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Hover Performance of Isolated Proprotors and Propellers—Experimental Data

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December 2017

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HOVER PERFORMANCE OF ISOLATED PROPROTORS AND PROPELLERS—EXPERIMENTAL DATA

F. D. Harris[1]

Ames Research Center

SUMMARY

This report expands the experimental data base of both proprotors and propellers so that comparisons of tests and various theories can be made to several more configurations of these propulsive devices used by V/STOL aircraft.

With this background in mind, an effort has been made to report—in a concise manner—the hover performance of eight proprotors and eight propellers. The experimental hover performance data obtained with the several propeller/proprotor configurations and examined in this report are listed as follows:

1. XV-15 Metal Blade Proprotor, NASA OARF and WADC Tests (Mtip = 0.60–0.73).
2. XV-15 Advanced Technology Blade (ATB) Proprotor, NASA OARF Test (Mtip = 0.60–0.74).
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14. 5-Ft-Diameter Propeller, Canadair Ltd. 1968-1E14, Canadair Ltd. Test (Mtip = 0.40–0.74).
15. 5-Ft-Diameter Propeller, Canadair Ltd. 240-3C14, Canadair Ltd. Test (Mtip = 0.40–0.74).
16. 5-Ft-Diameter Propeller, Canadair Ltd. 240-2C14, Canadair Ltd. Test (Mtip = 0.40–0.74).

Sixteen appendices in this report provide tabulated experimental data, blade geometry, and several performance graphs for each of the above configurations. This should make comparisons between test and theory somewhat easier. Summary background about each of these 16 propulsive devices is also provided. *Note that rotor nomenclature and English units have been used throughout this report*.

The following discussion includes:

a. an overall comparison of the first five proprotor configurations listed above,

b. the influence of blade number at equal solidity using configurations 6 and 7,

c. the influence of blade twist holding all other blade geometry constant using configurations 8, 9, and 10,

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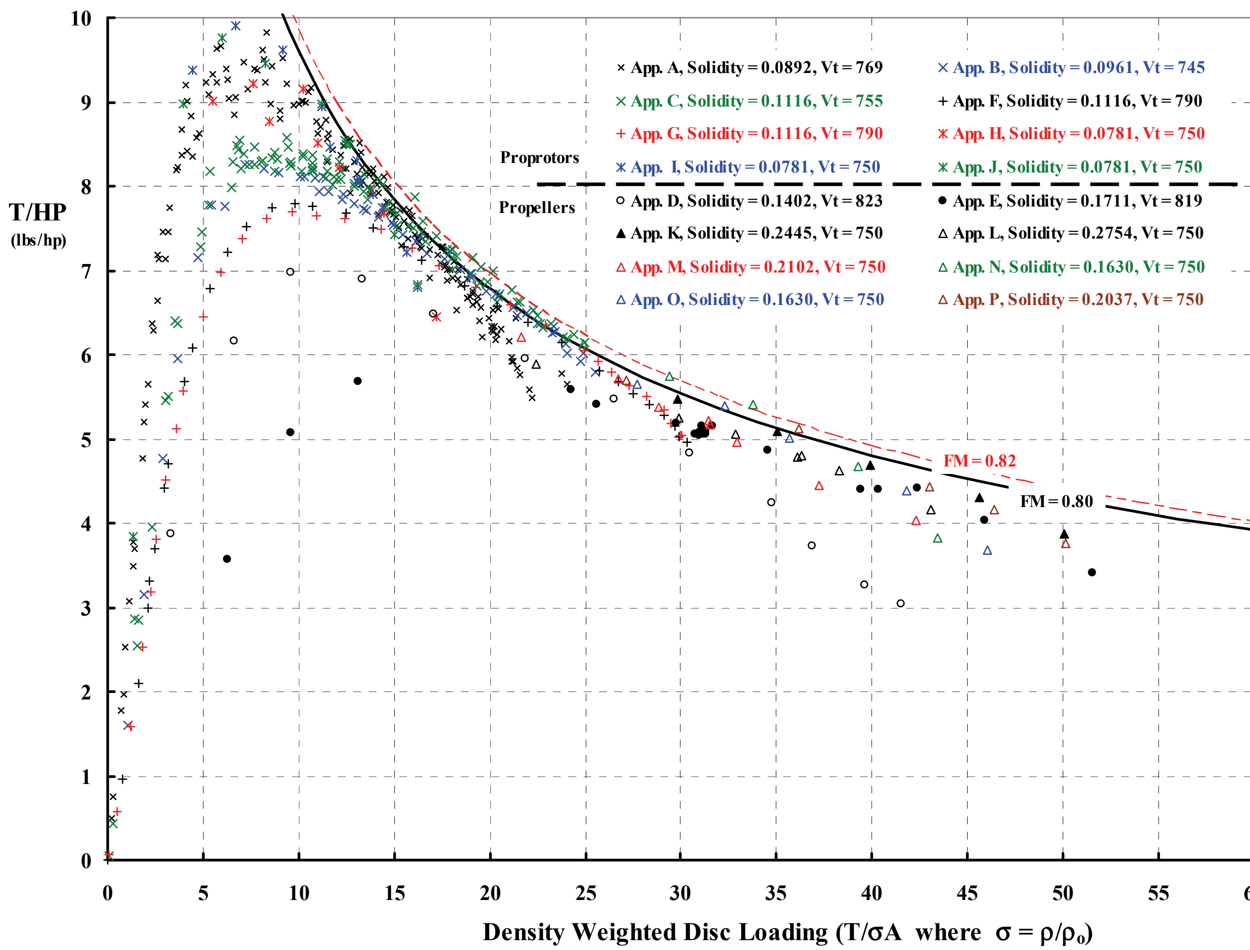
d. the influence of scaling the proprotor using configurations 3 and 6, and

