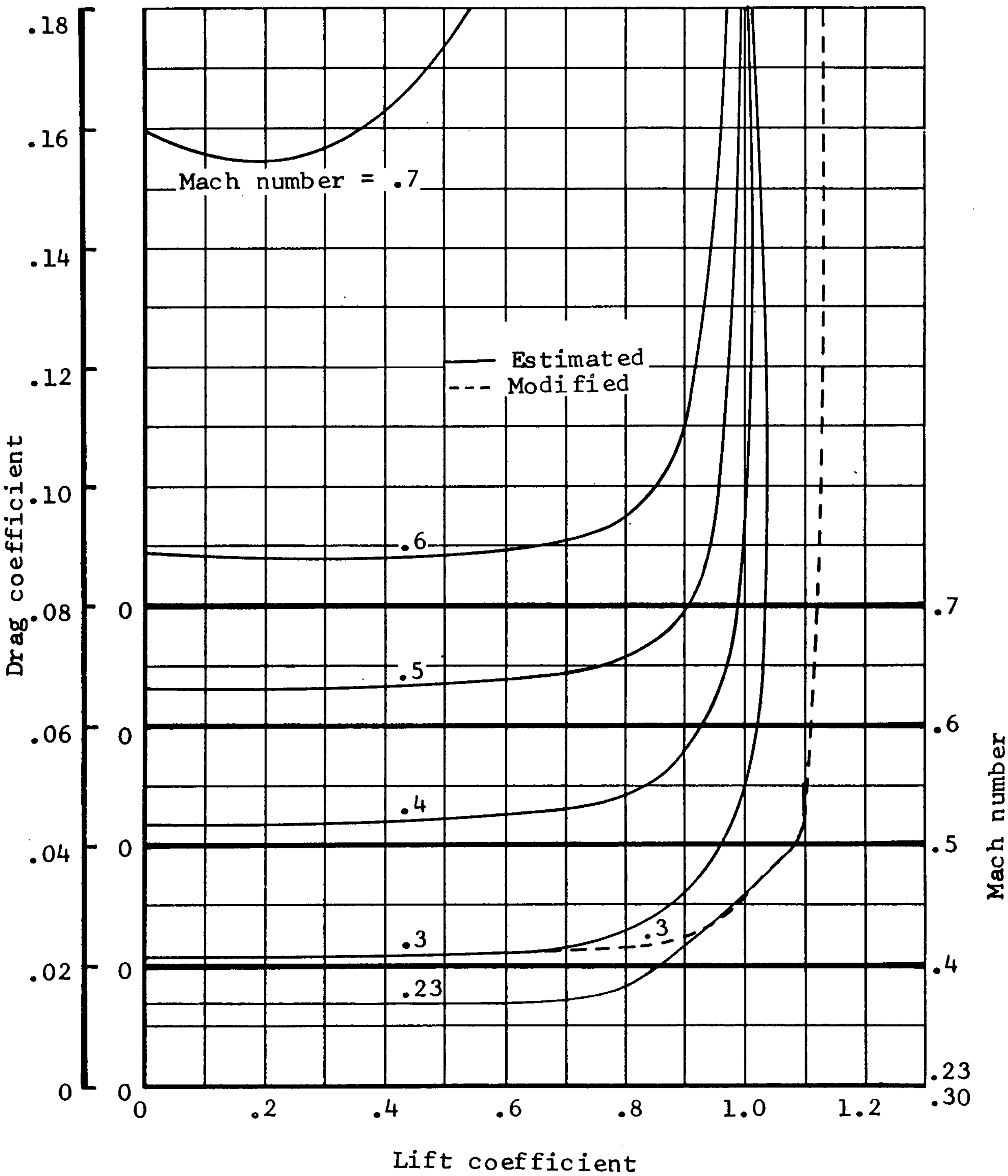

Figure IV-9. Blade Section Lift and Drag Coefficients, Airfoil Section No. 1, 64X28, 15-Percent Radius.

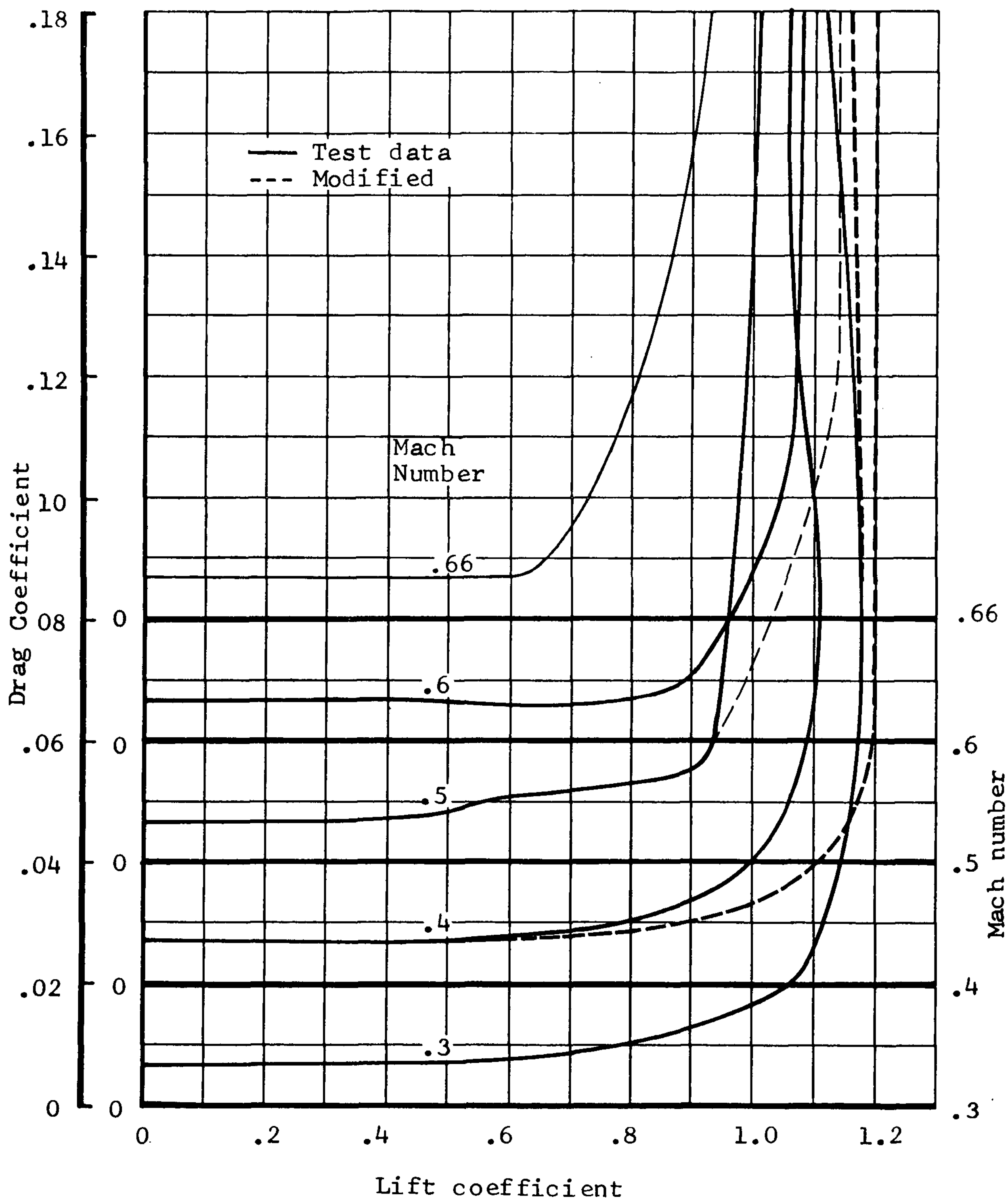

Figure IV-10. Blade Section Lift and Drag Coefficients, Airfoil Section No. 2, 64X18, 50 Percent Radius.

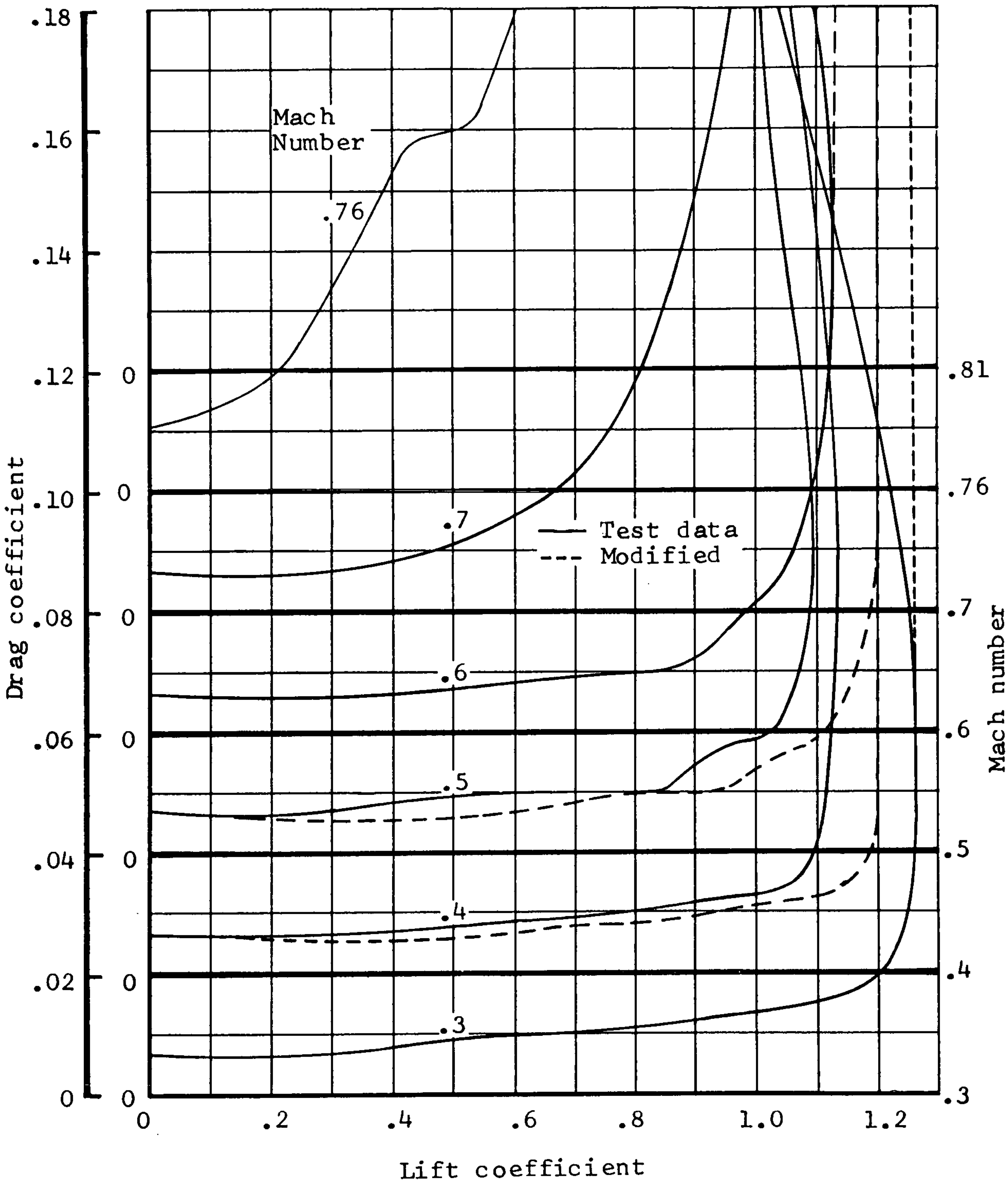

Figure IV-11. Blade Section Lift and Drag Coefficients, Airfoil Section No. 3, 64X12, 90-Percent Radius.

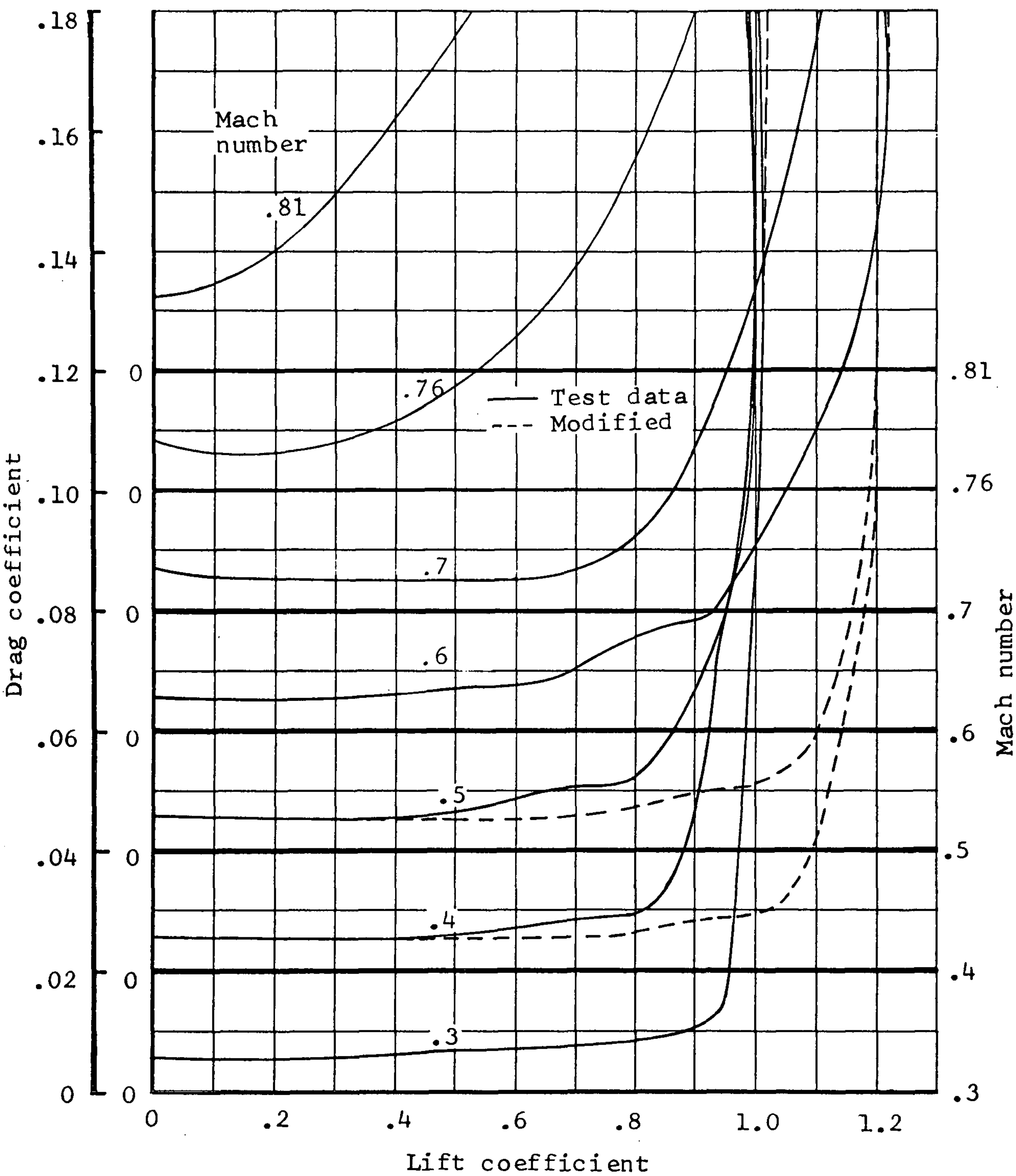

Figure IV-12. Blade Section Lift and Drag Coefficients, Airfoil Section No. 4, 64X08, Blade Tip.

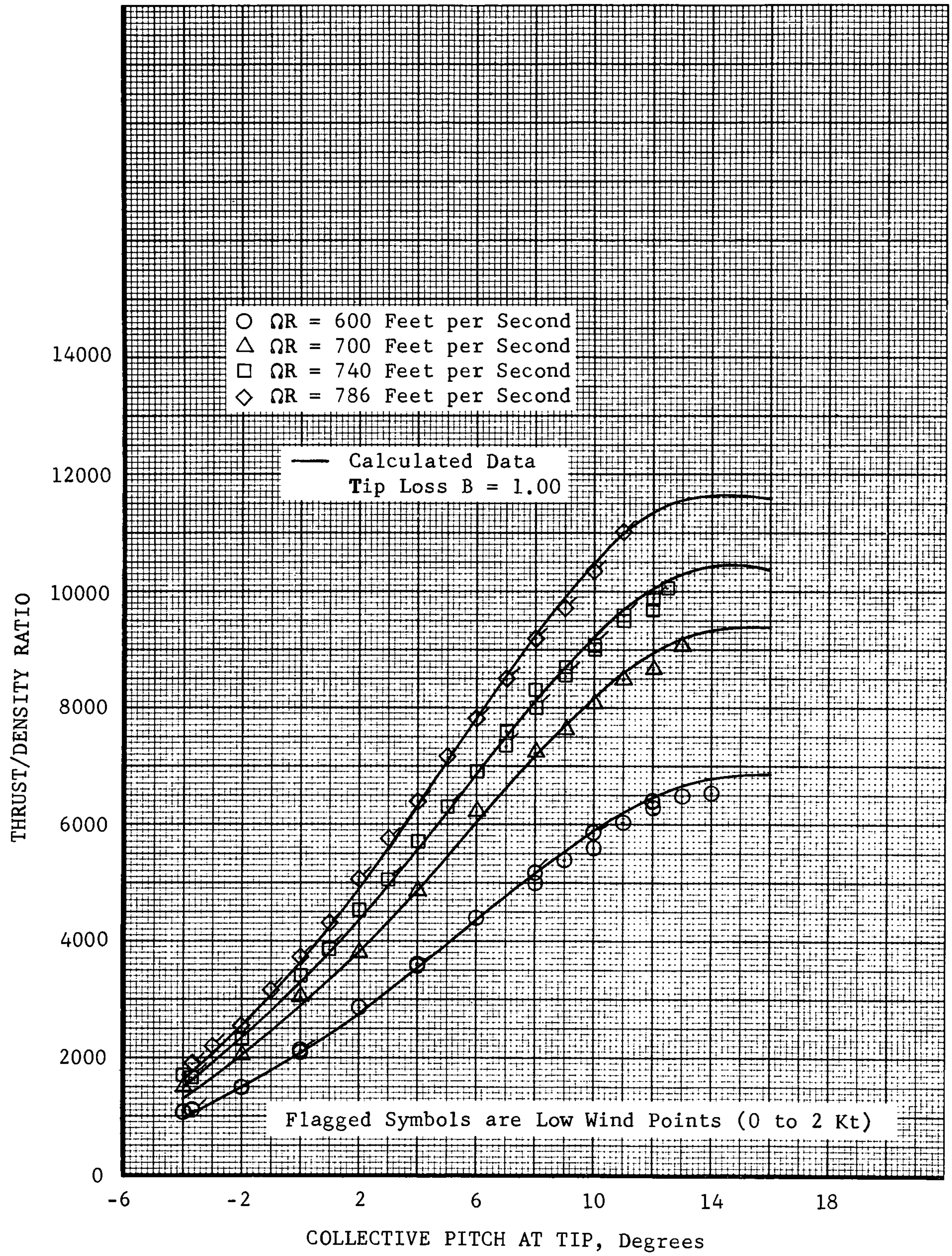

Figure IV-13. Dimensional Hover Thrust Versus Collective Pitch at Tip.

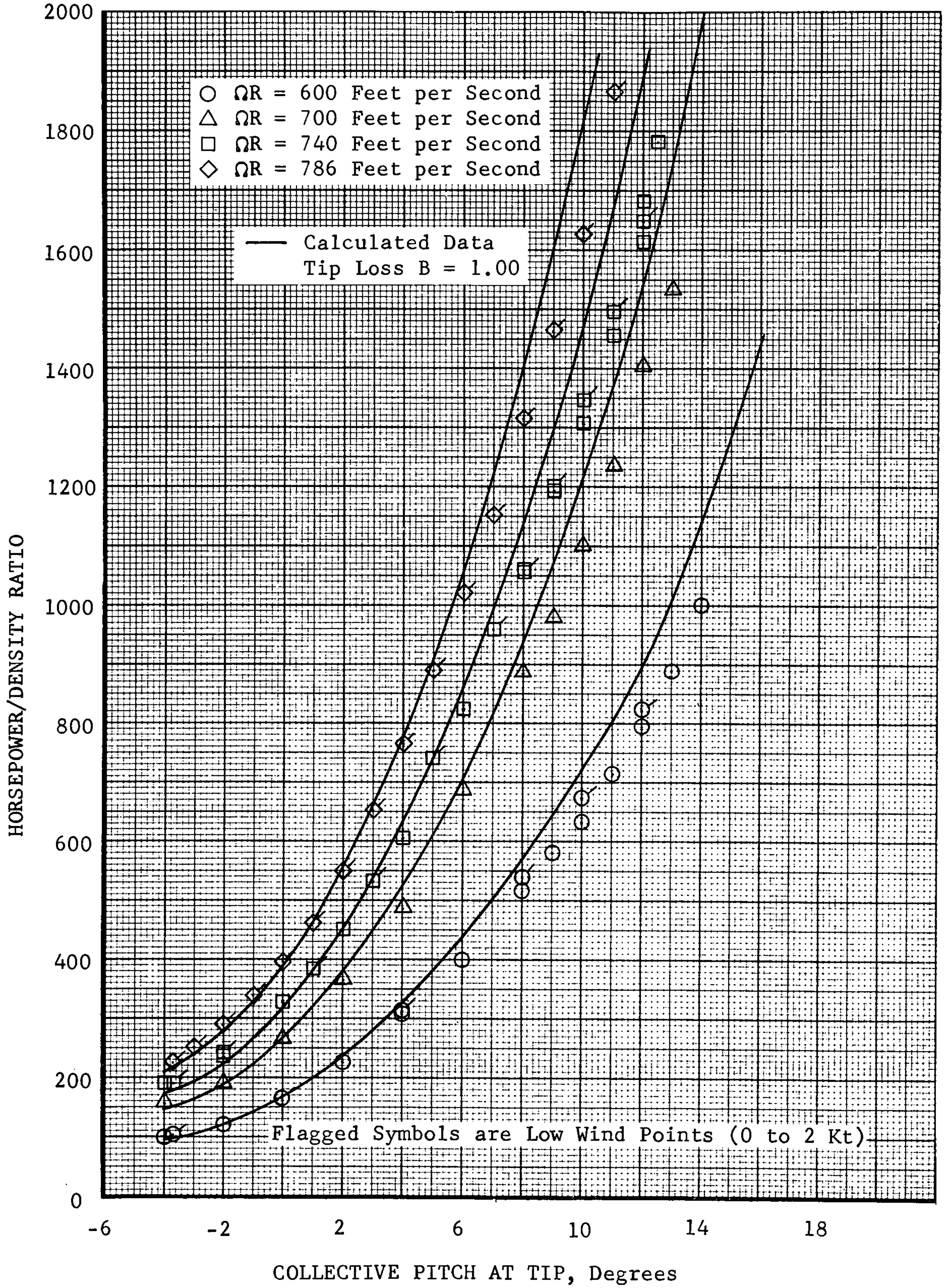

Figure IV-14. Dimensional Hover Power Versus Collective Pitch at Tip.

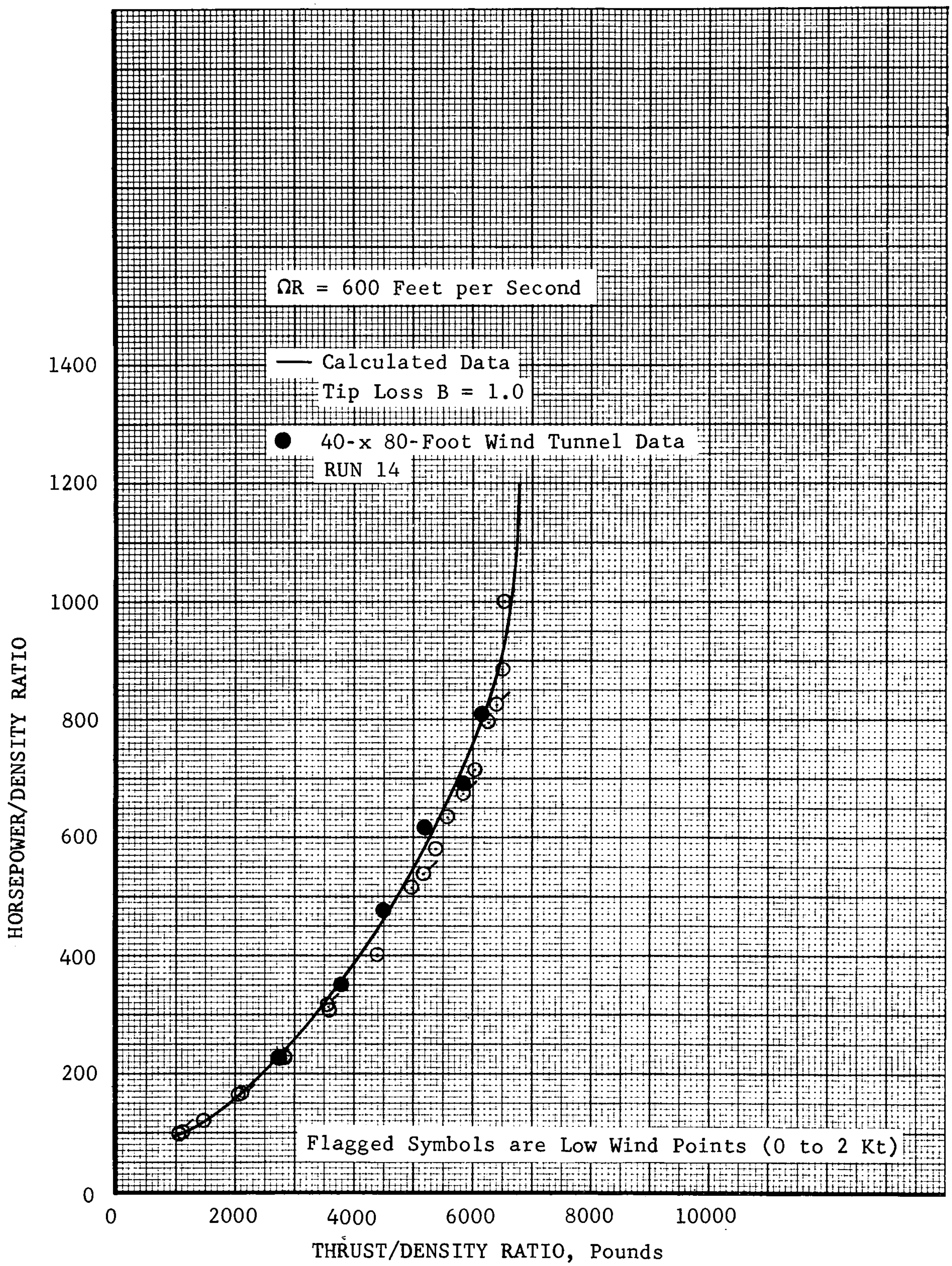

Figure IV-15. Dimensional Hover Power Required at 600 Feet Per Second Tip Speed.

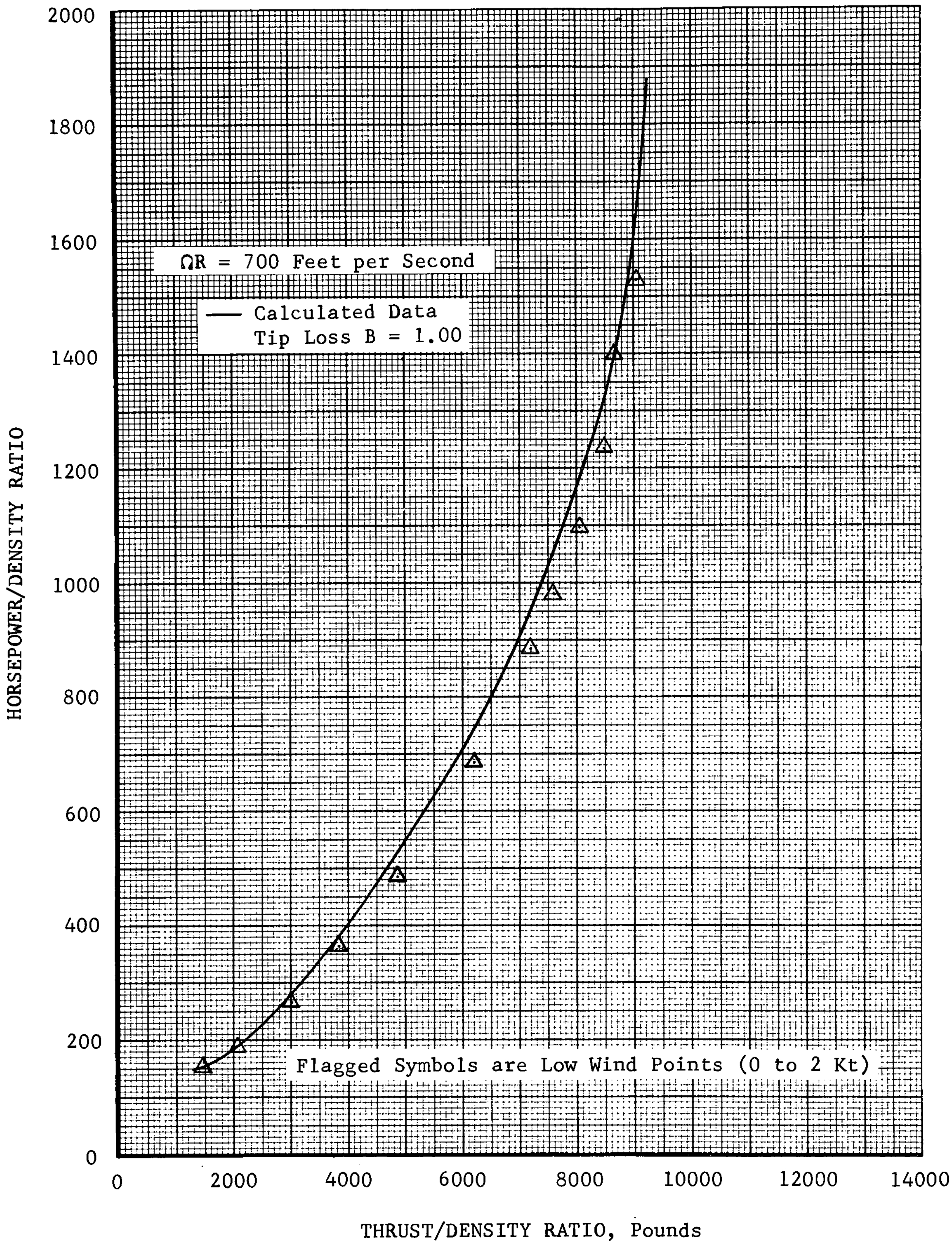

Figure IV-16. Dimensional Hover Power Required at 700 Feet Per Second Tip Speed.

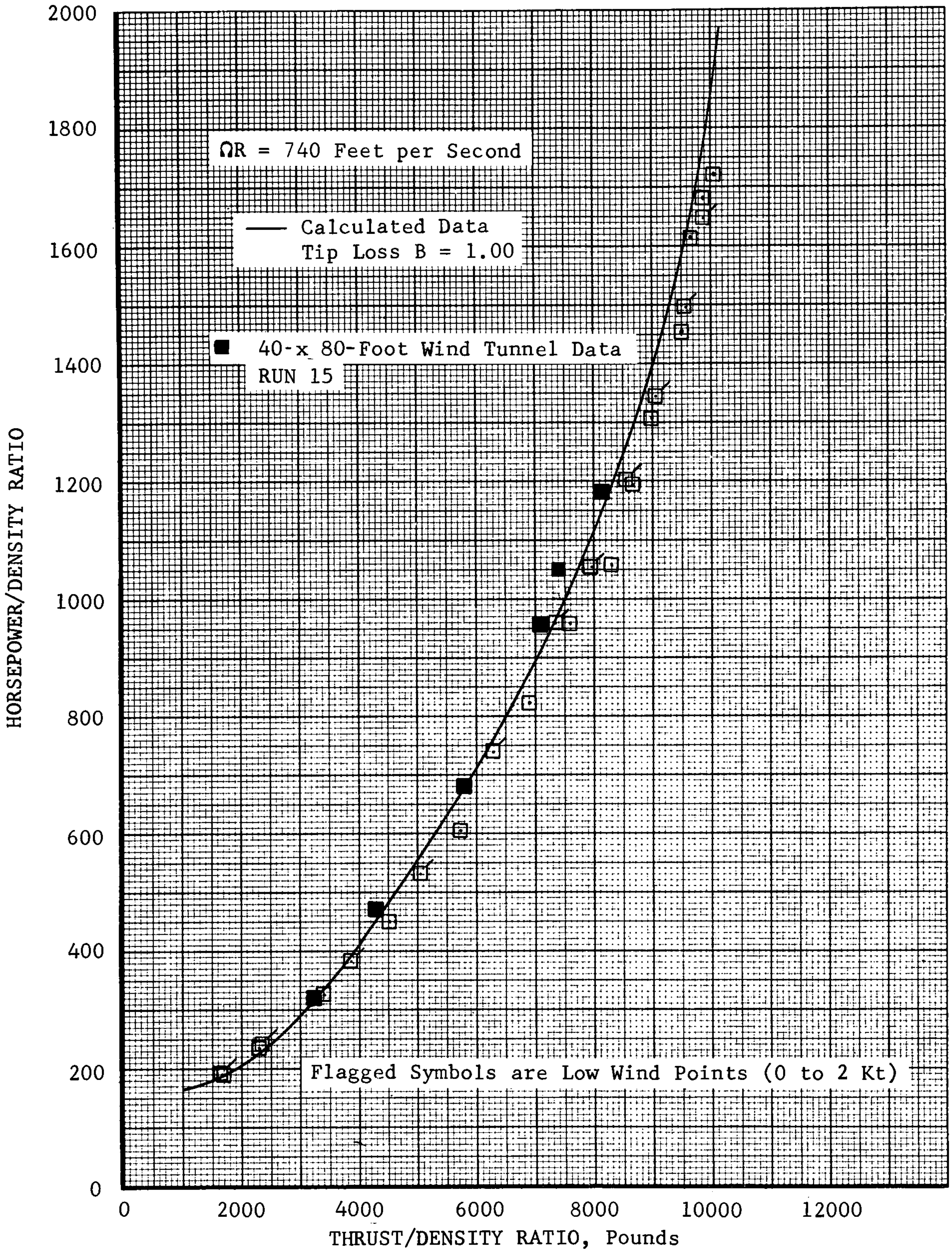

Figure IV-17. Dimensional Hover Power Required at 740 Feet Per Second Tip Speed.

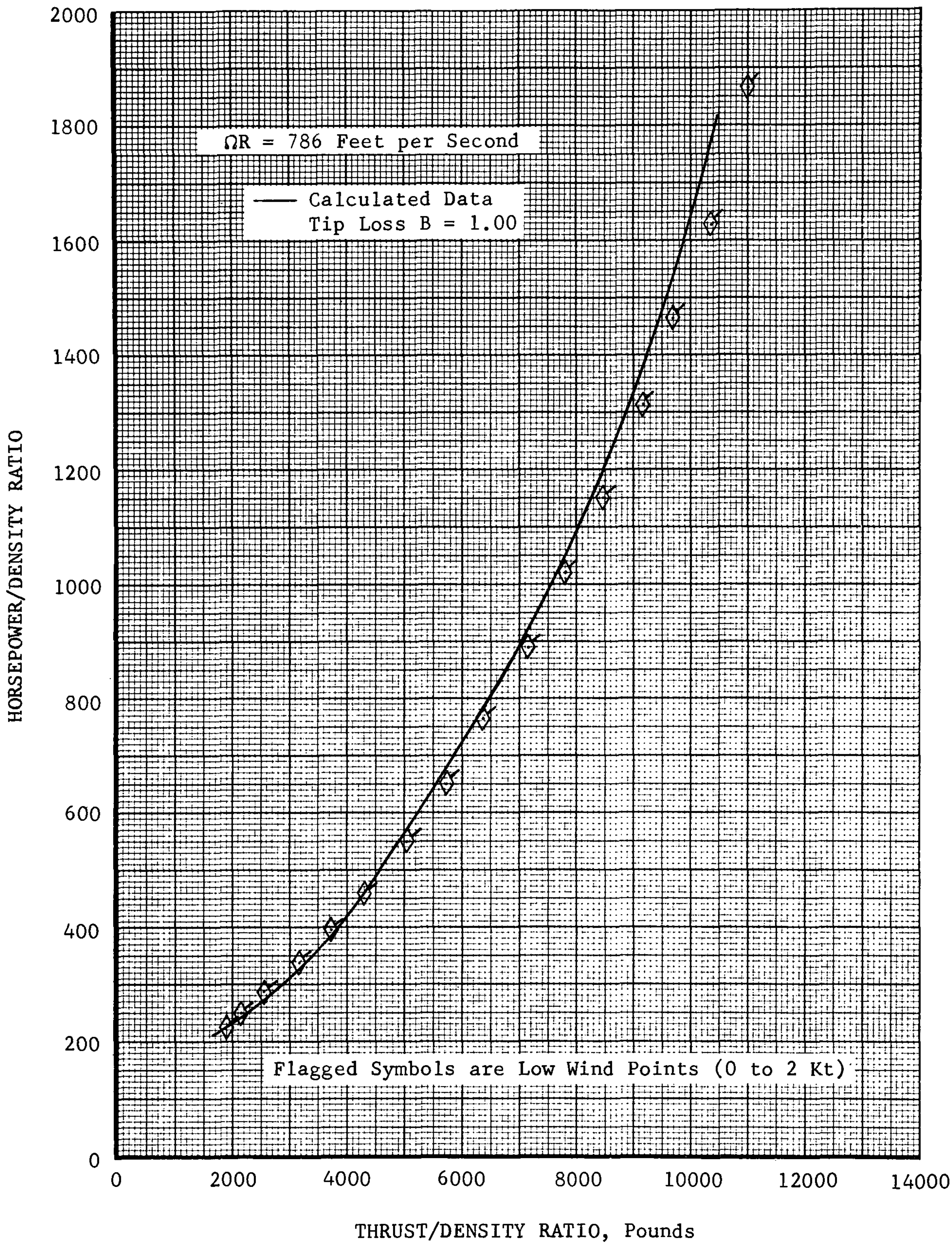

Figure IV-18. Dimensional Hover Power Required at 786 Feet Per Second Tip Speed.

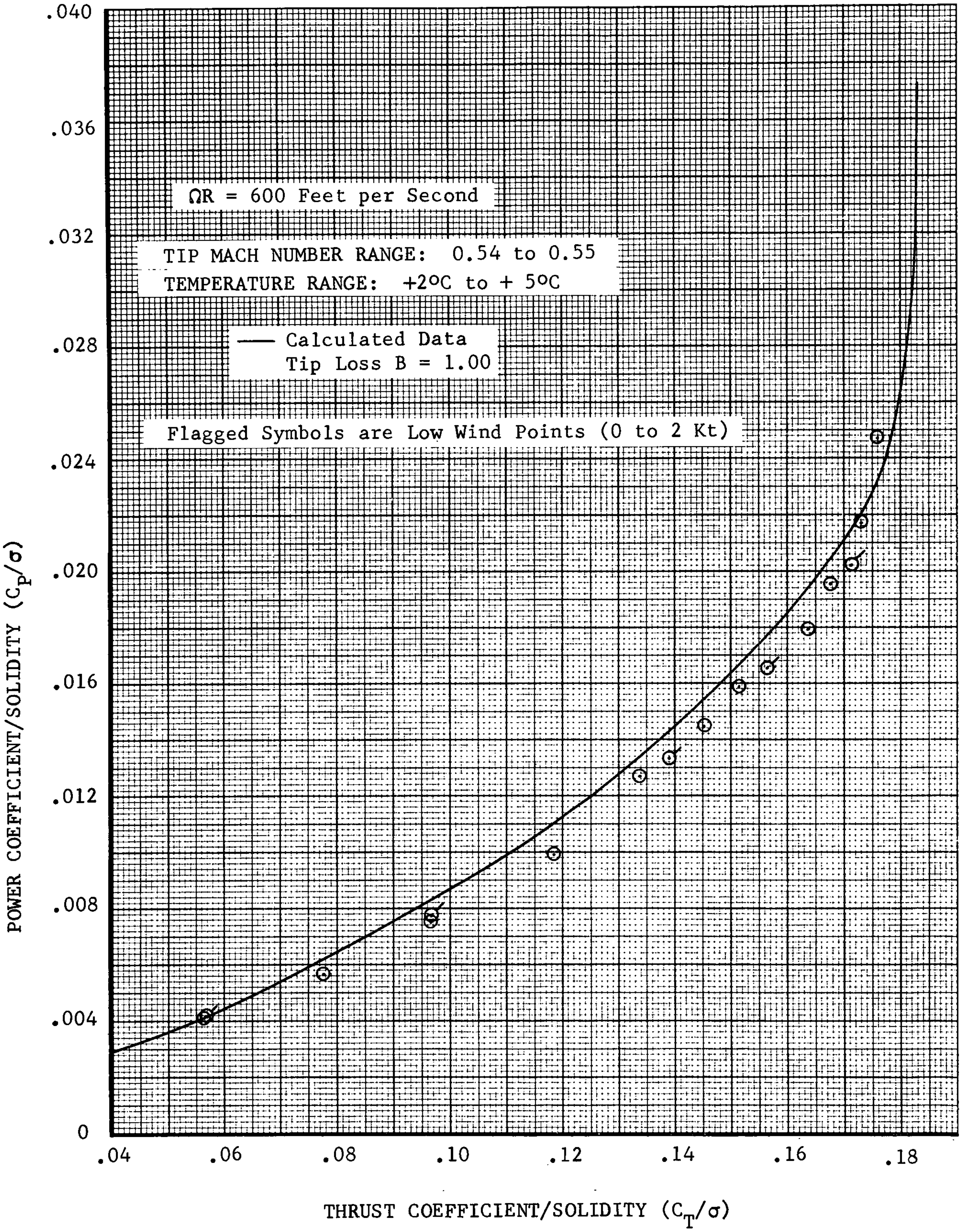

Figure IV-19. Nondimensional Hover Power Required at 600 Feet Per Second Tip Speed.