e. the influence of blade geometry, solidity, and airfoil camber using configurations 11 through 16.

The experimental static performance data gathered in this report and summarized in figure 1 below strongly suggests that conceptual design of proprotors and propellers for V/STOL aircraft should be expected to achieve an isolated hover Figure of Merit of 0.80 for any density weighted disc loading between 10 and 35, provided the tip Mach number is above 0.40 and less than 0.775. The key design variables are tip speed, power weighted solidity, and blade airfoil camber. The secondary variables are the radial distributions of blade airfoil thickness ratio, chord, and twist. Experimental data for two equal solidity proprotors (three wide chord and four narrow chord blades but otherwise equal blade geometry of taper ratio, twist, and airfoil radial distributions), suggests that blade number by itself is not a driving factor in achieving a hover performance Figure of Merit of 0.80.



Note: Power weighted solidity = $\dfrac{\text{Blade No.}}{\pi\,\text{Radius}}\left[4\int_{\text{root}}^{\text{Tip}} x^3 c_x\,dx\right]$ where $x = r/R$ and c_x = chord distribution.

Figure 1. Measured hover performance of eight proprotors and eight propellers shows that a Figure of Merit of 0.80 can be achieved over a wide range in density weighted disc loading providing the tip Mach number is less than 0.775.

INTRODUCTION

The use of Computational Fluid Dynamics (CFD) is gaining momentum within the aeronautical community. A relatively small segment of this community is applying CFD technology to the prediction of V/STOL aircraft performance. An even smaller group of engineers are refining and applying fluid dynamics solvers to the problem of predicting the hover performance of helicopter rotors and proprotors designed by rotorcraft advocates. This small group of CFD engineers who are attacking the hover performance problem have, today, been using a quite limited experimental data base upon which to demonstrate their progress. This is because their concentration has been on only two successful tiltrotors flying; namely the XV-15 (fig. 2) and the MV-22B (fig. 3). No attention appears (as yet) to be directed at the CL-84 (fig. 4) or the XC-142A (fig. 5), which use propellers.

The purpose of this report is to expand the experimental data base of both proprotors and propellers so that comparisons of tests and various theories can be made to several more configurations of these propulsive devices used by V/STOL aircraft.

Figure 2. Bell/NASA/Army XV-15.

Figure 3. Bell-Boeing/Marine MV-22B.

Figure 4. Canadair CL-84.

Figure 5. LTV/Air Force XC-142A.

DISCUSSION

By way of background, static performance of propellers has received little attention by fixed wing advocates over the many decades since the Wright Brothers' first successful flights in December of 1903 (refs. 1, 2). However, a major step was to give propellers variable pitch so that cruise performance could be optimized without undo penalty to takeoff and climb performance. More precisely, the propeller's blade geometry was optimized for cruise speed at altitude. Any takeoff distance shortcomings were solved by building longer runways. Propeller design technology remained rather static until the need for a propeller-driven STOL, and even a VTOL aircraft, became apparent in the early 1950s on up to the mid-1970s.