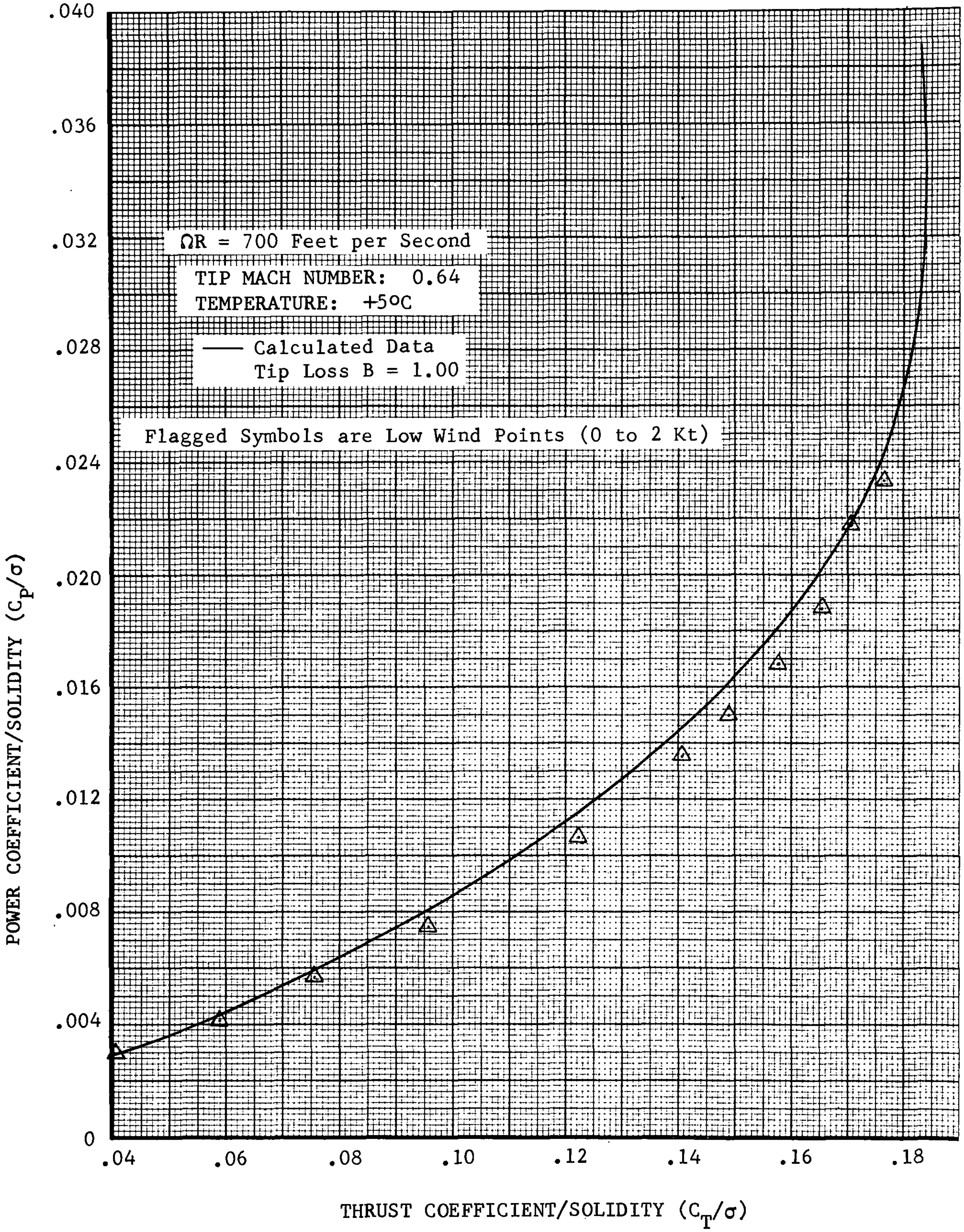

Figure IV-20. Nondimensional Hover Power Required at 700 Feet Per Second Tip Speed.

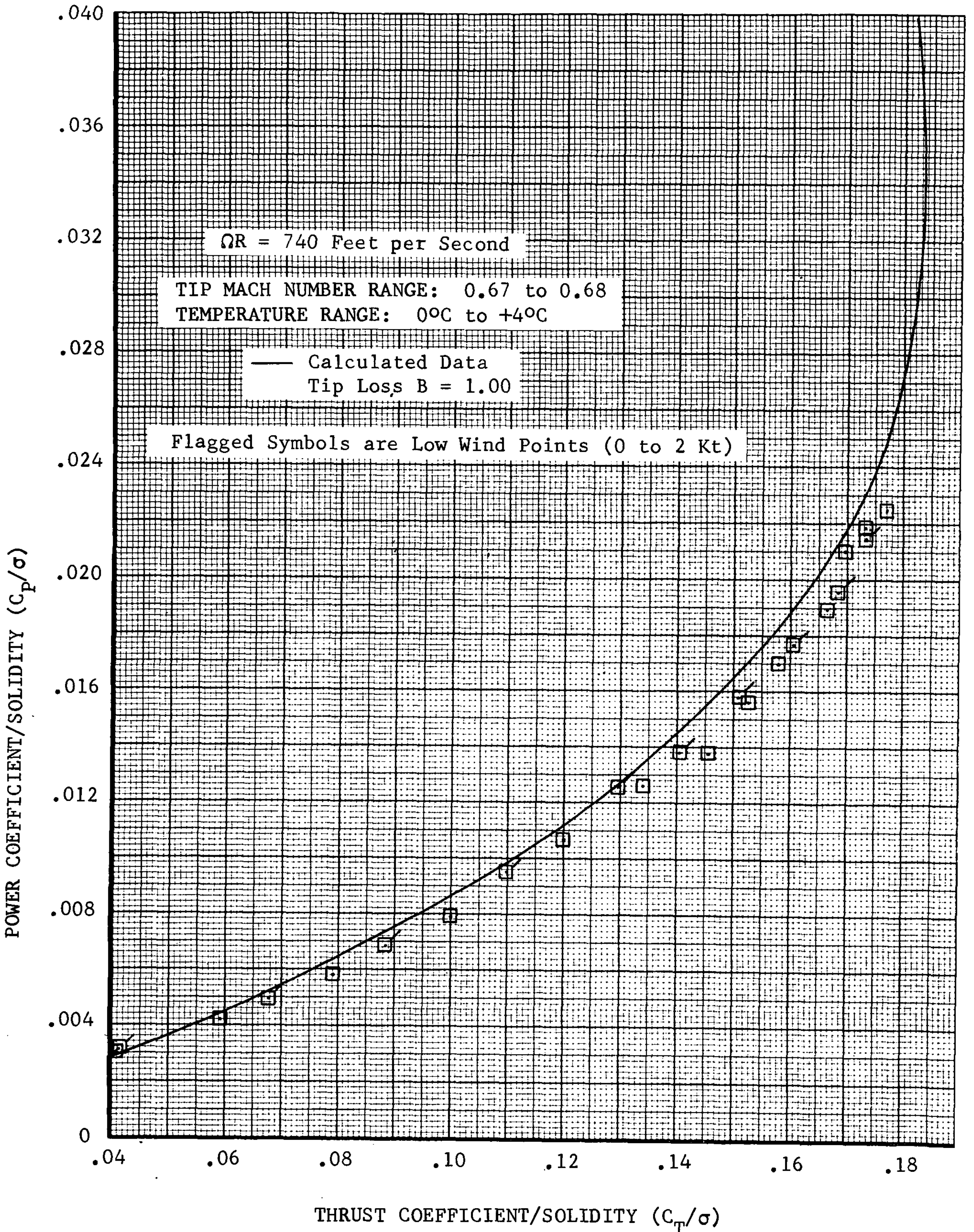

Figure IV-21. Nondimensional Hover Power Required at 740 Feet Per Second Tip Speed.

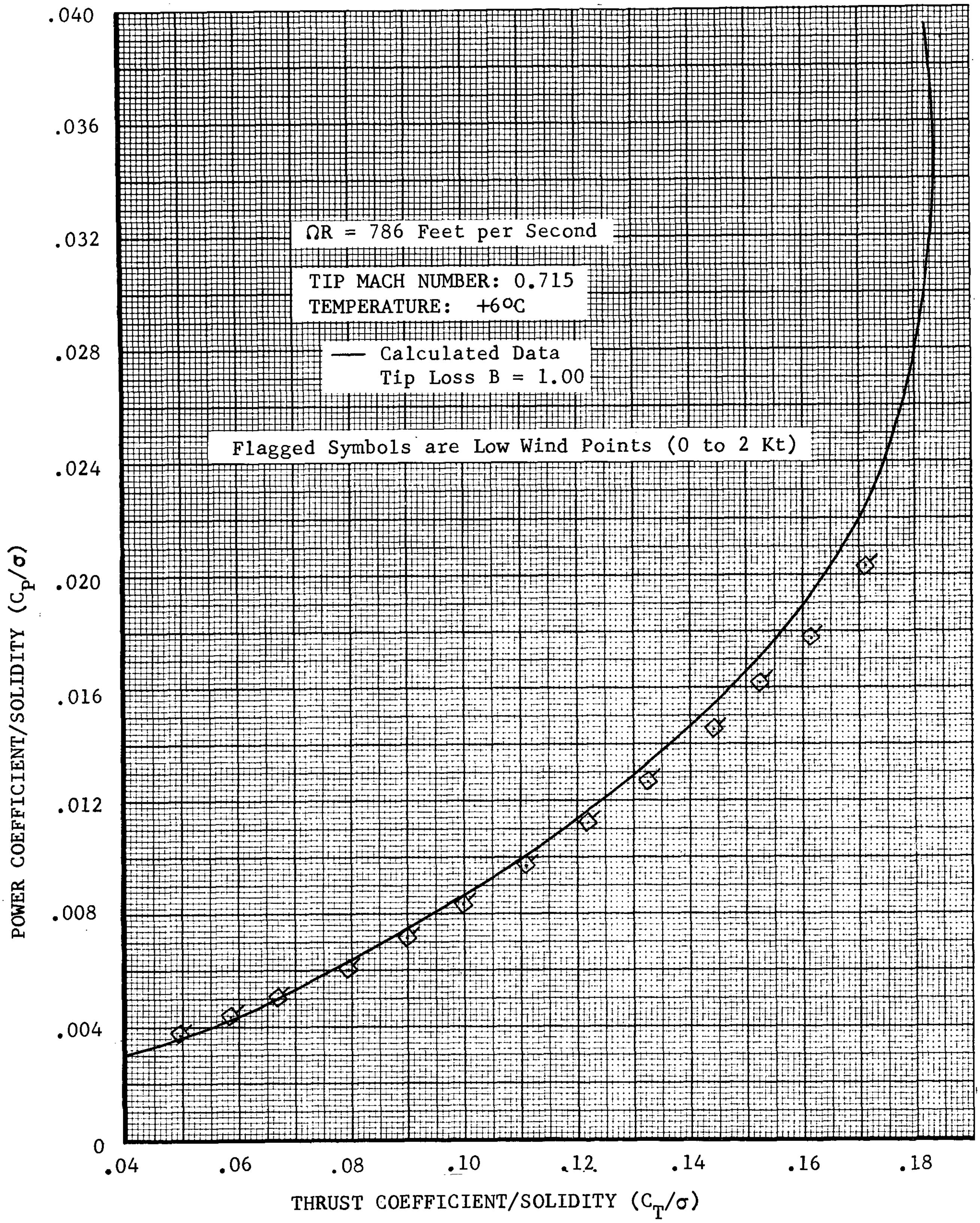

Figure IV-22. Nondimensional Hover Power Required at 786 Feet Per Second Tip Speed.

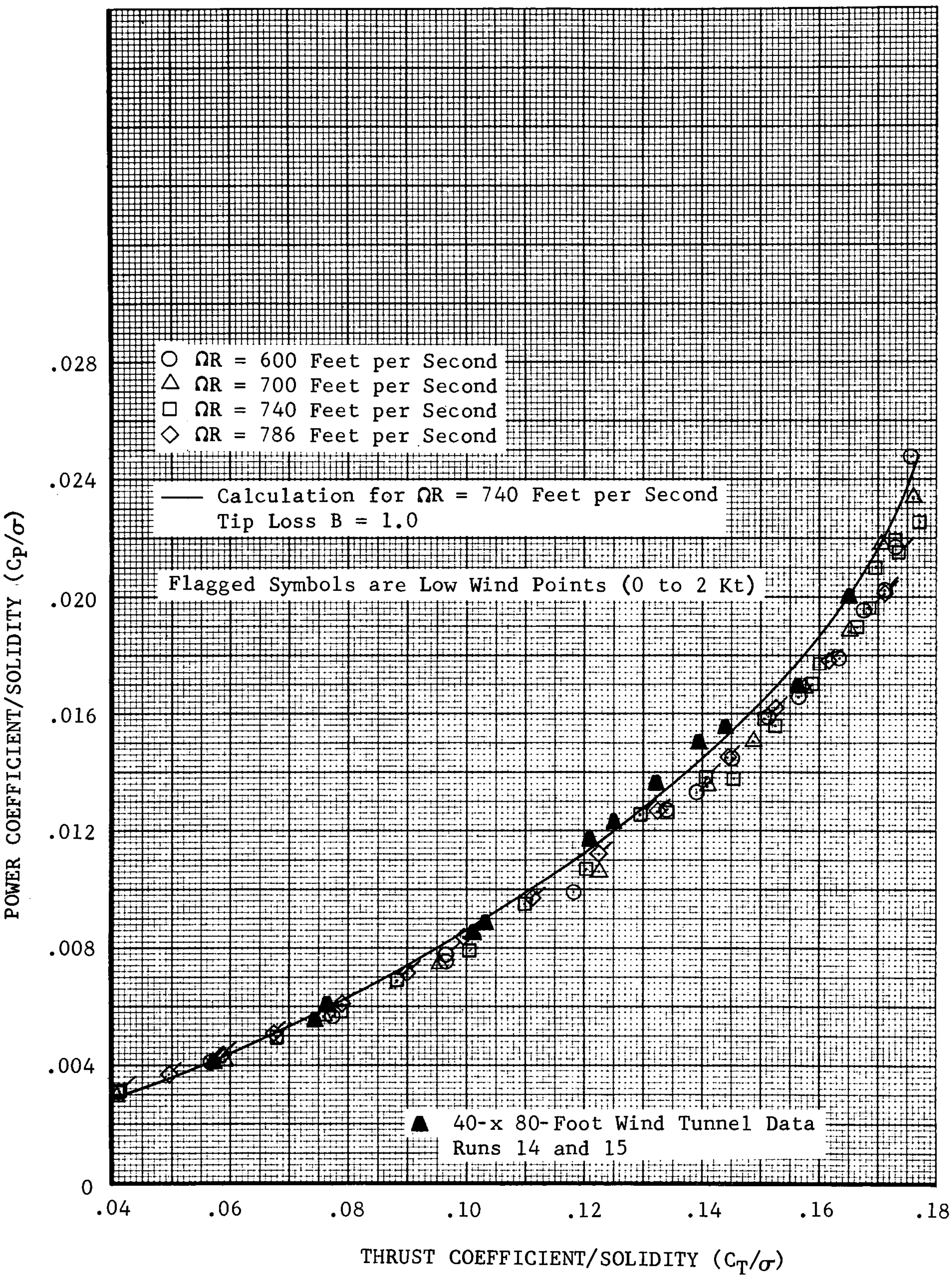

Figure IV-23. Nondimensional Hover Power Required.

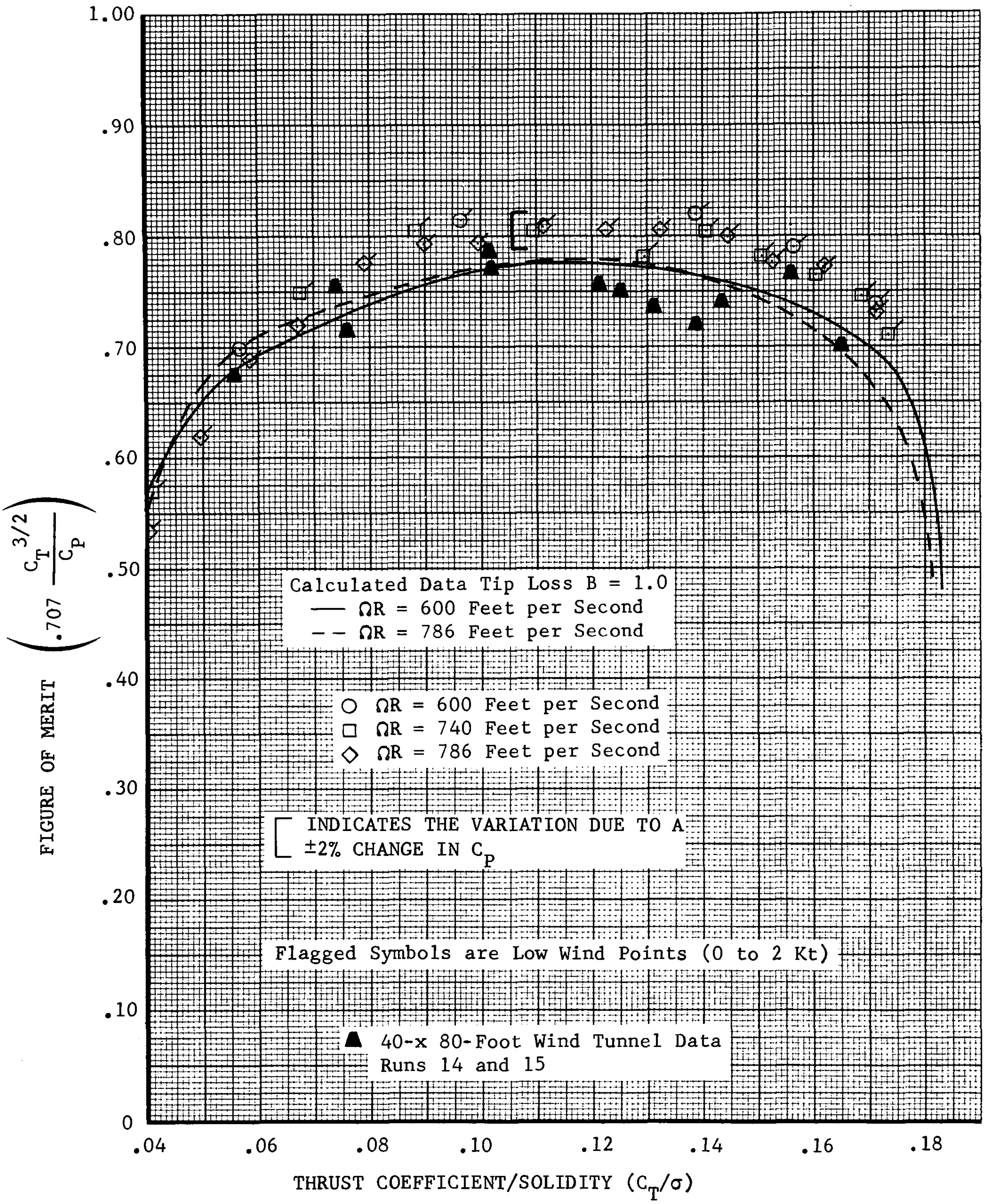

Figure IV-24. Tilt Rotor Figure of Merit Versus Thrust Coefficient/Solidity, From Low Wind Test Data.

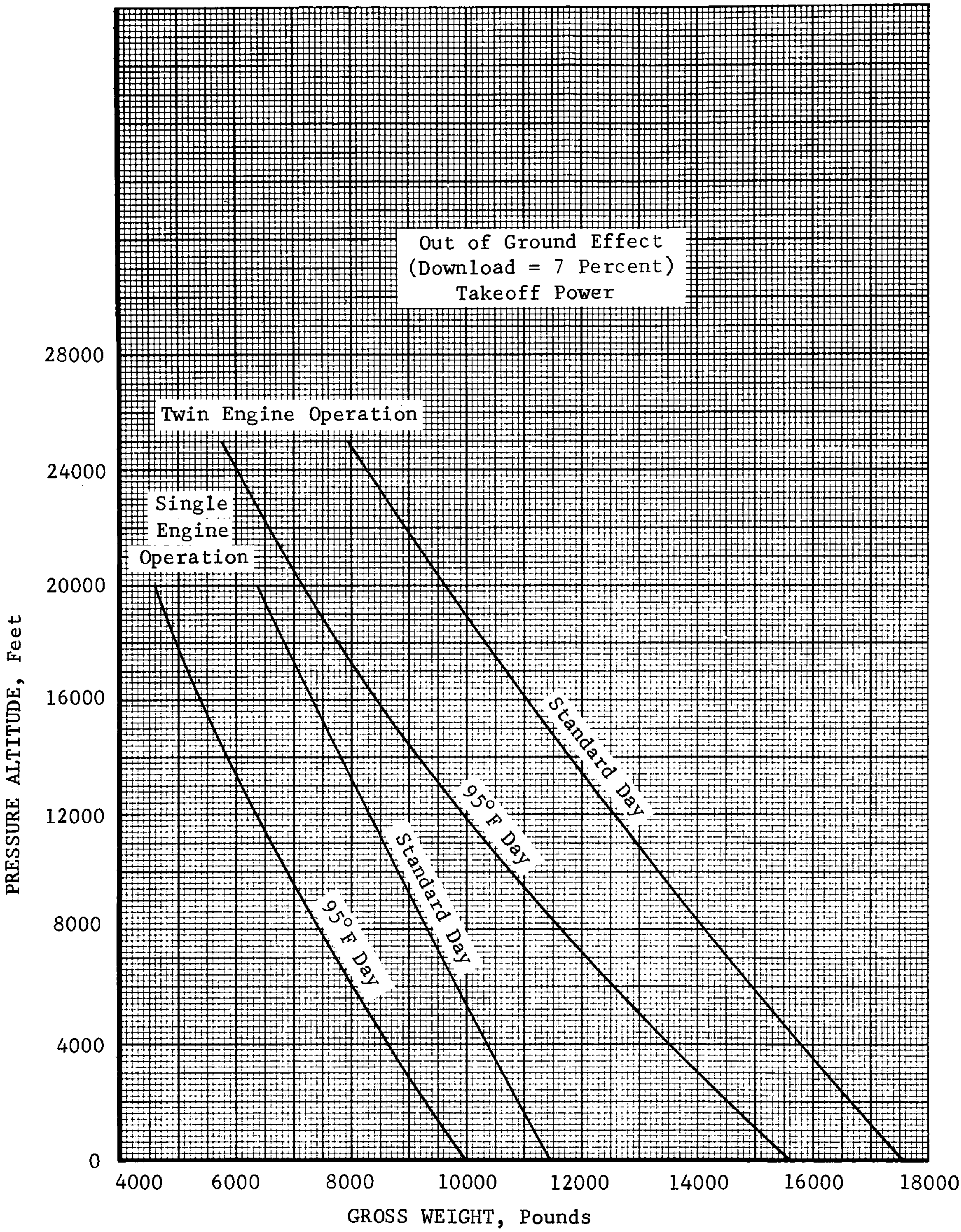

Figure IV-25. Model 301 Calculated Hover Ceiling Based on Hover Test Data.