While fixed wing aerodynamicists searched for some sort of powered-lift aircraft, rotorcraft advocates began to extrapolate their helicopter rotor expertise to what they called a proprotor. The distinction between a propeller and a proprotor is rather difficult to summarize. Perhaps the best way is to note that successful propeller-driven aircraft appear to be constrained by the clearance between the propeller's tip and the ground and/or the aircraft's fuselage. This fact of life has kept propeller diameters considerably below 20 feet. In contrast, proprotor-driven VTOLs—either as compound helicopters, tiltrotors, or tiltwings—appear to have no physical limit to diameter. Of course, there are many detailed structural differences between a propeller and a proprotor, but the blade geometry technology is quite similar. For instance, blade radial distributions of chord, airfoil selection, and twist are paramount in the early design process for both propulsive devices. There is, however, one significant difference between propeller and rotorcraft designers. This difference is their nomenclature for performance and blade geometry parameters. For example, a blade's pitch angle at the 3/4 radius station is denoted as Beta ($\beta_{0.75R}$) by propeller advocates while proprotor advocates call it collective pitch and use ($\theta_{0.75R}$) as their symbol. More importantly, the thrust and power coefficients are presented in quite different nondimensional forms. That is,

$$\text{Prop } C_T = \frac{T}{\rho n^2 D^4} = \frac{\pi^3}{4}\left(\text{Rotor } C_T = \frac{T}{\rho A V_t^2}\right) \qquad \text{Prop } C_P = \frac{P}{\rho n^3 D^5} = \frac{\pi^4}{4}\left(\text{Rotor } C_P = \frac{P}{\rho A V_t^3}\right)$$

$$FM = \sqrt{\frac{2}{\pi}}\frac{\left(\text{Prop } C_T\right)^{3/2}}{\text{Prop } C_P} = \frac{1}{\sqrt{2}}\frac{\left(\text{Rotor } C_T\right)^{3/2}}{\text{Rotor } C_P}$$

Other notations that differ between propeller and proprotor designers are:

Parameter	Proprotor	Propeller
Diameter	D	D
Radius	R	R
Blade chord	c	b
Blade number	b	N or B
Airfoil thickness	t	h
Blade width ratio	Rarely used	b/D
Airfoil thickness ratio	t/c	h/b
Blade pitch angle	θ	β_0
Blade radial station	r or x = r/R	r or x = r/R
Shaft rotational speed	Ω in rad/sec	ω in rad/sec or n in rev/sec
Tip speed	$V_t = \Omega R$	$V_t = \omega R = nD/4\pi$

Note that rotor nomenclature for both proprotors and propellers has been used throughout this report.

With this background in mind, an effort has been made to report—in a concise manner—the hover performance of eight proprotors and two propellers. The experimental hover performance data obtained with the several propeller/proprotor configurations and examined in this report are listed as follows:

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d. the influence of scaling the proprotor using configurations 3 and 6, and
e. the influence of blade geometry, solidity, and airfoil camber using configurations 11 through 16.

Primary Configurations Overview

The first three proprotors and the following two propellers (1 through 5 in the list above) are configuration designs for VTOLs that reached flight testing. To begin with, the full-scale, 25-foot, three-metal-bladed proprotor was designed for the XV-15 and was first tested in the NASA Ames 40- by 80-foot wind tunnel in forward flight during July of 1970. Then in November 1970, hover testing (fig. 6) was conducted with results reported in reference 3. The objective of these tests was to confirm that the proprotor design would be flight worthy. The hover test results were, however, unsatisfactory because the wind tunnel test section contaminated the performance data with restricted flow to the rotor downwash.[2] This

[2] This interference effect was studied by Koning in some detail in 2016 with CFD as reported in reference 4.

unsatisfactory result led to testing of the XV-15 proprotor on the Rig #3 propeller test stand (fig. 7) located at the U.S.A.F. Wright Air Development Center (WADC) in Dayton, Ohio. This test was successfully conducted in March of 1973 with reasonable experimental hover performance results reported in reference 5. However, interference ground effects were suspected because of the work platform, and the safety enclosure introduced questions about the measured results. By 1979/1980, NASA Ames Research Center had its Outdoor Aerodynamic Research Facility (OARF) test stand fully operational, and in March 1984 the XV-15 proprotor was tested again (fig. 8). This last hover test provided experimental data (ref. 6) considered by many to be the “gold standard of hover performance data” for the isolated XV-15 metal-bladed proprotor (Appendix A).