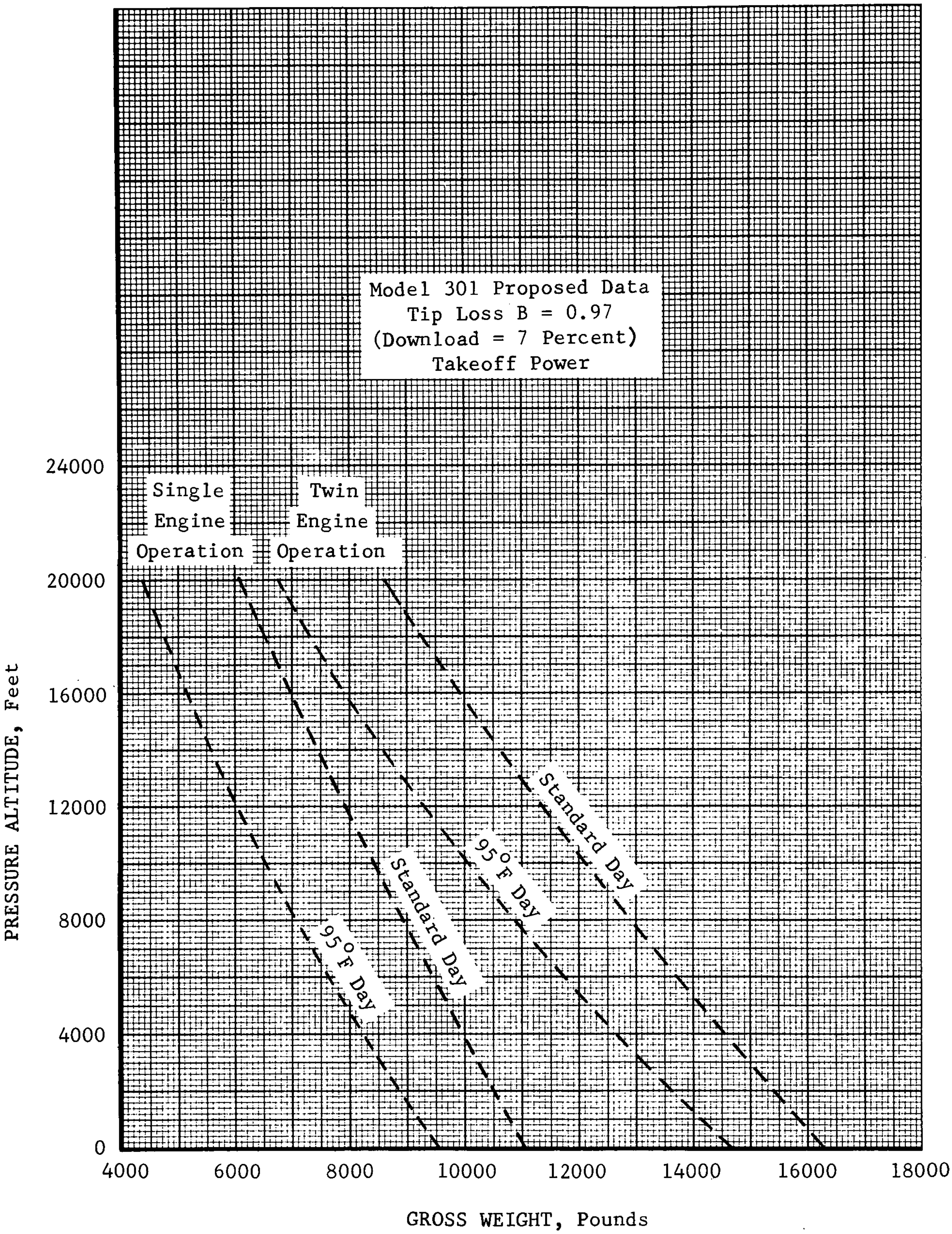

Figure IV-26. Model 301 Calculated Hover Ceiling With Tip Loss of 0.97.

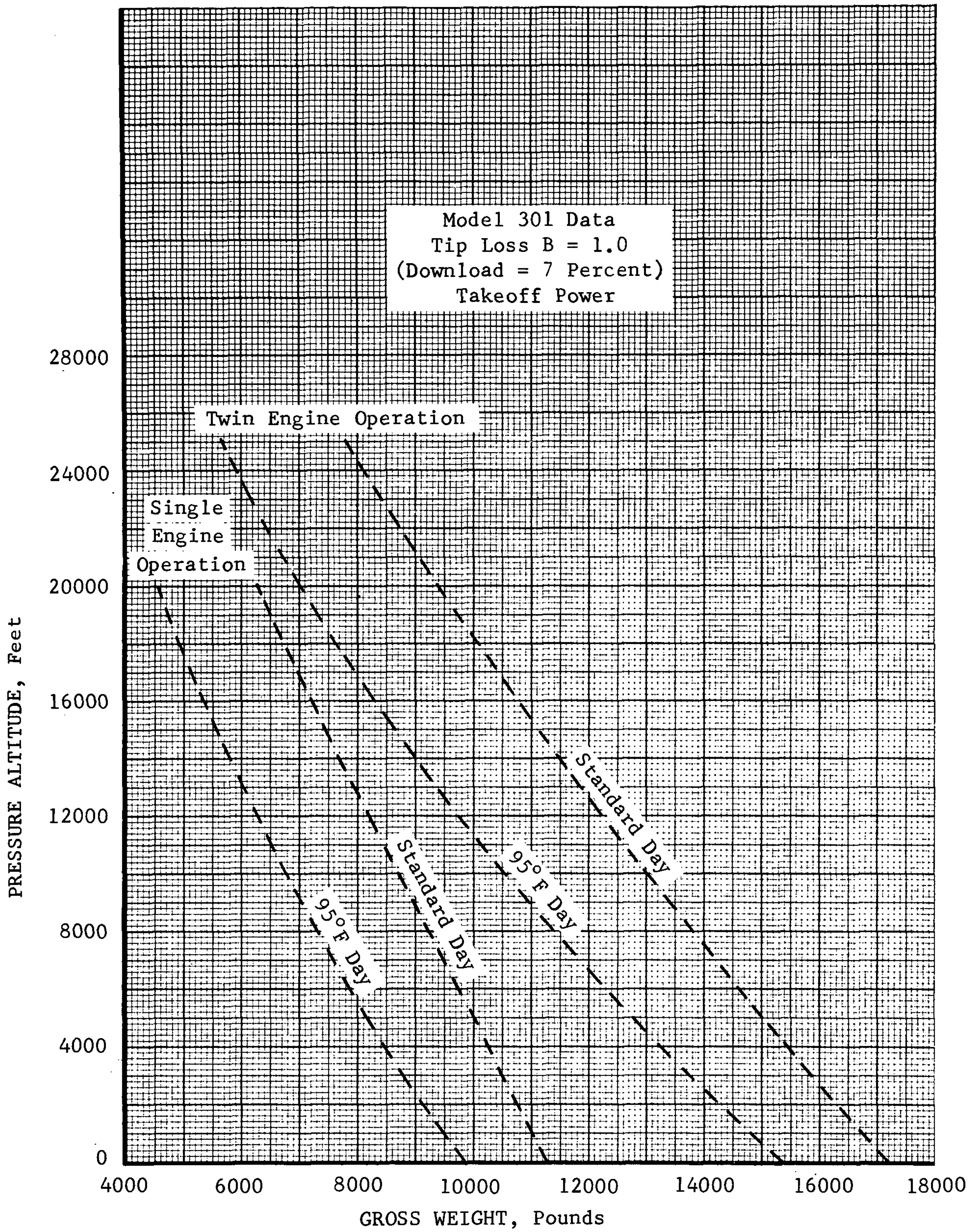

Figure IV-27. Model 301 Calculated Hover Ceiling With Tip Loss of 1.00.

V. ROTOR AND CONTROL SYSTEM LOADS DATA

During each run the rotor and control system loads were monitored to ensure static and dynamic limits were not exceeded. Rotor performance was limited by loads only in the sense that tests at 740 feet per second and 786 feet per second were terminated when the mast design limit torque was approached. Oscillatory loads did not limit rotor performance. However, unexpectedly high two-per-rev loads were encountered during runs at 740 feet per second. Analysis shows that these resulted from dynamic coupling between the test stand and the rotor and do not indicate an aircraft problem.

A. STEADY LOADS

The pitch link and yoke spindle steady loads are plotted as a function of C_T/σ in Figures V-1 through V-3. For comparison the steady loads from run 15 of the powered test of the 25-foot tilt rotor in the 40- by 80-foot wind-tunnel test are also shown. The wind tunnel loads of run 15 were used for all pre-test predictions (Reference 4) and are shown on the above figures. The full-scale wind-tunnel test loads data is taken from Reference 2.

B. OSCILLATORY LOADS

There were several sources of oscillatory excitation present in the hover test.

1. Oscillatory airloads were generated by interaction of the rotor induced flow and downwash with the test stand structure. The support beam for an overhead hoist was located approximately 25 feet above the rotor hub and a walkway which extended out to 45 percent of rotor radius was located 6 feet below the hub.

2. The rotor near wake and turbulent flow from stalled regions of the blades contributed oscillatory airloads.

3. Ground winds inside the test cage ranging up to 6 knots were present during the test.

Figure V-4 shows the pitch link oscillatory loads versus C_T/σ. At C_T/σ's below 0.15 the frequency content of the load was dominantly one and two-per-rev. At C_T/σ above 0.15 loads at six-per-rev and nine-per-rev caused a marked increase in the overall oscillatory load. These high frequency loads were probably caused by stall over the inboard portion of the rotor. There was no evidence of stall flutter or other form of instability even at the maximum C_T/σ.

Figures V-5 and V-6 show the yoke spindle beamwise and chordwise oscillatory bending moments versus C_T/σ. The spindle beam load was primarily one and three-per-rev and the spindle chord load predominantly one and two-per-rev. The spindle chord two-per-rev loads became sufficiently large at the 740 tip speed to cause concern during the test (however, the spindle chord load never exceeded 25 percent of the endurance limit).

Oscillatory loads at blade stations 22.8 and 52.5 showed similar trends to those of the yoke spindle. Loads at these stations were low.

C. ROTOR-TEST STAND DYNAMIC COUPLING

Analysis of the dynamics of the coupled test stand-rotor showed that the relatively high two-per-rev loads were caused by the blade advancing inplane bending mode being in resonance with two-per-rev at the 740 feet per second tip speed. The reason for the resonance can be explained with the aid of Figures V-7 and V-8 as follows:

For inplane excitation, the rotor-test stand dynamic system may be considered in terms of four uncoupled modes: (1) a mode representing whirling of the hub in the direction of rotation and (2) a mode representing whirling of the hub opposite to the direction of rotation. Modes (1) and (2) are primarily mast bending and in the rotating coordinate system have a frequency equal to the uncoupled mast bending frequency minus and plus one-per-rev respectively, as shown in Figure V-7. The blade inplane motion is represented by two uncoupled modes, the advancing and regressing blade modes. The advancing and regressing modes represent the whirl of the center of gravity of the displaced blades in the direction of rotation and opposite to the direction of rotation respectively. The frequencies of the uncoupled advancing and regressing blade modes are the same as is shown in Figure V-7, and are equal to the frequency of the blade fundamental cantilevered inplane bending mode.

When the forward and backward whirl mast bending modes and the advancing and regressing blade modes couple, the frequencies of the coupled modes vary considerably from the uncoupled frequencies as shown in Figure V-8. Strong coupling between the advancing blade mode and the forward whirl mast bending mode is evident in the range where the frequencies of the uncoupled modes are equal (see Figure V-7). A hand shake test of the nonrotating test stand-rotor assembly showed the coupled mast bending frequency to be 2.62 cycles-per-rev referenced to 740 feet per second tip speed. Using this coupled frequency, the uncoupled mast bending frequency was calculated to be 2.25 cycles-per-rev which, as shown in Figure V-8, resulted in the blade advancing inplane bending mode being in resonance with two-per-rev.

Resonance of the advancing blade mode with two-per-rev was also encountered during the powered test of the 25-foot tilt rotor in the 40- by 80-foot wind tunnel. During that test, the rotor was mounted on a propeller test rig and had a mast bending frequency slightly lower than the mast bending frequency on the whirl stand. Two-per-rev resonance occurred at 700 feet per second tip speed restricting testing at that tip speed. This problem has been considered in the design of the Model 301 tilt rotor pylon for use with the Model 300 rotor. The location of pylon natural frequencies has been carefully controlled during the design and the blade advancing inplane mode is well clear of two-per-rev resonance. (It should be noted that no attempt was made to control the location of the mast bending frequency on the whirl stand since the dynamic characteristics of the stand were not known.)

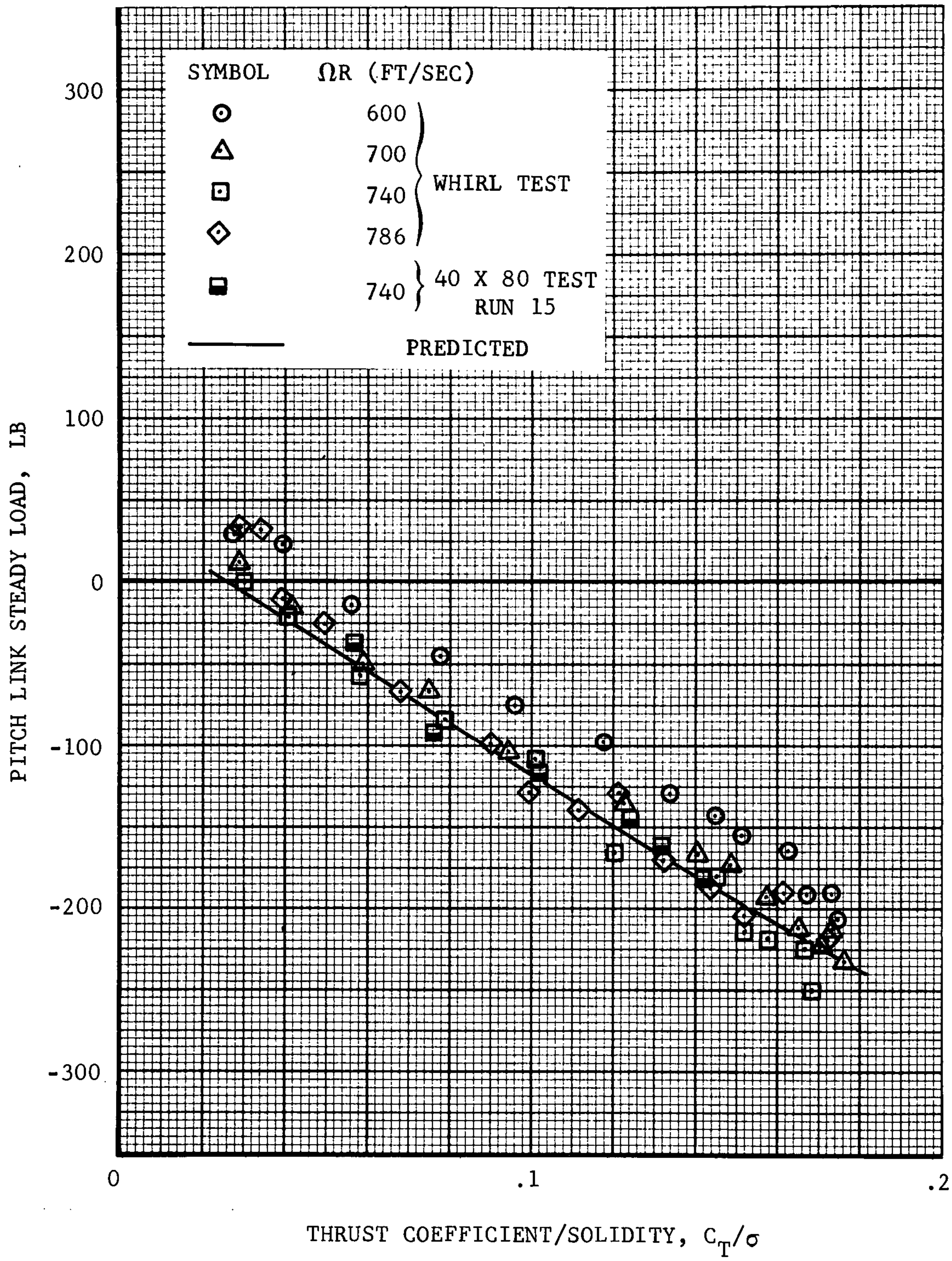

Figure V-1. Pitch Link Steady Load Versus C_T/σ.

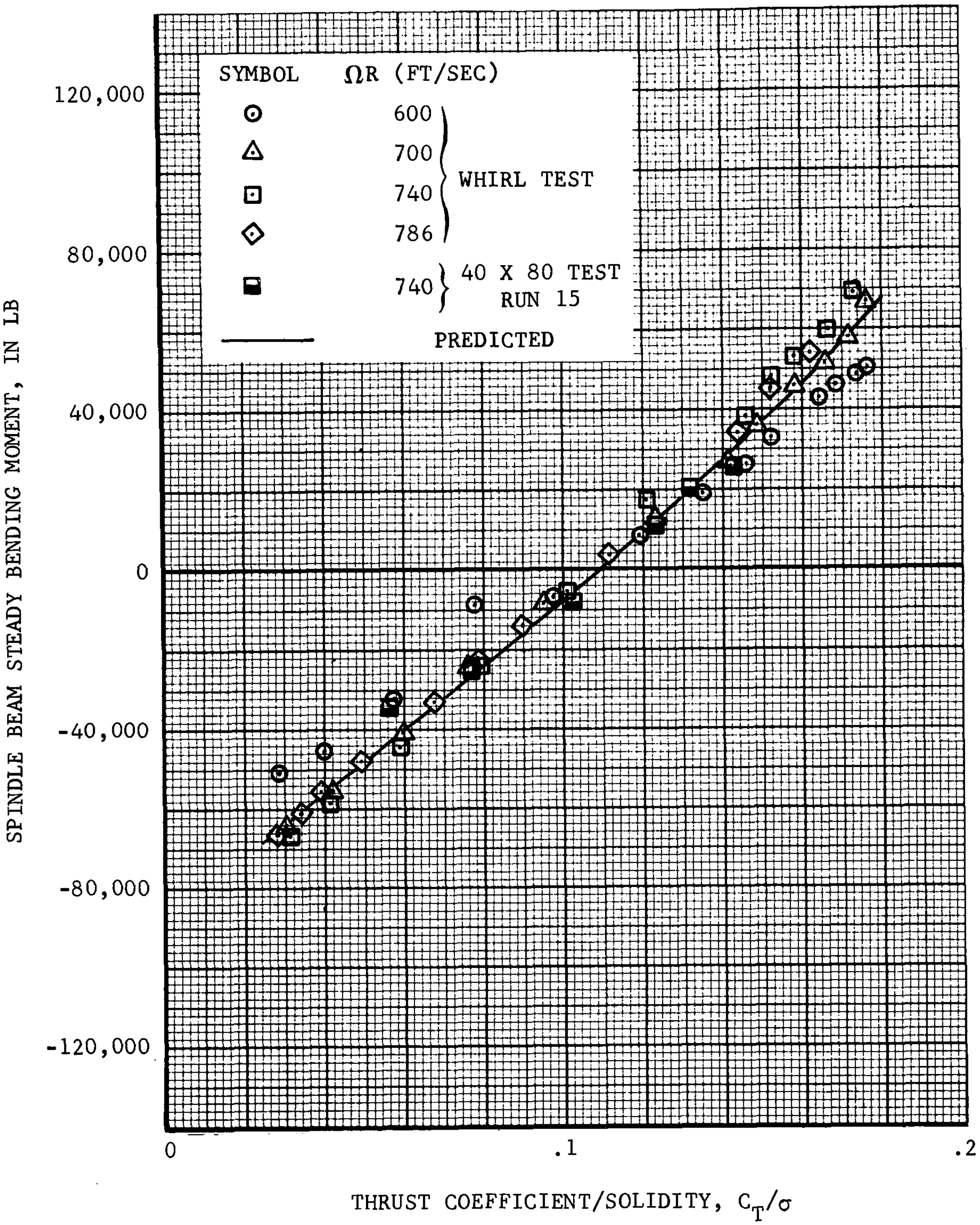

Figure V-2. Yoke Spindle Beam Steady Bending Moment Versus C_T/σ.

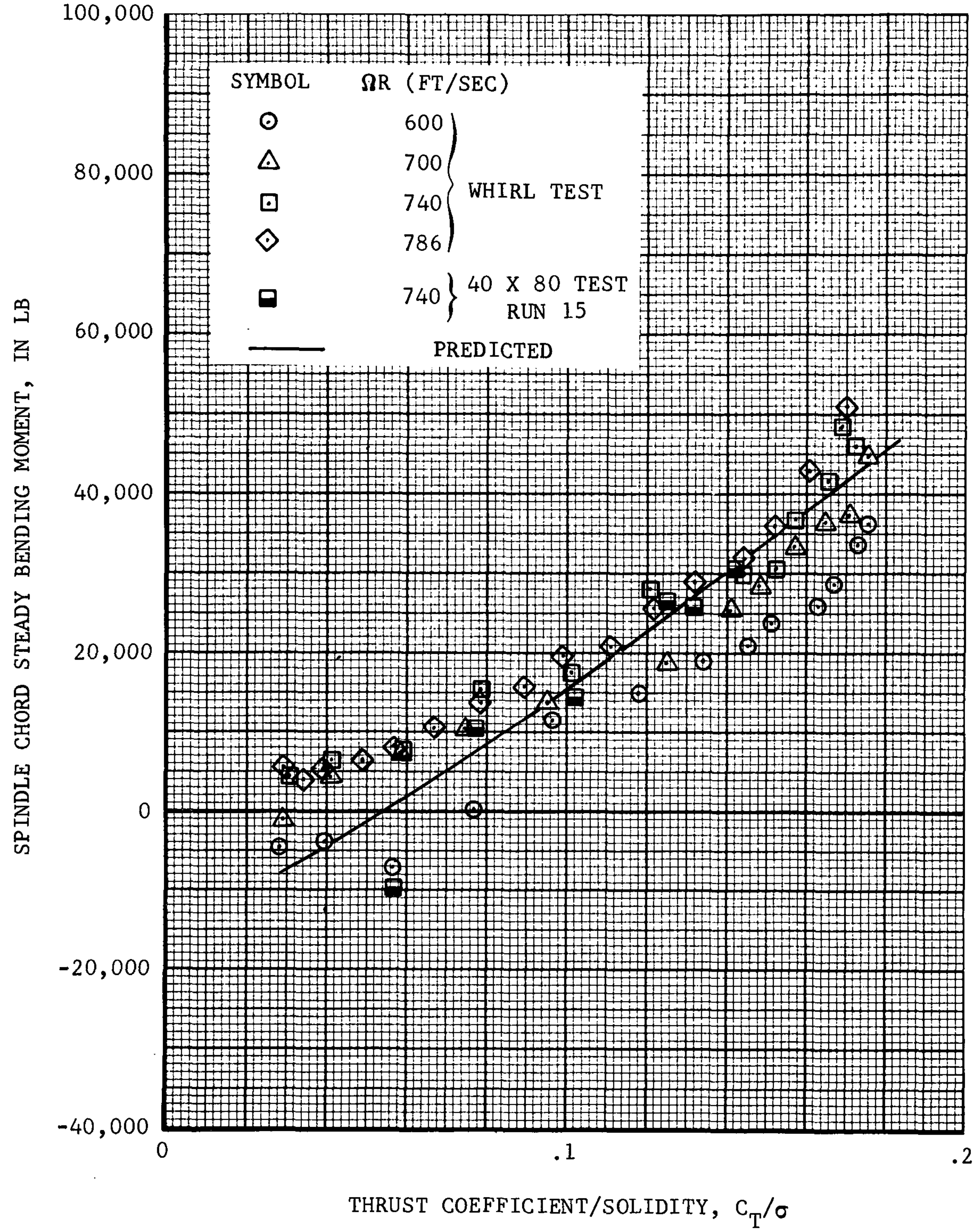

Figure V-3. Yoke Spindle Chordwise Steady Bending Moment Versus C_T/σ.

F

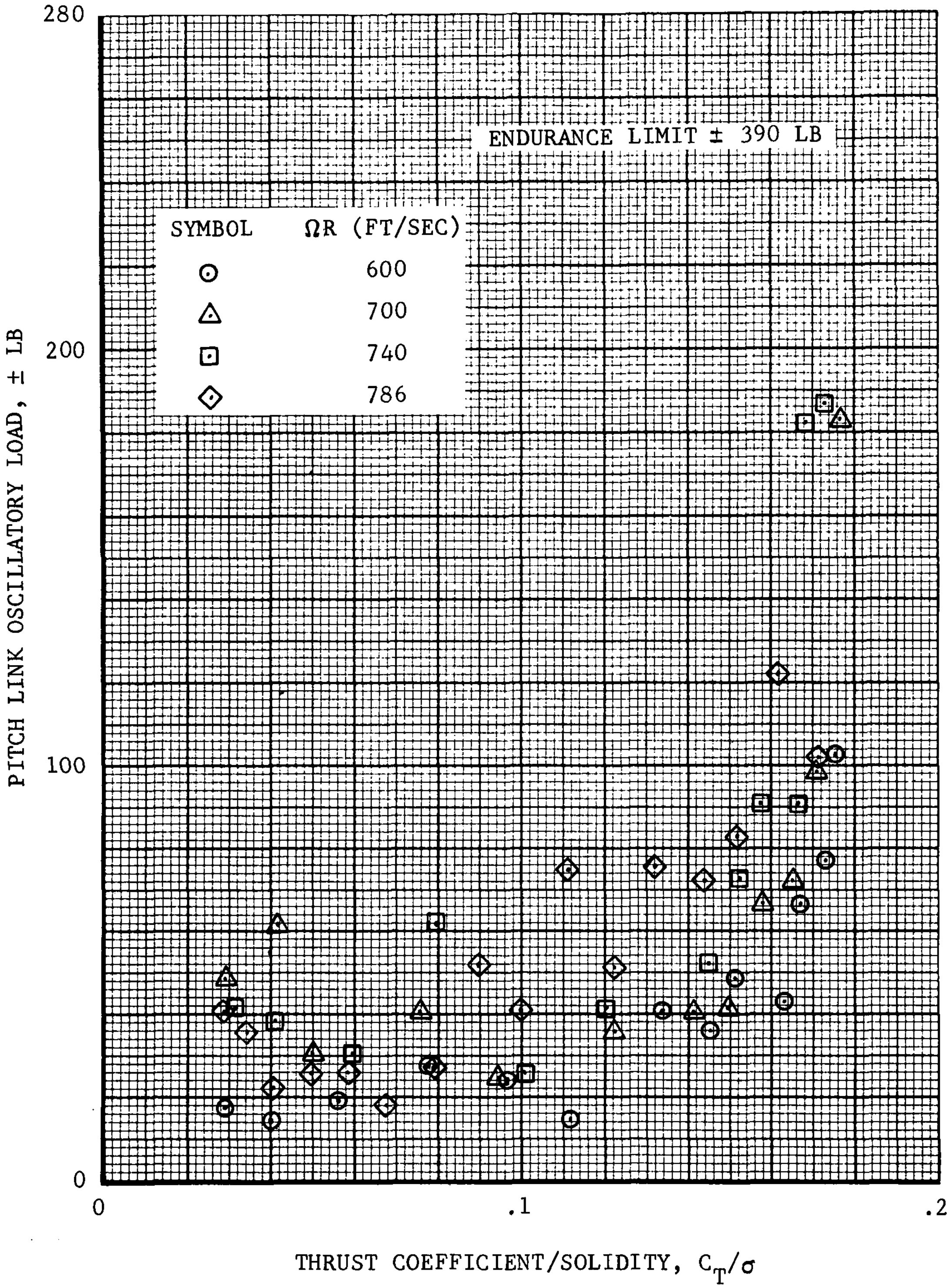

Figure V-4. Pitch Link Oscillatory Load Versus C_T/σ.

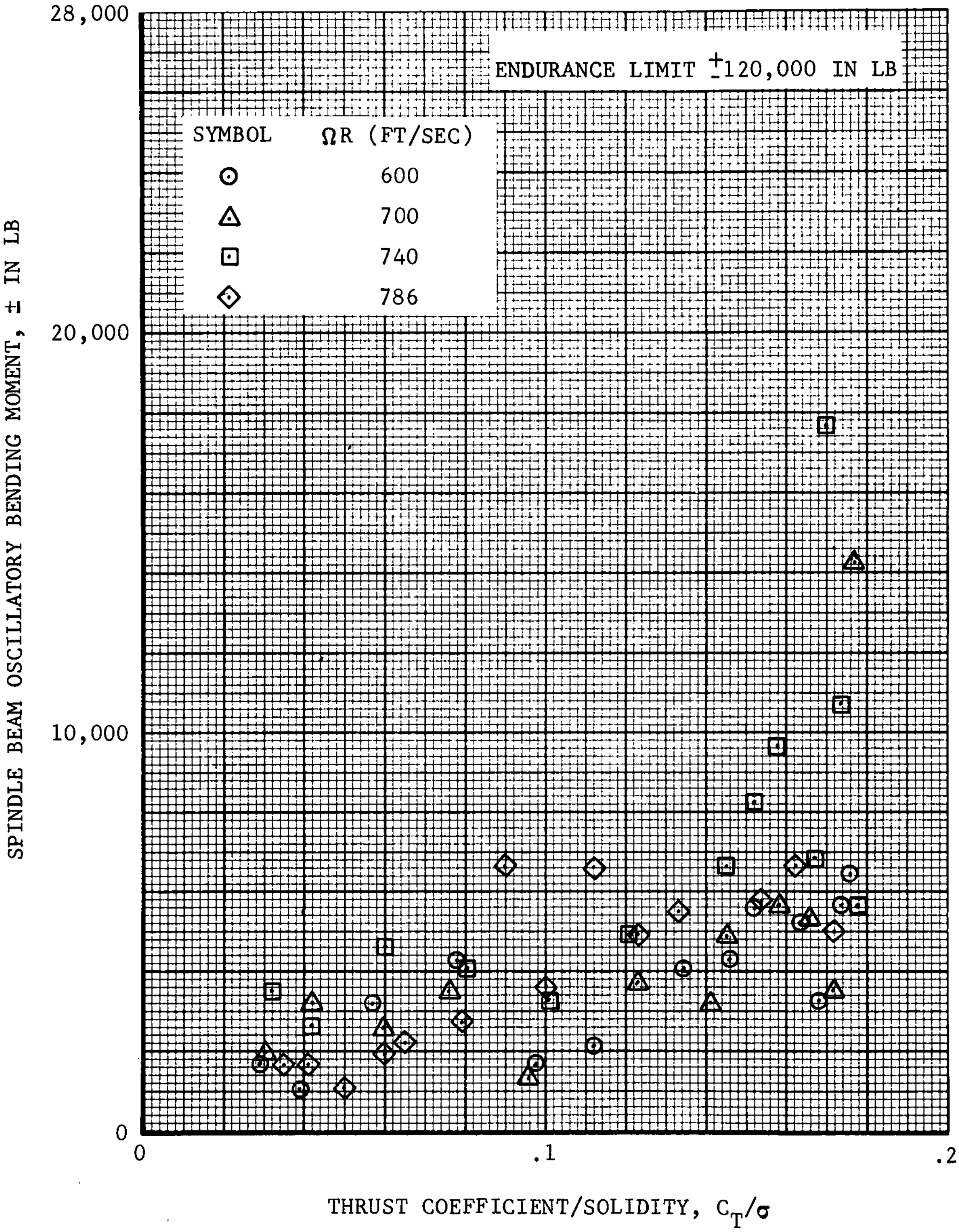

Figure V-5. Yoke Spindle Beam Oscillatory Bending Moment Versus C_T/σ.

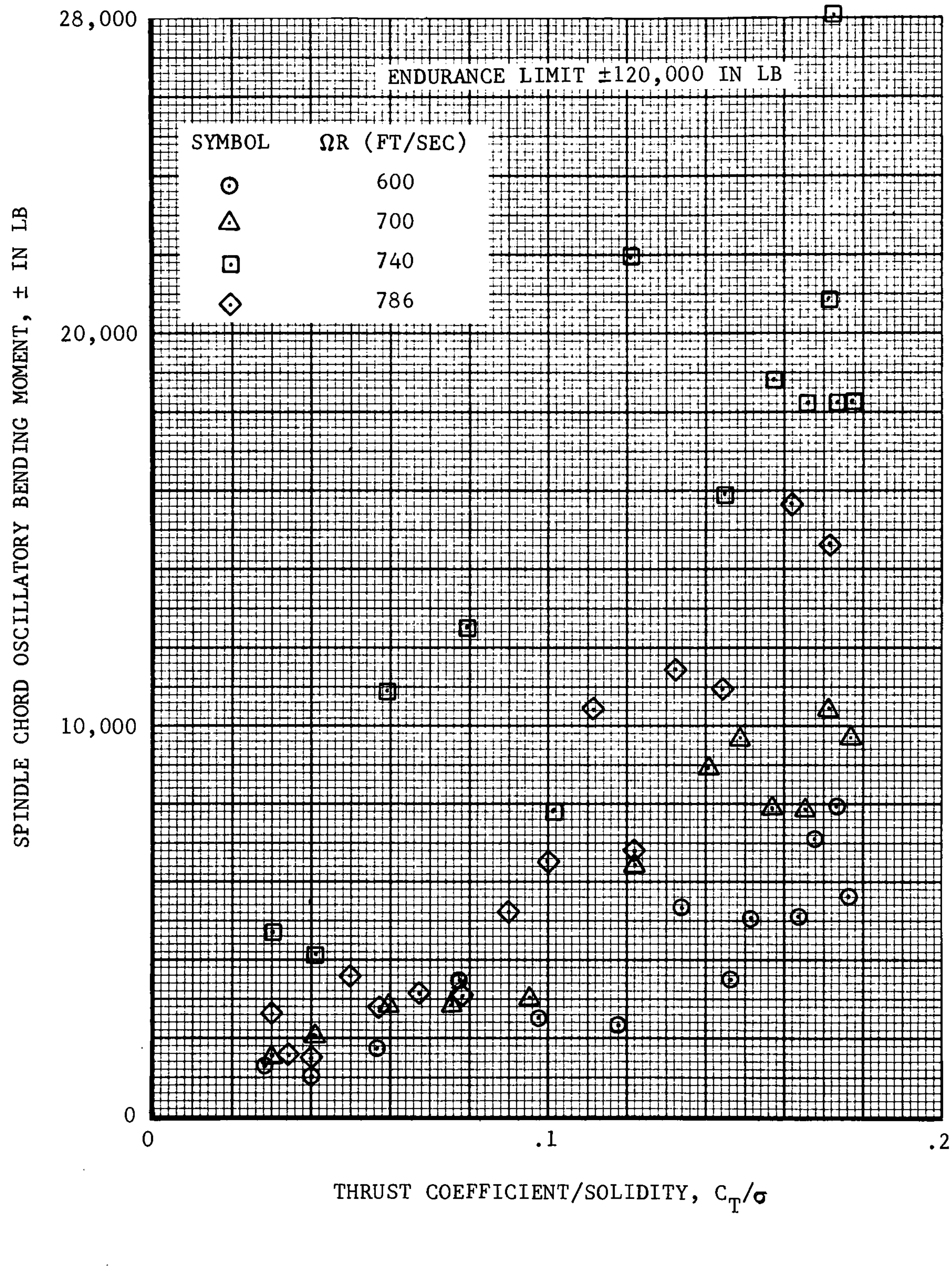

Figure V-6. Yoke Spindle Chord Oscillatory Bending Moment Versus C_T/σ.

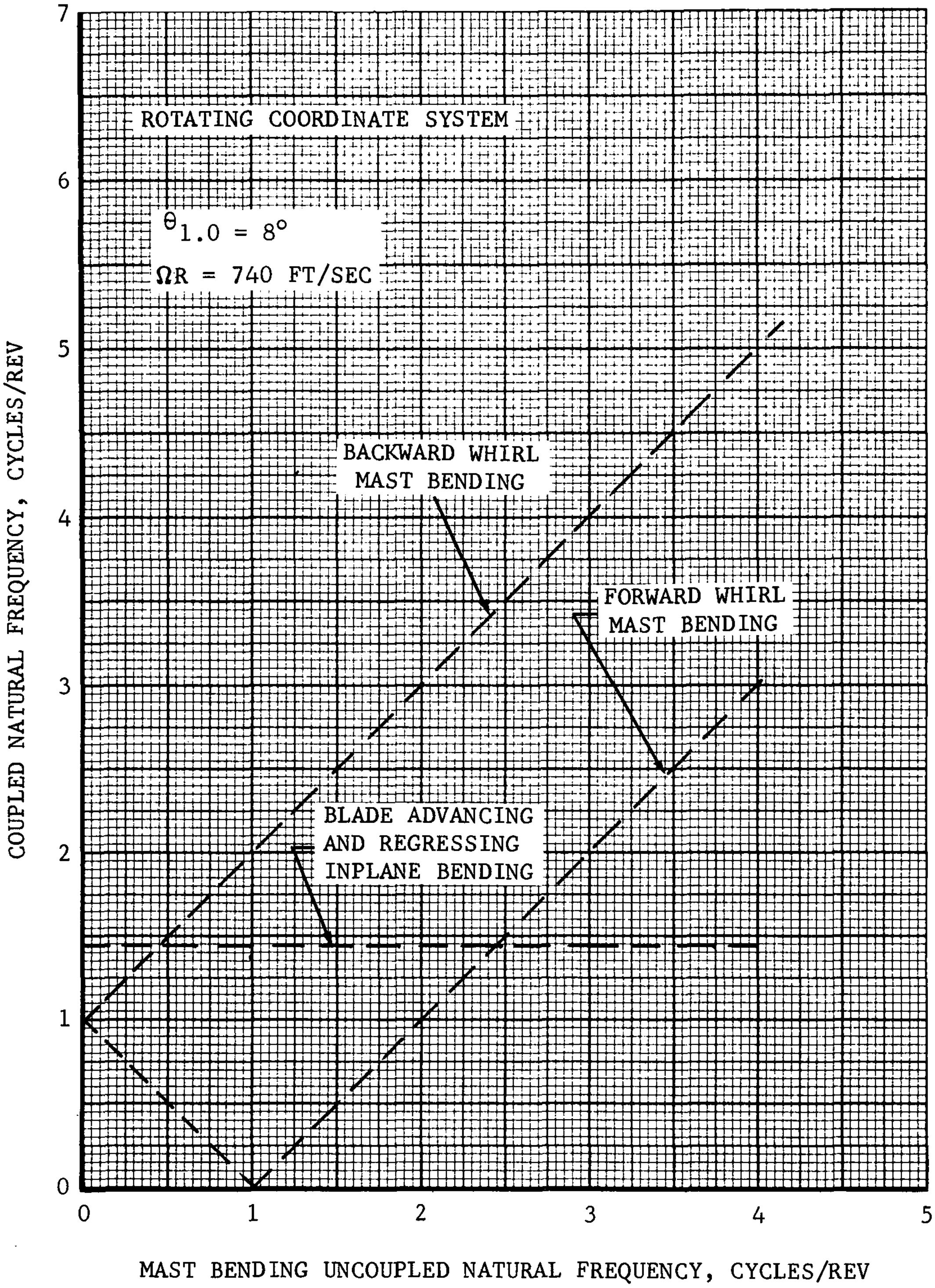

Figure V-7. Test Stand and Rotor Uncoupled Natural Frequencies Versus Mast Bending Uncoupled Natural Frequency.

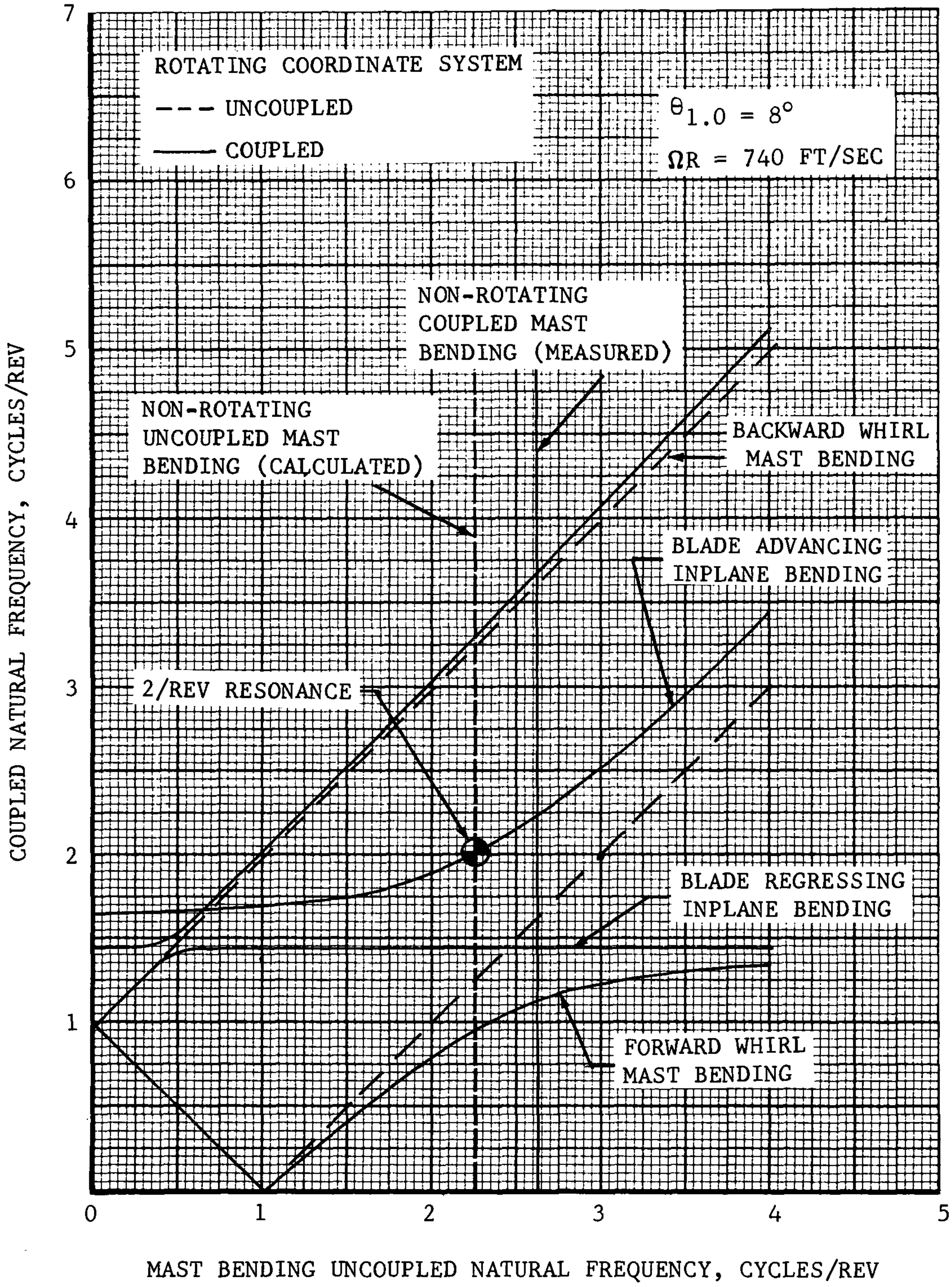

Figure V-8. Test Stand and Rotor Coupled Natural Frequencies Versus Mast Bending Uncoupled Natural Frequency.

VI. NOISE DATA

A. TEST

Prior to the test, the Air Force Flight Dynamics Laboratory (AFFDL) installed noise measuring microphones in the immediate test area at various distances from the rotor. The microphone locations are shown in Figure VI-1. During the test, noise was recorded by AFFDL at each tip speed and collective setting for all 11 microphones. This data is not a part of the NASA/Bell program and is, therefore, only briefly discussed in this report. Based on limited data from the test as supplied by NASA, a comparison with the noise data from the previous full-scale wind-tunnel tests was made and is given in paragraph B. This shows that the noise frequencies and sound pressure levels are similar and that the perceived noise level at a 500 foot side line distance will be about 92 PNdb for a single rotor at the design gross weight hover condition.

B. NOISE CORRELATION

The 25-foot diameter rotor hover noise characteristics measured during whirl stand and wind-tunnel tests are presented in Figures VI-2 and VI-3. Sound pressure levels graphed as a function of frequency distribution, Figure VI-2, show reasonable agreement. Rotor thrust levels and microphone distances are approximately equal for each set of data. However, the microphone is located 3-degrees above the rotor plane in the wind tunnel and is positioned 20.5 degrees below the rotor for the whirl stand. Directivity influence on peak perceived noise levels (illustrated in Figure VI-3) shows a 3-PNdb difference between inplane and 20 degrees below the plan viewing angles at approximately 37-feet distance. Thus, the wind-tunnel sound pressure level at 3 degrees above the rotor should produce slightly lower peak noise levels than shown. Wind-tunnel enclosure corrections were applied to the tunnel sound pressure level data using tables from Reference 12. These corrections apply for operation with the wind-tunnel ceiling doors closed. During hover tests, however, the tunnel doors were open introducing additional correction factors.

Peak perceived noise levels are shown as a function of distance from the rotor in Figure VI-3. Data were available for a maximum distance of 74.6 feet; thus, projected noise levels are indicated to 2000 feet. The upper straight line represents a 6 PNdb intensity decrease per doubled distance from the source (due to spherical wave spreading) and is based on the 74-foot whirl stand data point. The lower projection includes distance effects and atmospheric absorption (based on the frequency distribution of Figure VI-2) using an atmosphere with 40 percent relative humidity. A peak perceived noise calculation for the single rotor is shown at 500-feet distance using Lowson's chart method, Reference 13. A 6 PNdb increment based on wind tunnel test-theory correlation studies was added to the calculated value to agree with the wind-tunnel data. The calculated noise level for the Model 301 aircraft will be 3 PNdb higher than the single rotor noise which indicates the aircraft noise prediction will be 95 PNdb at 500 feet.

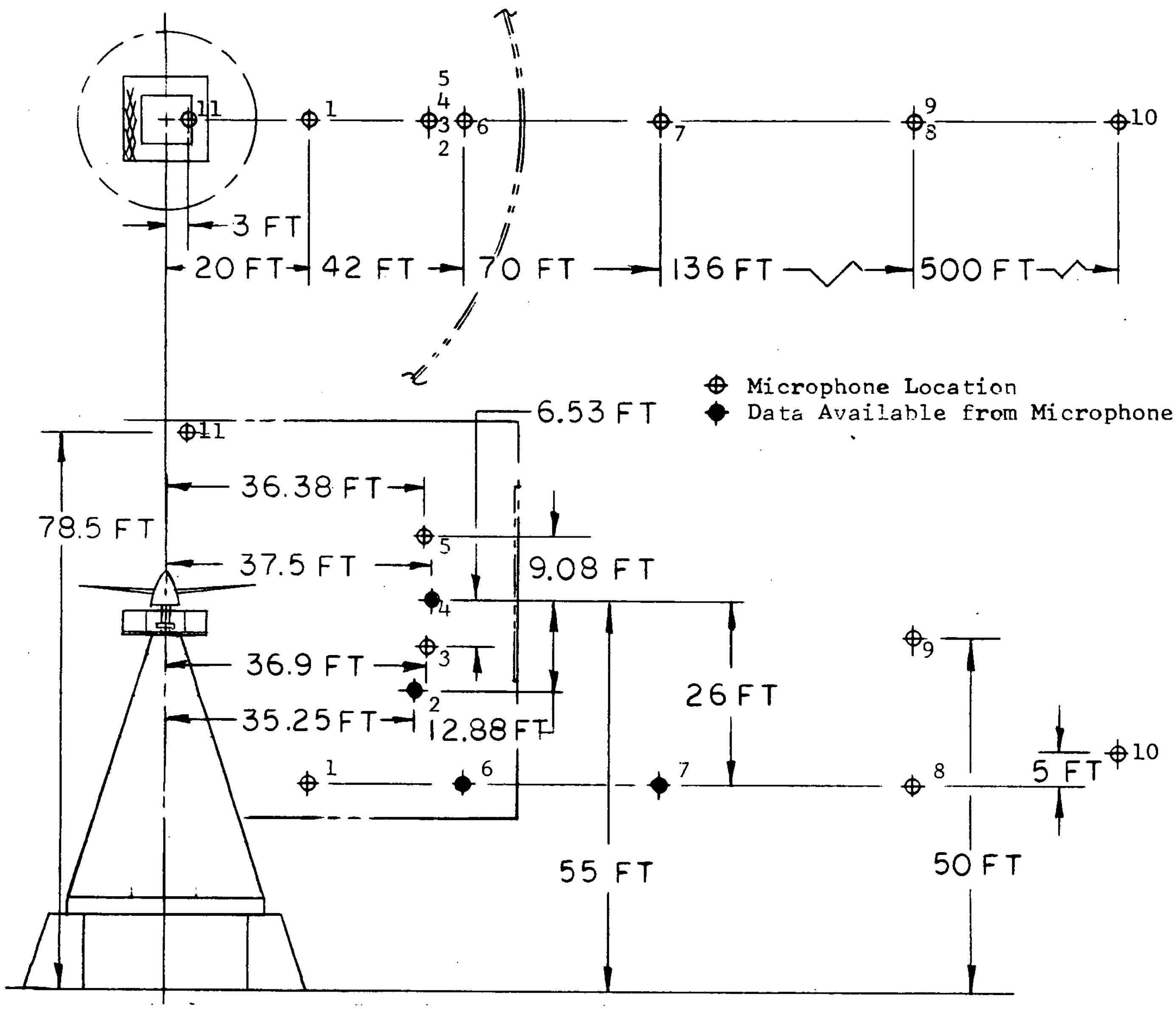

Figure VI-1. Microphone Locations

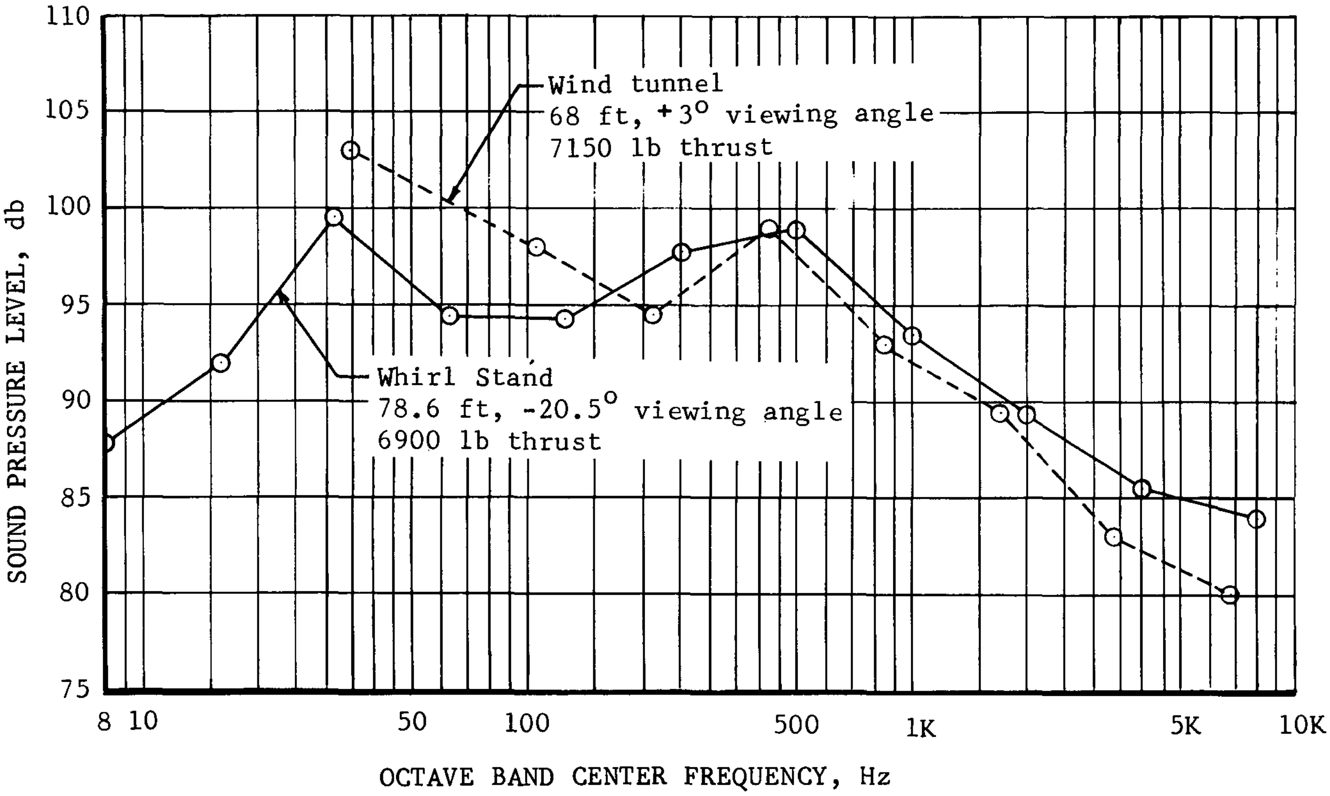

Figure VI-2. Tilt Rotor Hover Noise Level Versus Frequency Distribution (Single Rotor).

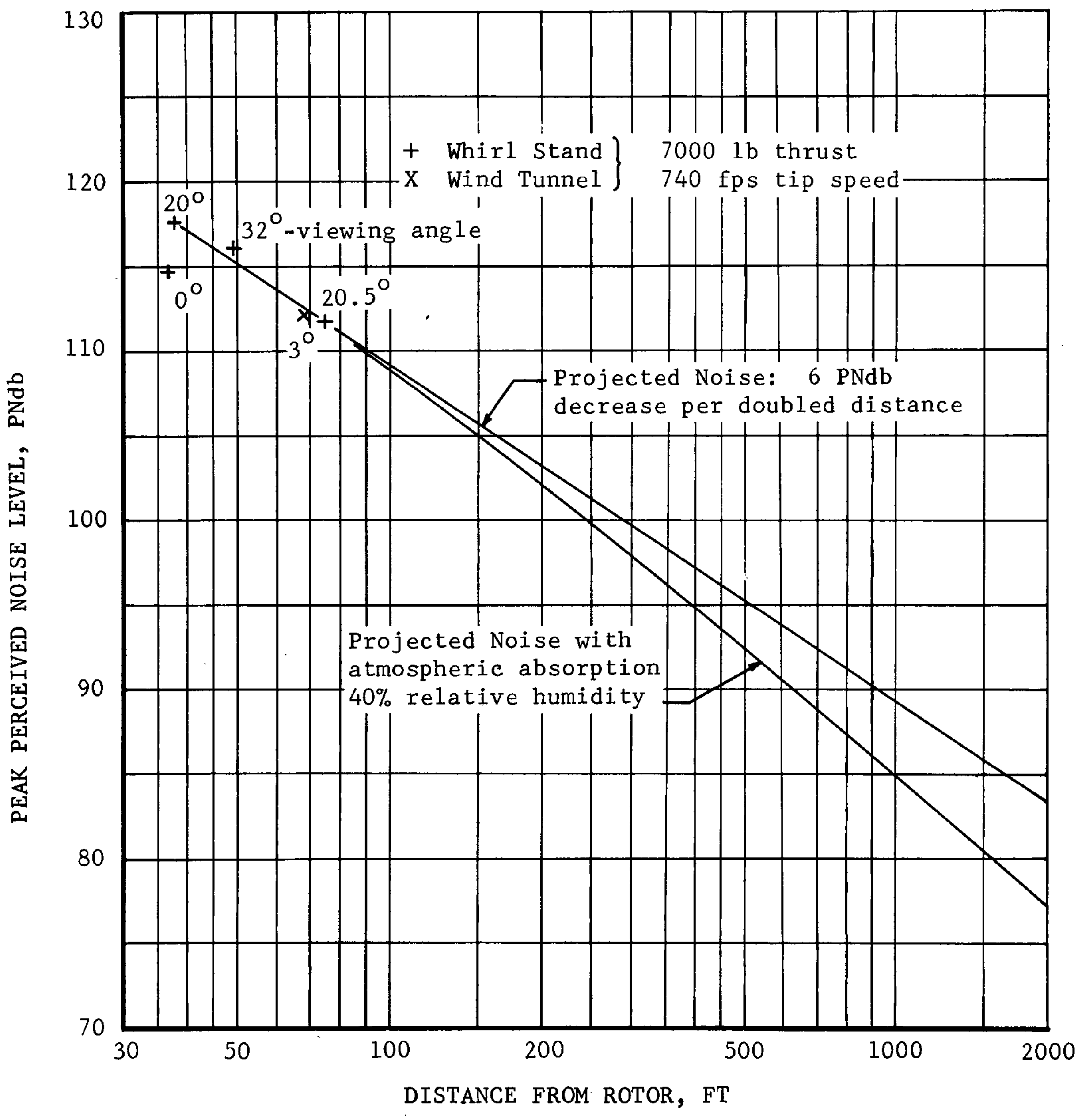

Figure VI-3. Peak Perceived Noise Levels of Single Tilt Rotor in Hover Versus Distance From Rotor.

VII. LIST OF REFERENCES

1. Abbott, R. J.: NASA Contract NAS2-7308, "Full-Scale Rotor Hover Tests of a 25-Foot Low Disc Loading Tilt Rotor," 13 November 1972.

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3. Anon: "Advancement of Proprotor Technology, Task I - Design Study Summary," NASA Contract NAS2-5386 CR114363 (Bell Helicopter Company Report 300-099-003).

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5. Griffin, T. F.: Two-Dimensional Wind-Tunnel Test of Nine Bell Airfoil Sections at Supersonic Speeds, UAC Research Labs Report F9305971, December 1967.

6. General Dynamics, Convair Division, Report GDLST 525, "Low Speed 2-Dimensional Wind-Tunnel Test of Various Cuff Airfoil Sections for the Bell Helicopter Company," January 1969.

7. McCormick, Barnes W.; Tangler, James L.; and Sherrier, Harold L.: "Structure of Trailing Vortices," Journal of Aircraft, May 1968.

8. Clark, David R.; Leiper, Albert C.: "The Free Wake Analysis," Journal of the American Helicopter Society, January 1970.

9. Sforza, P. M.: "Aircraft Vortices: Benign or Baleful," Space/Aeronautics, April 1970.

10. Tangler, James L.; Wohlfeld, Robert M.; and Stan, J.: "An Experimental Investigation of Vortex Stability, Tip Shapes, Compressibility and Noise for Hovering Model Rotors," Draft Report prepared under Contract NAS1-10946, Bell Helicopter Company Report 399-099-641.

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12. Hartman, J. R.; Soderman, P. T.: Determination of the Acoustical Properties of the NASA-Ames 40- by 80-Foot Wind Tunnel. Working Paper No. 237, Ames Research Center, Moffett Field, California, August 1967.

13. Lowson, M. V.; Ollerhead, J. G.: Studies of Helicopter Rotor Noise. USAAVLABS Technical Report 68-60, January 1969.

APPENDIX

Whirl Test Data Sheets

Data Comparison Tables

Drawings

Whirl Test Data Sheets

Air Force Aero Propulsion Laboratory
Wright-Patterson Air Force Base, Ohio
20 March 1973 thru 23 March 1973

Pages A-3 thru A-15

G

PROPELLER WHIRL TEST DATA SHEET

DATE 12 MAR 73	RIG ROT F-I	HUB DWG NO. 300-010-100	ENGINEER	TEMP +5
MFR. BELL 25FT dia	ADAPTER MOD. 300 ROT	HUB SERIAL NO.	CREW CHIEF MEDISCH	BAROMETER 29.19
PROJ. NO. G22-01F 01	BAFFLES SOUND RECORDED	BLADE DWG NO. 300-010-001	TEST CREW CROUCH	AIR FACTOR 1.0107
WHIRL TEST NO.		BLADE SERIAL NO.	HOWERTON	RIG FACTOR .985
SHEET NO. 1	T.T.=0:00	ALL RUNS-0° CYC.		TH FACTOR .9955

ANGLE COLL	-2°	-2°	-2°	-2°	-2°	-2°	0°	+2°	+4	+6	+8	
RPM	101	202	298	400	455	455	455	456	456	455	455	
COR HP			37	67	98	119	137	221	284	399	509	
COR TH		240	462	839	1095	1462	2120	2833	3546	4345	4977	
ARM VOLTS	22	45	68	92	105	105	104	104	104	104	103	
MULTIPLIER	X32										X32	
ARM AMPS	0	0	0	.1	.15	.15	.30	.56	.74	1	1.24	
MULTIPLIER	X960										X1920	
ARM WATTS	8	21	46	92	127	143	156	222	273	363	224	
CU LOSS				0	0	0	0	0	1	1	1	
F W I LOSS			22	50	64	64	63	63	63	63	62	
GEAR LOSS												
TOTAL HP	10	27	59	118	183	184	201	286	351	467	577	
TOTAL LOSS			22	50	64	64	63	63	64	64	63	
NET HP			37	68	99	120	138	223	287	403	514	
TH SCALE		239	460	835	1090	1455	2110	2820	3530	4325	4955	
BAL THRUST											+70	
ACTUAL TH												
START	14:20											
STOP											15:11	
TEST TIME											0:51	
START												
STOP												
RIG TIME												

REMARKS 14:20 ON LINE FOR CHECK RUN.
THRUST WAS NOT BALLANCED

T.T.=0:51

INITIAL CHECKOUT RUN

AFAPL FORM DEC 67 14a

300-099-010

A-3

BELL HELICOPTER COMPANY

300-099-010

PROPELLER WHIRL TEST DATA SHEET

DATE 20 MAR 73	RIG ROT. 2	HUB L. NO	ENGINEER	TEMP +5
MFR. Bell 25 FT dia	ADAPTER MOD. 300 ROT.	HUB SERIAL NO. 300-010-100	CREW CHIEF MCDISCH	BAROMETER 29.08
PROJ NO. 62201F01	BAFFLES SOUND RECORDED	BLADE DWG NO.	TEST CREW CROUCH	AIR FACTOR 1.0069
WHIRL TEST NO.		BLADE SERIAL NO.	HOWERTON, Steele	RIG FACTOR .985
SHEET NO. 2	T.Tr = 0:51	0° cyc ALL RUNS	CAMPBELL	TH FACTOR .9918

ANGLE Coll	-3.7°	-2°	0°	+2°	+4°	+6°	+8°	+9°	+10°	+11	+12	+13
RPM	456	456	457	455	458	457	457	456	455	455	458	459
COR HP	97	121	163	225	307	400	514	580	633	714	794	888
COR TH	1049	1472	2097	2853	3610	4396	4981	5374	5575	6029	6261	6488
ARM VOLTS	102	101	101	100	100	100	100	101	101	100	100	100
MULTIPLIER	X32						X32					
ARM AMPS	.15	.15	.40	.6	.81	1.03	1.3	1.4	1.52	1.73	1.9	2.13
MULTIPLIER	X960						X1920					
ARM WATTS	123	141	174	222	287	360	225	251	272	303	335	372
Cam-loss / FW	60	59	59	59	59	59	59	60	60	59	60	60
F-loss Col					1	1	2	2	2	2	3	3
GEAR LOSS												
TOTAL HP	158	181	224	285	369	463	579	646	700	780	862	957
TOTAL LOSS	60	59	59	59	60	60	61	62	62	61	63	63
NET HP	98	122	165	227	309	403	518	584	638	919	799	894
TH SCALE	1040	1460	2080	2830	3580	4360	4940	5330	5530	5980	6210	6435
BAL THRUST												
ACTUAL TH												
START	13:17											
STOP												
TEST TIME												
START												
STOP												
RIG TIME												

REMARKS

Cont on #3

RUN 1

BELL HELICOPTER COMPANY

A-4

AFAPL FORM DEC 67 14a REPLACES ASD-0 FORM 283 WHICH MAY BE USED.

300-099-010

BELL HELICOPTER COMPANY

PROPELLER WHIRL TEST DATA SHEET

DATE	RIG ROT 2	HUB DWG NO	ENGINEER	TEMP +5
MFR Bell 25FT dia	ADAPTER MOD300 ROT.	HUB SERIAL NO. 300-010-100	CREW CHIEF McDISCH	BAROMETER 29.19
PROJ NO. 62201F01	BAFFLES SOUND RECORDED	BLADE DWG NO.	TEST CREW CROUCH CAMPBELL	AIR FACTOR 1.0107
WHIRL TEST NO.		BLADE SERIAL NO.	HOWERTON	RIG FACTOR .995
SHEET NO. 2		0° CYC ALL RUNS	Steele	TH FACTOR .995

ANGLE Coll	+14°											
RPM	457											
COR HP	1000											
COR TH	1534											
ARM VOLTS	100											
MULTIPLIER X	32											
ARM AMPS	2.4											
MULTIPLIER X	3840											
ARM WATTS	208											
CU LOSS	4											
F W I LOSS	60											
GEAR LOSS												
TOTAL HP	1071											
TOTAL LOSS	64											
NET HP	1007											
TH SCALE	6480											
BAL THRUST												
ACTUAL TH	13a1	+12										
START												
STOP	13:54											
TEST TIME	:37											
START												
STOP												
RIG TIME												

REMARKS

Down - Rotor Flapping. Excessive wind. TT = 1:28

RUN 1

AFAPL FORM DEC 67 14a REPLACES ASD-0 FORM 283 WHICH MAY BE USED.

300-099-010

BELL HELICOPTER COMPANY

PROPELLER WHIRL TEST DATA SHEET

DATE 20 MAR 73	RIG ROT 2	HUB ... NO	ENGINEER		TEMP +5
MFR Bell 25FT dia	ADAPTER MOD 300 ROT	HUB SERIAL NO. 300-010-100	CREW CHIEF MCDISCH		BAROMETER 29.06
PROJ NO. 62201F01	BAFFLES SOUND Recorded	BLADE DWG NO.	TEST CREW Campbell CROUCH		AIR FACTOR 1.0062
WHIRL TEST NO.	T.T. = 1:28	BLADE SERIAL NO.	HOWERTON		RIG FACTOR .985
SHEET NO. 4		0°CYC. ALL RUNS	Steele		TH FACTOR .9911

ANGLE Coll	-3°	-2°	0°	+2°	+4°	+6°	+8°	+9°	10°	11°	12°	13°
RPM	535	534	535	533	535	534	536	536	536	537	534	537
COR HP	156	190	266	363	484	683	883	979	1097	1234	1403	1530
COR TH	1193	2058	3007	3834	4863	6215	7204	7608	8052	8475	8657	9040
ARM VOLTS	113	113	112	112	112	111	111	111	111	111	110	109
MULTIPLIER X	32			X32			X32					
ARM AMPS	.13	.14	.65	.83	1.1	1.55	1.9	2.1	2.35	2.64	2.93	3.35
MULTIPLIER X	960			1920			X3840					
ARM WATTS	182	208	269	172	220	298	188	207	230	257	290	315
CU LOSS	0	0	1	1	2	3	3	3	3	4	5	6
F W I LOSS	77	77	77	77	77	77	77	77	77	77	76	76
GEAR LOSS												
TOTAL HP	234	268	346	443	566	767	968	1065	1184	1323	1493	1621
TOTAL LOSS	77	77	78	78	79	80	80	80	80	81	81	82
NET HP	157	191	268	365	487	687	888	985	1104	1242	1412	1539
TH SCALE	1480	2040	2980	3800	4820	6160	7140	7540	7980	8400	8580	8960
BAL THRUST												+5
ACTUAL TH												
START	14:25											
STOP												14:49
TEST TIME												:24
START												
STOP												
RIG TIME												

REMARKS

T.T. 1:52

RUN 2

AFAPL FORM DEC 67 14a   REPLACES ASD-0 FORM 283 WHICH MAY BE USED.

PROPELLER WHIRL T DATA SHEET BAR TEMP COR.

DATE 21 MAR 73	RIG ROT #2	HUB DWG NO.	ENGINEER	TEMP 0.
MFR BELL 25FT dia	ADAPTER MOD 300 ROT	HUB SERIAL NO. 300-010-100	CREW CHIEF MEDISCH	BAROMETER 29.19
PROJ NO. 62201F01	BAFFLES SOUND RECORDED	BLADE DWG NO.	TEST CREW CROUCH CAMPBELL	AIR FACTOR 1.0297
WHIRL TEST NO.		BLADE SERIAL NO.	HOWERTON	RIG FACTOR .985
SHEET NO. 5	T.T.=1:52	0° CYC ALL RUNS	STEELE	TH FACTOR 1.0138

ANGLE Coll	-3.7°	-2	0	+2°	+4°	+6°	+8°	+9°	+10°	+11°	+12°	12°
RPM	565	565	567	567	565	567	566	565	566	566	566	566
COR HP	188	234	327	450	604	823	1058	1192	1307	1455	1681	1612
COR TH	1711	2308	3395	4518	5721	6885	8296	8670	8996	9489	9864	9667
ARM VOLTS	113	113	110	113	113	113	113	113	112	114	114	113
MULTIPLIER X	32	X32				X32						
ARM AMPS	.159	.65	.85	1.07	1.38	1.82	2.35	2.62	3.08	3.15	3.5	3.65
MULTIPLIER X	960	X1920				X3840						
ARM WATTS	213	125	163	212	274	181	228	255	278	308	353	339
CU LOSS	0	0	1	1	2	3	3	4	5	5	5	5
F W I LOSS	81	81	82	82	81	82	82	81	81	82	82	81
GEAR LOSS												
TOTAL HP	274	322	420	546	705	932	1174	1312	1431	1585	1817	1745
TOTAL LOSS	81	81	83	83	83	85	85	85	86	87	87	86
NET HP	193	241	337	463	622	847	1089	1227	1345	1498	1730	1659
TH SCALE	1735	2340	3440	4580	5800	6980	8410	8790	9120	9620	10,000	9800
BAL THRUST												
ACTUAL TH												
START	10:48											
STOP												
TEST TIME												
START												
STOP												
RIG TIME												

REMARKS RETORQUED RIG BOLTS.

RUN 3

AFAPL FORM DEC 67 14a

BELL HELICOPTER COMPANY

300-099-010

PROPELLER WHIRL TEST DATA SHEET BAR. TEMP COR.

DATE 21 MAR 73	RIG ROT #2	HUB DWG N.	ENGINEER	TEMP 0°
MFR BELL 25FT dia	ADAPTER MOD. 300 ROT	HUB SERIAL NO. 300-010-100	CREW CHIEF MCDISCH	BAROMETER 29.19
PROJ NO. 62201F01	BAFFLES SOUND RECORDED	BLADE DWG NO.	TEST CREW CROUCH, STEELE	AIR FACTOR 1.0292
WHIRL TEST NO.		BLADE SERIAL NO.	CAMPBELL	RIG FACTOR .985
SHEET NO. 6	T.T. = 1:52	0° CYC ALL RUNS	HOWERTON	TH FACTOR 1.0138

ANGLE	12.5°											
RPM	565											
COR HP	1721											
COR TH	10061											
ARM VOLTS	113											
MULTIPLIER												
ARM AMPS	3.65											
MULTIPLIER												
ARM WATTS	361											
CU LOSS	5											
F W I LOSS	82											
GEAR LOSS												
TOTAL HP	1858											
TOTAL LOSS	87											
NET HP	1771											
TH SCALE	10200											
BAL THRUST	+10											
ACTUAL TH												
START												
STOP	11:27											
TEST TIME	:39											
START												
STOP												
RIG TIME												

REMARKS

T.T. 2:31

RUN 3

AFAPL FORM DEC 67 14a

BELL HELICOPTER COMPANY

300-099-010

A-8

300-099-010

PROPELLER WHIRL TEST DATA SHEET

DATE	RIG ROT #2	HUB DWG NO.	ENGINEER	TEMP +5
MFR Bell 25FT dia	ADAPTER MOD 300 ROT	HUB SERIAL NO. 300-010-100	CREW CHIEF MCDISCH	BAROMETER 29.19
PROJ NO 62201F01	BAFFLES SOUND RECORDED	BLADE DWG NO.	TEST CREW CROUCH Steele	AIR FACTOR 1.0107
WHIRL TEST NO.		BLADE SERIAL NO.	HOWERTON	RIG FACTOR .985
SHEET NO 7	T.T. = 2:31	0° CYC ALL RUNS	CAMPBell	TH FACTOR .9955

ANGLE Coll	+7												
RPM	564												
COR HP	958												
COR TH	7594												
ARM VOLTS	111												
MULTIPLIER X	32												
ARM AMPS	2.05												
MULTIPLIER X	3840												
ARM WATTS	204												
CU LOSS	3												
F W I LOSS	79												
GEAR LOSS													
TOTAL HP	1050												
TOTAL LOSS	82												
NET HP	968												
TH SCALE	7560												
BAL THRUST													
ACTUAL TH													
START	14:24												
STOP	14:34												
TEST TIME	:10												
START													
STOP													
RIG TIME													

REMARKS
14:34 OFF LINE TO CHECK ROTOR ALIGNMENT. TOO MUCH LATERAL BENDING

T.T. = 2:41

RUN 4

AFAPL FORM DEC 67 14a

BELL HELICOPTER COMPANY

300-099-010

PROPELLER WHIRL TEST DATA SHEET

BAR TEMP COR

DATE 22 MAR. 73	RIG ROT #2	HUB DWG. NO.	ENGINEER		TEMP +5
MFR Bell 25FT dia	ADAPTER MOD. 300 ROT.	HUB SERIAL NO. 300-010-100	CREW CHIEF MEDISCH		BAROMETER 29.42
PROJ NO. 62201F01	BAFFLES SOUND RECORDED	BLADE DWG NO.	TEST CREW CROUCH, Steele		AIR FACTOR 1.0186
WHIRL TEST NO.		BLADE SERIAL NO.	HOWERTON		RIG FACTOR .985
SHEET NO. 8	T.T.=2:41	0° CYC. ALL RUNS	CAMPBELL		TH FACTOR 1.003

ANGLE Coll	-3.7°	-3.7°	-3.7°	-2°	0°	+2°	+4°	+6°	+8°			
RPM	301	451	561	566	564	565	565	567	565			
COR HP	35	97	192	233	333	457	627		1073			
COR TH	437	1037	1665	2353	3390	4526	5793	7049	8136			
ARM VOLTS	62	91	111	111	110	110	110	109	109			
MULTIPLIER X	32				X32		X	32				
ARM AMPS	.2	.12	.45	.6	.82	1.12	1.46	1.86	2.38			
MULTIPLIER X					X1920		X	3840				
ARM WATTS	48	119	214	247	163	212	280		228			
CU LOSS	0	0	0	1	1	1	2		3			
F W I LOSS	26	54	79	80	80	80	80		78			
GEAR LOSS												
TOTAL HP	62	153	275	318	420	546	721		1174			
TOTAL LOSS	26	54	79	81	81	81	82		81			
NET HP	36	99	196	237	339	465	639		1093			
TH SCALE	440	1040	1670	2360	3400	4540	5810	7070	8160			
BAL THRUST												
ACTUAL TH												
START	15:10											
STOP									15:35			
TEST TIME									25			
START												
STOP												
RIG TIME												

REMARKS CHECK RUN FOR LATERAL MAST BENDING

T.T. 3:06

RUN 5

BELL HELICOPTER COMPANY

AFAPL FORM DEC 67 14a

300-099-010

PROPELLER WHIRL TEST DATA SHEET BAR. TEMP. COR.

DATE 23 MAR 73	RIG ROT #2	HUB DWG NO.	ENGINEER	TEMP +2
MFR Bell 25FT dia	ADAPTER MOD 300 ROT.	HUB SERIAL NO. 300-010-100	CREW CHIEF MEDISCH	BAROMETER 29.55
PROJ NO 62201F01	BAFFLES SOUND RECORDED	BLADE DWG NO.	TEST CREW CROUCH STEELE	AIR FACTOR 1.0343
WHIRL TEST NO.		BLADE SERIAL NO.	HOWERTON	RIG FACTOR .985
SHEET NO. 9	T.T. = 3:06	0° CYC. ALL RUNS	CAMPBELL	TH FACTOR 1.0188

ANGLE Coll		-3.7°	0°	+4°	+8°	+10°	+12°					
RPM		458	457	456	457	458	458					
COR HP		102	165	312	538	673	823					
COR TH		1080	2110	3573	5163	5840	6390					
ARM VOLTS		94	96	95	95	95	95					
MULTIPLIER X		X32		X32			X32					
ARM AMPS		.2	.55	.88	1.45	1.79	2.1					
MULTIPLIER X		X960		X1920			X3840					
ARM WATTS		125	177	295	239	293	177					
CU LOSS		0	0	1	2	2	3					
F W I LOSS		56	57	56	57	56	57					
GEAR LOSS												
TOTAL HP		161	228	380	615	754	911					
TOTAL LOSS		56	57	57	59	58	60					
NET HP		105	171	323	556	696	851					
TH SCALE		1100	2150	3640	5260	5950	6510					
BAL THRUST							10.16					
ACTUAL TH												
START	09:01	10:05										
STOP	09:06											
TEST TIME	:05											
START												
STOP												
RIG TIME												

[illegible]

REMARKS THIS RUN WITH SIDE JACKS TIGHT - NO THRUST INDICATED
10:05 LOOSENED SIDE JACKS SO THRUST WOULD INDICATE

RUN 6

T.T. see Sheet #10

BELL HELICOPTER COMPANY

AFAPL FORM DEC 67 14a

300-099-010

PROPELLER WHIRL TEST DATA SHEET

BAR. TEMP. COR.

DATE 23 MAR. 73	RIG ROT #2	HUB DWG NO.	ENGINEER	TEMP 42, +4°
MFR Bell 25FT dia	ADAPTER MOD. 300 ROT	HUB SERIAL NO. 300-010-100	CREW CHIEF McDISCH	BAROMETER 29.55
PROJ NO 62201F01	BAFFLES SOUND RECORDED	BLADE DWG NO.	TEST CREW CROUCH Steele	AIR FACTOR 1.0313/1.026
WHIRL TEST NO.		BLADE SERIAL NO.	HOWERTON	RIG FACTOR .985
SHEET NO. 10	T.T. = 3:06	0° CYC. ALL RUNS	CAMPBELL	TH FACTOR 1.0188/1.0114

ANGLE Coll	-4°	-2°	+1°	+3°	+5°	+7°	+8°	+9°	+10°	11°	12°	
RPM	565	569	566	567	568	565	565	564	564	565	566	
COR HP	190	240	382	531	739	959	1054	1200	1345	1496	1648	
COR TH	1669	2363	3866	5052	6298	7356	7979	8533	9077	9581	9887	
ARM VOLTS	110	109	109	109	109	109	109	108	108	109	109	
MULTIPLIER X	x 32					x32						
ARM AMPS	.5	.6	.94	1.27	1.72	2.15	2.38	2.63	3.3	3.35	3.65	
MULTIPLIER X	1920					x3840						
ARM WATTS	107	126	183	243	326	206	225	254	283	313	343	
CU LOSS	0	0	1	2	2	3	4	4	5	5	5	
F W I LOSS	79	78	78	78	78	78	78	78	78	78	78	
GEAR LOSS												
TOTAL HP	275	324	471	625	839	1066	1164	1314	1464	1619	1775	
TOTAL LOSS	79	78	79	80	80	81	82	82	83	83	83	
NET HP	196	246	392	545	759	985	1092	1232	1381	1536	1692	
TH SCALE	1700	2390	3910	5110	6370	7440	8070	8630	9180	9690	10 000	
BAL THRUST											+10 lb	
ACTUAL TH												
START												
STOP											11:26	
TEST TIME											1:26	
START												
STOP	Temp	Temp. +4°										
RIG TIME	+2°											

REMARKS ↑ CHANGED COUNTERS. T.T 4:32

RUN 6

AFAPL FORM DEC 67 14a

BELL HELICOPTER COMPANY

300-099-010

PROPELLER WHIRL TEST DATA SHEET

BAR. TEMP COR.

DATE 23 MAR. 73	RIG ROT 2	HUB I.D. NO.	ENGINEER	TEMP. +6	
MFR Bell 25FT	ADAPTER MOD 300 ROT.	HUB SERIAL NO. 300-010-100	CREW CHIEF MEDISCH	BAROMETER 29.54	
PROJ NO. 622 01 F01	BAFFLES SOUND RECORDED	BLADE DWG NO.	TEST CREW HOWERTON	AIR FACTOR 1.0191	
WHIRL TEST NO.		BLADE SERIAL NO.	CROUCH, STEELE	RIG FACTOR .985	
SHEET NO. 11	T.T. 432	0° CYC. All RUNS	CAMPBELL	TH FACTOR 1.0038	

ANGLE Coll	-3.7°	-3°	-2°	-1°	0°	+1	+2	+3°	+4°	+5°	+6°	+7°
RPM	599	599	599	599	598	600	599	599	600	601	599	599
COR HP	225	250	287	338	395	461	549	652	763	888	1020	1152
COR TH	1893	2182	2550	3168	3736	4304	5041	5938	6376	7143	7810	8468
ARM VOLTS	117	117	116	116	116	116	116	115	116	115	115	115
MULTIPLIER X	32	x32						X32				
ARM AMPS	.57	.63	.68	.82	.9	1.06	1.23	1.41	1.66	1.9	2.16	2.42
MULTIPLIER X	960	1920						X3840				
ARM WATTS	245	133	147	167	190	216	251	146	168	193	219	246
CU LOSS	0	1	1	1	1	1	2	2	2	3	3	4
F W I LOSS	86	86	85	85	85	85	85	85	85	85	85	85
GEAR LOSS												
TOTAL HP	315	342	378	430	489	556	646	751	865	993	1127	1266
TOTAL LOSS	86	87	86	86	86	86	87	87	87	88	88	89
NET HP	229	255	292	344	403	470	559	664	778	905	1039	1174
TH SCALE	1900	2190	2560	3180	3750	4320	5060	5760	6400	7170	7840	8500
BAL THRUST												
ACTUAL TH												
START	13:25											
STOP												
TEST TIME												
START												
STOP												
RIG TIME												

REMARKS

RUN 7

T.T. See S-#12

AFAPL FORM DEC 67 14a

BELL HELICOPTER COMPANY

300-099-010

PROPELLER WHIRL TEST DATA SHEET

BAR. TEMP. COR.

DATE	RIG	HUB DWG NO.	ENGINEER	TEMP
23 MAR. 73	ROT #2			76
MFR Bell 25FT	**ADAPTER** MOD 300 ROT.	**HUB SERIAL NO.** 300-010-100	**CREW CHIEF** MeDISCH	**BAROMETER** 29.54
PROJ NO. 622 01F01	**BAFFLES** SOUND RECORDED	**BLADE DWG NO.**	**TEST CREW** HOWERTON	**AIR FACTOR** 1.0191
WHIRL TEST NO.		**BLADE SERIAL NO.**	Steele Crouch	**RIG FACTOR** .985
SHEET NO. 12	T.T. = 4:32	0° cyc. ALL RUNS	CAMPBell	**TH FACTOR** 1.0038

ANGLE Coll	+8°	+9	+9°	+10	+11							
RPM	598	598	598	600	601							
COR HP	1313	1434	1464	1627	1866							
COR TH	9185	9165	9743	10361	11008							
ARM VOLTS	113	113	112	114	113							
MULTIPLIER												
ARM AMPS	2.76	2.99	3.1	3.9	4							
MULTIPLIER												
ARM WATTS	277	301	307	340	387							
CU LOSS	5	5	5	7	7							
F W I LOSS	83	83	83	85	83							
GEAR LOSS												
TOTAL HP	1426	1549	1580	1750	1992							
TOTAL LOSS	88	88	88	92	90							
NET HP	1338	1461	1492	1658	1902							
TH SCALE	9220	9200	9780	10400	11050							
BAL THRUST					+10							
ACTUAL TH												
START												
STOP					14:01							
TEST TIME					:36							
START												
STOP												
RIG TIME												

REMARKS

T.T. = 5:08

RUN 7

AFAPL FORM DEC 67 14a

BELL HELICOPTER COMPANY

300-099-010

PROPELLER WHIRL TEST DATA SHEET BAR. TEMP. COR.

DATE 23-MAR 73	RIG ROT #2	HUB DWG. NO.	ENGINEER	TEMP. 78
MFR BELL 25FT dia	ADAPTER MOD 300 ROT	HUB SERIAL NO. 300-010-100	CREW CHIEF MEDISCH	BAROMETER 29.54
PROJ NO. 62201F01	BAFFLES SOUND RECORDED	BLADE DWG NO.	TEST CREW HOWERTON	AIR FACTOR 1.0119
WHIRL TEST NO.		BLADE SERIAL NO.	CROUCH, Steele	RIG FACTOR .985
SHEET NO. 13	T.T. = 5:08	0° CYC ALL RUNS	HOWERTON	TH FACTOR .9967

ANGLE Coll	6°	8°												
RPM	565	565												
COR HP	821	1048												
COR TH	6963	8047												
ARM VOLTS	113	113												
MULTIPLIER X	32	32												
ARM AMPS	1.85	2.25												
MULTIPLIER X														
ARM WATTS	178	221												
CU LOSS	3	3												
F W I LOSS	82	82												
GEAR LOSS														
TOTAL HP	916	1137												
TOTAL LOSS	85	85												
NET HP	831	1052												
TH SCALE	6940	8020												
BAL THRUST														
ACTUAL TH														
START	14:27													
STOP		14.37												
TEST TIME		10												
START														
STOP														
RIG TIME														

REMARKS SIDE JACKS LOCKED TIGHT T.T. = 5:18

LOAD CHECK ONLY RUN

AFAPL FORM DEC 67 14a

A-15

BELL HELICOPTER COMPANY

DATA COMPARISON TABLES

C2

TABLE I. POWER COMPARISON - MAST TORQUE POWER TO STAND POWER

ΩR = 740 FT/SEC (565 RPM)

MAST TORQUE MEASUREMENT

DATA PT.	TIP COLLEC-TIVE (DEG)	OSC VALUE (IN)	NET VALUE (IN)	TORQUE (in #)	OSC RPM	OSC HORSEPOWER $(HP=\frac{Q\,N}{63,025})$	OSC H.P./σ'	COR STAND H.P./σ'	Δ H.P.	PERCENT OF STAND H.P.
3-21-73 RUN 3			(ZERO=1.060)	(95,500 in #/in)			(σ'=1.0292)			
1	-3.7	1.280	0.220	20,900	561	186	181	188	-7	-3.72
2	-2	1.350	0.290	27,700	562	246	239	234	+5	+2.13
3	0	1.460	0.400	38,100	563	338	328	327	+1	+0.3
4	2	1.610	0.550	52,500	563	468	454	450	+4.0	+0.9
5	4	1.820	0.760	72,400	563	645	627	604	+23	+3.8
6	6	2.080	1.020	97,100	563	865	840	823	+17	+2.0
7	8	2.390	1.330	127,000	564	1132	1100	1058	+42	+4.0
8	9	2.570	1.510	142,000	564	1268	1232	1192	+40	+3.35
9	10	2.710	1.650	157,500	563	1405	1365	1307	+58	+4.4
10	11	2.860	1.800	172,000	563	1530	1486	1455	+31	+2.1
11	12	3.120	2.060	196,500	564	1755	1705	1681	+24	+1.4
12	12.5	3.160	2.100	200,500	564	1790	1739	1721	+18	+1.0
										AVERAGE 2.4%
RUN 4			(ZERO=1.07)				(σ'=1.0107)			
1	7	2.23	1.16	110,780	564	991	981	963	+18	+1.8
3-23-73 RUN 6			(ZERO=1.32)	(95,500 in #/in)			(σ'=1.0268)			
7	-3.7	-	-	-	-	-	-	190	-	-
8	-2	1.60	.28	26,740	563	238	232	240	-8	-3.3
9	1	1.77	.45	42,975	564	384	374	382	-8	-2.1
10	3	1.95	.63	60,165	564	538	524	531	-7	-1.3
11	5	2.20	.88	84,040	563	751	731	739	-8	-1.0
12	7	2.45	1.13	107,915	563	964	939	959	-20	-2.1
13	8	2.58	1.26	120,330	563	1075	1047	1054	-7	-0.6
14	9	2.75	1.43	136,565	562	1218	1186	1200	-14	-1.1
15	10	2.92	1.60	152,800	562	1363	1327	1345	-18	-1.3
16	11	3.10	1.78	169,900	562	1516	1476	1496	-20	-1.3
17	12	3.27	1.95	186,225	562	1661	1618	1648	-30	-1.8
										AVERAGE -1.5%

TABLE II. POWER COMPARISON - MAST TORQUE POWER TO STAND POWER

ΩR = 786 FT/SEC (600 RPM)

3-23-73 RUN 7 — MAST TORQUE MEASUREMENT

DATA PT.	TIP COLLECTIVE (DEG)	OSC VALUE (IN)	NET VALUE (IN) (ZERO=1.32)	TORQUE (IN LB) (95,500 in #/in)	OSC RPM	OSC HORSEPOWER $(HP=\frac{QN}{63,025})$	OSC H.P./σ' (σ'=1.0191)	COR STAND H.P./σ'	Δ H.P.	PERCENT OF STAND H.P.
1	-3.7	1.57	.25	23,875	597	226	222	225	-3	-1.3
2	-3	1.59	.27	25,785	597	244	240	250	-10	-4.0
3	-2	1.64	.32	30,560	596	289	284	287	-3	-1.0
4	-1	1.69	.37	35,335	596	334	328	338	-10	-2.9
5	0	1.77	.45	42,975	597	407	399	395	+4	+1.0
6	1	1.84	.52	49,660	598	471	462	461	+1	+0.2
7	2	1.94	.62	59,210	597	561	550	549	+1	+0.1
8	3	2.07	.75	71,625	597	678	666	652	+14	+2.1
9	4	2.17	.85	81,175	598	770	756	763	-7	-0.9
10	5	2.30	.98	93,590	598	888	871	888	-17	-1.9
11	6	2.45	1.13	107,915	598	1024	1005	1020	-15	-1.5
12	7	2.62	1.30	124,150	597	1176	1154	1152	+2	+0.2
13	8	2.78	1.46	139,430	596	1344	1318	1313	+5	+0.4
14	9	2.96	1.64	156,620	597	1484	1456	1432	+24	+1.7
15	9	2.98	1.66	158,530	598	1504	1476	1464	+12	+0.8
16	10	3.16	1.84	175,720	598	1667	1636	1627	+9	+0.5
17	11	3.39	2.07	197,685	599	1879	1844	1866	-22	-1.2

AVERAGE 1.75%

TABLE III. CORRELATION WITH CALCULATED THRUST

TIP SPEED	RUN NUMBER	TIP COLLECTIVE PITCH (deg)	CORRECTED MEASURED THRUST (LB)	CALCULATED THRUST (LB)	Λ THRUST (LB)	PERCENT OF CALCULATED THRUST
740	3	6	6885	6850	35	0.5
	4	7	7594	7500	94	1.25
	6	8	7979	8120	141	1.7
	6	9	8533	8700	167	1.9
	6	10	9077	9250	173	1.9
600	6	8	5163	5180	17	0.3
	1	9	5374	5520	146	2.6
	6	10	5840	5900	60	1.0
	1	11	6029	6180	151	2.45
	6	12	6390	6460	70	1.0

TABLE IV. CORRELATION WITH CALCULATED POWER

TIP SPEED	RUN NUMBER	TIP COLLECTIVE PITCH (deg)	CORRECTED POWER H.P.	CALCULATED POWER H.P.	Λ POWER	PERCENT OF CALCULATED POWER
740	3	6	823	855	32	3.7
	4	7	958	992	34	3.4
	6	8	1054	1130	76	6.7
	6	9	1200	1295	95	7.3
	6	10	1345	1465	120	8.2
600	6	8	538	570	32	5.6
	1	9	580	645	65	10.0
	6	10	673	720	47	6.5
	1	11	714	800	86	10.8
	6	12	823	895	72	8.0

TABLE V. SCATTER IN THRUST DATA POINTS

TIP SPEED	RUN NUMBER	TIP COLLECTIVE PITCH (deg)	CORRECTED THRUST (LBS)	DELTA THRUST (LBS)	PERCENT OF CORRECTED THRUST	MEAN SCATTER (PERCENT)
600	6	8	5163	-	-	3.4
	1		4981	182	3.6	
	6	10	5840	-	-	
	1		5575	265	4.7	
	6	12	6390	-	-	
	1		6261	129	2.0	
740	4	7	7594	-	-	2.1
	6		7356	238	3.2	
	3	8	8296	-	-	
	6		7979	317	4.0	
	3	9	8670	-	-	
	6		8533	137	1.6	
	6	10	9077	-	-	
	3		8996	81	0.9	
	6	11	9581	-	-	
	3		9489	92	0.9	
	6	12	9887	-	-	
	3		9667	220	2.3	

TABLE VI. SCATTER IN POWER DATA POINTS

TIP SPEED	RUN NUMBER	TIP COLLECTIVE PITCH (deg)	CORRECTED POWER	DELTA POWER	PERCENT OF CORRECTED POWER	MEAN SCATTER (PERCENT)
600	6	8	538	-	-	4.9
	1		514	24	4.7	
	6	10	673	-	-	
	1		633	40	6.3	
	6	12	823	-	-	
	1		794	29	3.7	
740	6	10	1345	-	-	2.5
	3		1307	38	2.9	
	6	11	1496	-	-	
	3		1455	41	2.8	
	6	12	1648	-	-	
	3		1612	36	2.2	
	3	12	1681	-	-	
	6		1648	33	2.0	

LIST OF DRAWINGS

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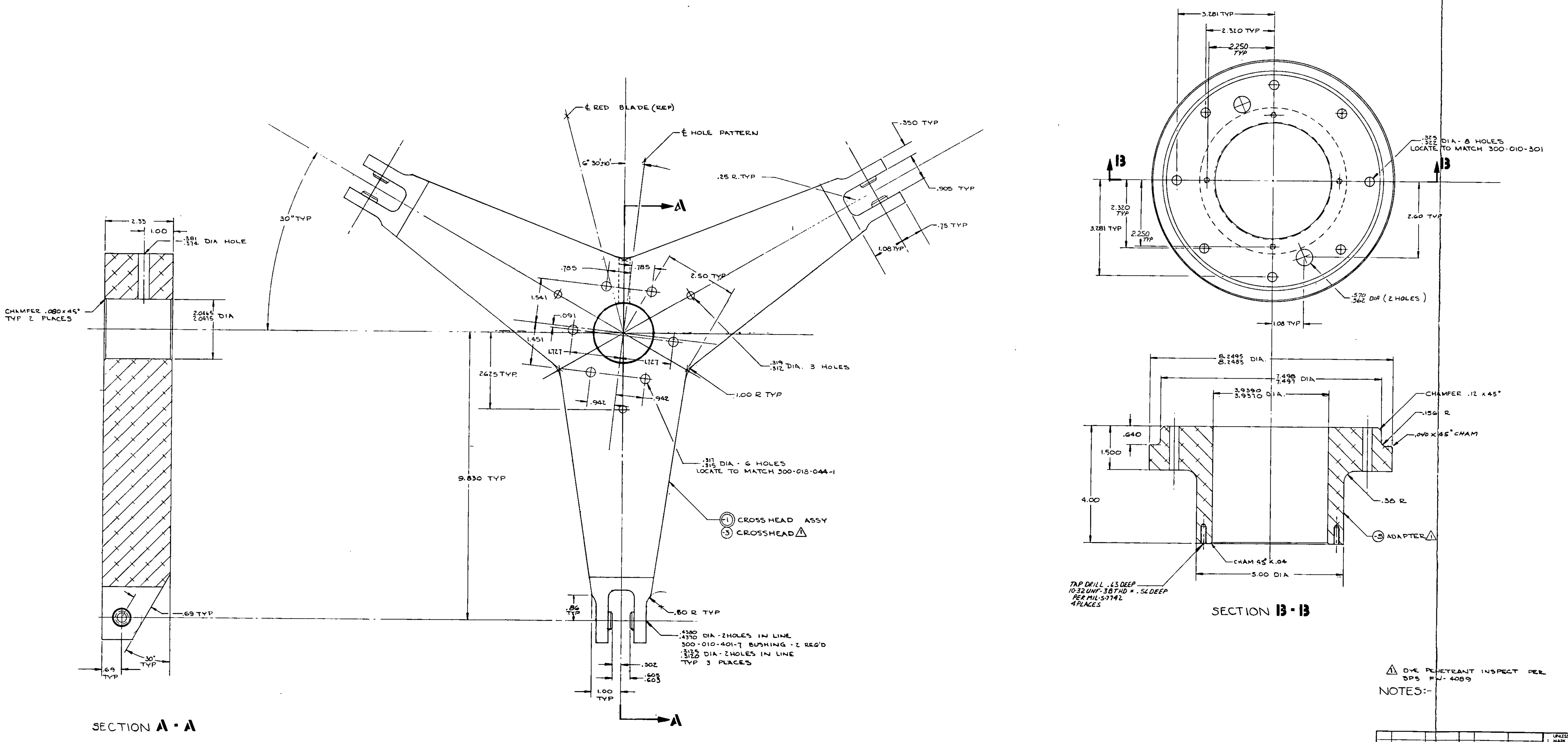


⚠ DYE PENETRANT INSPECT PER BPS FW-4089

NOTES:-

6 300-010-401-7 BUSHING A4

LAST SECTION LETTER USED B

QTY REQD	PART OR IDENTIFYING NO	CODE IDENT NO.	NOMENCLATURE OR DESCRIPTION	STOCK SIZE	MATERIAL	MATERIAL SPEC	TENSILE 1000 PSI OR COND	FINISH CODE 299-099-031		ZONE
	300-018-045-5		ADAPTER	9.0 DIA x 4.5	2014 AL ALY	MIL-A-22771 COND T6	-T62	A	–	B3
1	300-018-045-3		CROSSHEAD	3.0 x 18.0 x 20.0	7075 AL ALY	MIL-A-22771 COND T73	-T73	A	–	B4
-1	300-018-045-1		CROSSHEAD	ASSY						B4

REF: E.O. 300HES123

PARTS LIST

UNLESS OTHERWISE SPECIFIED
1. MARK PER BPS FW 4050
2. BREAK ALL SHARP EDGES .015 x 45° OR .015 R
3. TORQUE PER BPS FW 4018
4. SAFETY PER BPS FW 4043
5. DIMENSIONAL LIMITS APPLY AFTER PLATING

APPLICABLE DOCUMENTS: ABBREVIATIONS PER MIL-STD-12; DIMENSIONING AND TOLERANCING PER USAS Y14.5; ELECTRICAL SYMBOLS PER USAS Y32.2; ELECTRICAL REF DESIGNATIONS PER USAS Y32.16

DASH NO	NEXT ASSY	USED ON
-5	300-018-046	TEST
-1	300-018-046	TEST

HEAT TREAT BPS FW-4139

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES. TOLERANCES ON DECIMALS XXX ± .010, XX ± .03, X ± .1; ANGLES ± 1°

125 ✓ MACHINED SURFACES

DRAWN D. MYERS 10/5/72
STRESS U. Brockhaus 10/?/72
GROUP ENGR 10/?/72
MFT DESIGN 10/?/72
PROJECT D.E. Brown 10/?/72

BELL HELICOPTER COMPANY

TITLE MISCELLANEOUS DETAILS HOVER TEST MODEL 300

DWG SIZE J6 | CODE IDENT NO 97499 | DWG NO 300-018-045

SCALE 1/1 | SHEET 1 OF 1

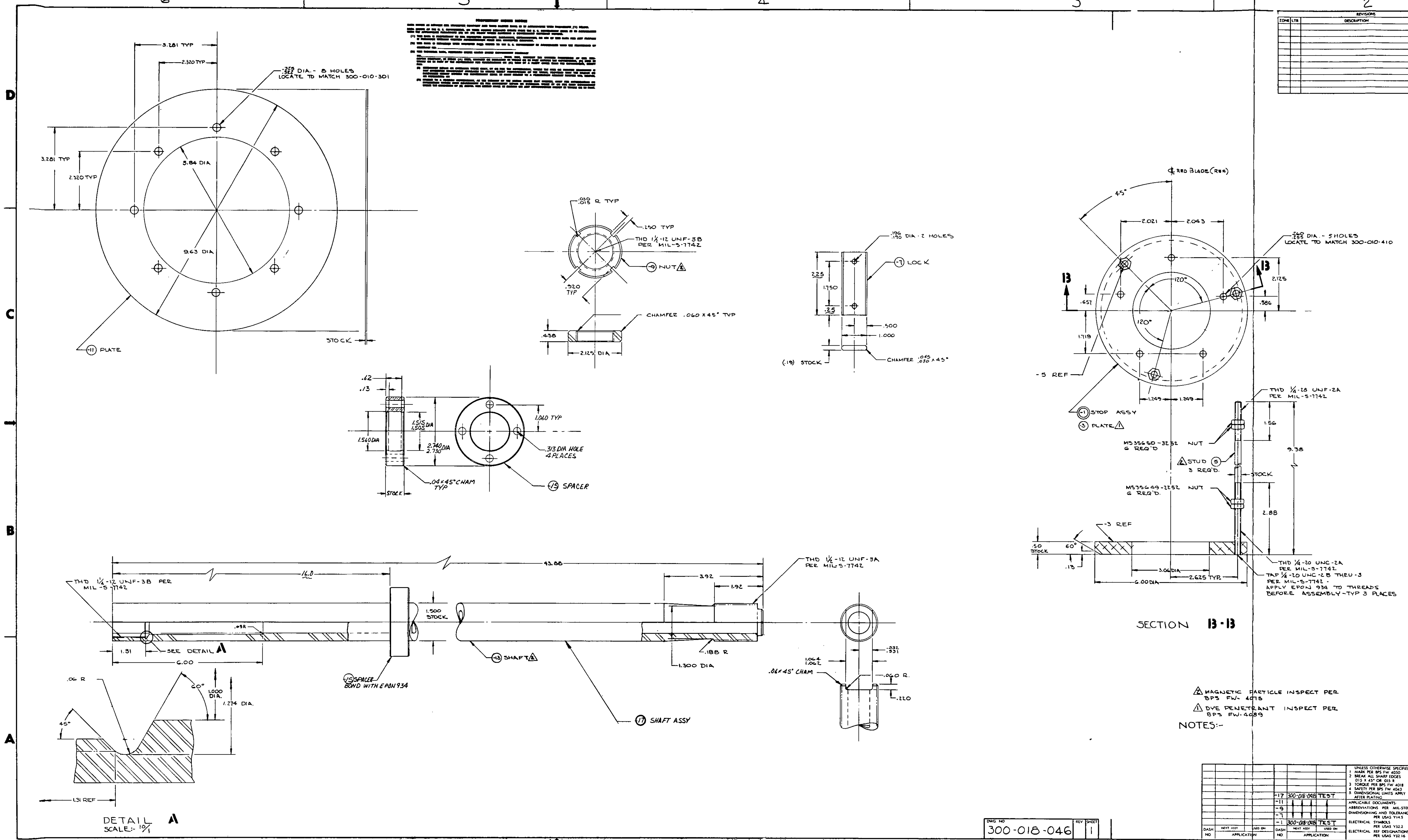
DWG NO 300-018-045 REV SHEET 1

FOLDOUT FRAME 1

FOLDOUT FRAME 2

FOLDOUT FRAME 3

[redacted]



⚠ MAGNETIC PARTICLE INSPECT PER BPS FW-4075

⚠ DYE PENETRANT INSPECT PER BPS FW-4089

NOTES:-

		A/R	EPON 934		ADHESIVE				
		6	MS35650-3252		NUT		STD		
		6	MS35649-2252		NUT		STD		
			300-018-046-17		SHAFT ASSY				
	1		300-018-046-15		SPACER	.75 × 3.0 × 3.0	PHENOLIC	MIL-P-15035FBM	

LAST SECTION LETTER USED B

300-018-046

	QTY REQD	PART OR IDENTIFYING NO	CODE IDENT NO.	NOMENCLATURE OR DESCRIPTION	STOCK SIZE	MATERIAL	MATERIAL SPEC	TENSILE 1000 PSI OR COND	FINISH CODE 299-099-031	ZONE
1		300-018-046-13		SHAFT	1.5 DIA X .313W X 48.0	4130 STL	MIL-T-6736	125/180	CB-2	—
		-11		PLATE	.063 X 10.0 X 10.0	2024 AL ALY	QQ-A-250/5 COND -T3	-T3	K	PEG-1
		-9		NUT	.44 X 2.25 X 2.25	4340 STL	MIL-S-5000 COND C4	125/145	CB-2	—
		-7		LOCK	.19 X 1.0 X 2.75	4340 STL	MIL-S-5000 COND C4	125/145	CB2	—
	3	-5		STUD	.75 DIA X 9.50	4340 STL	MIL-S-5000 COND C4	125/145	CB2	—
	1	-3		PLATE	.50 X 6.3 X 6.3	2024 AL ALY	QQ-A-250/5 COND T351	-T351	A	—
		300-018-046-1		STOP ASSY						
17	-1									

REF: E.O. 300 HES 123

PARTS LIST

DASH NO.	NEXT ASSY	USED ON
-17	300-018-048	TEST
-11		
-9		
-7		
-1	300-018-048	TEST

APPLICATION

UNLESS OTHERWISE SPECIFIED:
1. MARK PER BPS FW 4050
2. BREAK ALL SHARP EDGES .015 X 45° OR .015 R
3. TORQUE PER BPS FW 4018
4. SAFETY PER BPS FW 4043
5. DIMENSIONAL LIMITS APPLY AFTER PLATING

APPLICABLE DOCUMENTS:
ABBREVIATIONS PER MIL-STD-12
DIMENSIONING AND TOLERANCING PER USAS Y14.5
ELECTRICAL SYMBOLS PER USAS Y32.2
ELECTRICAL REF DESIGNATIONS PER USAS Y32.16

RIVET CODE PER NAS 523
BASIC CODE: 1 BJ MS20470AD; 2 BB MS20426AD
INSTALL PER (EXCEPT AS NOTED) BPS FW 4019, BPS FW 4034, BPS 4038
BASIC CODE; DASH NO FOR DIA; N - MFG HEAD NEAR SIDE; F - MFG HEAD FAR SIDE; DASH NO FOR LENGTH
1. ALL RIVETS EQUALLY SPACED BETWEEN END RIVETS UNLESS OTHERWISE SHOWN QUANTITY AS SHOWN OR NOTED
2. EDGE DISTANCE UNIVERSAL HEAD—2 TIMES SHANK DIA; COUNTERSUNK HEAD—2 1/2 TIMES SHANK DIA UNLESS OTHERWISE SHOWN

HEAT TREAT BPS FW 4140
FINISH SPEC
UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES
TOLERANCES ON DECIMALS .XXX ± .010, .XX ± .03, .X ± .1; ANGLES ± 1°
SURFACE ROUGHNESS PER USAS B46.1
125 MACHINED SURFACES EXCEPT AS NOTED

CONTRACT NUMBER
DRAWN D. MYERS 10/6/72
CHECKED
STRESS W. Bradshaw 10/10/72
WEIGHTS
GROUP ENGR P. Keefer 10-10-72
DER
MGT DESIGN M. A. Green 10/10/72
PROJECT U. E. Brown 10/10/72
CUSTOMER

BELL HELICOPTER COMPANY

TITLE MISCELLANEOUS DETAILS HOVER TEST MODEL 300

DWG SIZE J6 | CODE IDENT NO 97499 | DWG NO 300-018-046
SCALE 1/1 | SHEET 1 OF

DWG NO 300-018-046 | REV | SHEET 1

FOLDOUT FRAME 1

FOLDOUT FRAME 2

FOLDOUT FRAME 3 5-6

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