A competitor to what arrived as the very successful Bell XV-15 was the Boeing Vertol Model 222. Boeing Vertol lost this competition, but their Advanced Technology Blade (ATB) proprotor was deemed a candidate for testing on the XV-15 tiltrotor aircraft (ref. 7). The three-bladed ATB proprotor with a 25-foot diameter was tested at the OARF in July and August of 1984 (fig. 9), and the results were published in references 8 through 11.

Figure 6. XV-15 metal-bladed proprotor tested in hover in the NASA Ames 40- by 80-Foot Wind Tunnel.

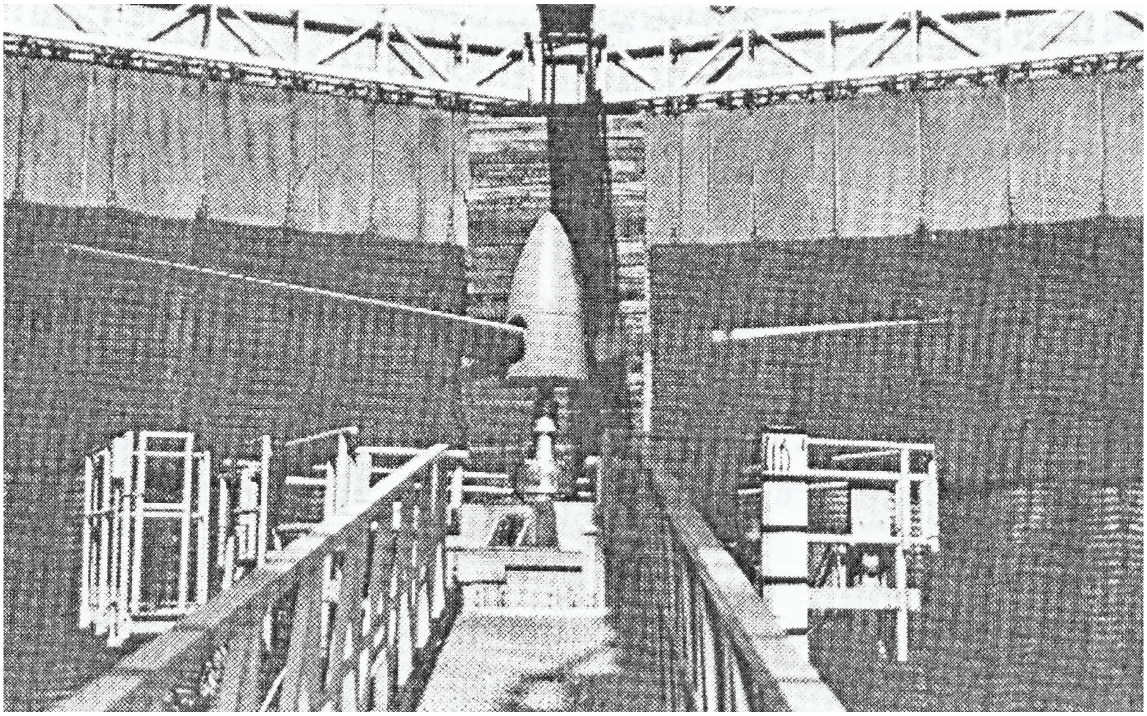

Figure 7. XV-15 metal-bladed proprotor tested in hover on WADC Rig #3.

Figure 8. XV-15 metal-bladed proprotor tested in hover at the NASA OARF.

Figure 9. ATB composite-bladed proprotor tested in hover at the NASA OARF.

Composite materials were used in the ATB blade design (fig. 10) as well as very nonlinear twist and chord radial distributions as shown in Appendix B. This proprotor had a thrust-weighted solidity of 0.1016 versus the XV-15 metal-bladed proprotor, which had a thrust-weighted solidity of 0.0892. The power-weighted solidities were 0.0891 and 0.0961, respectively. These solidities (σ_T and σ_P) are used by rotorcraft advocates who define them as:

$$\text{Thrust-Weighted Solidity} \equiv \sigma_T = \frac{b}{\pi R}\left[\frac{\int_{xc}^{1} c_x x^3 dx}{\int_{xc}^{1} x^3 dx}\right] \qquad \text{Power-Weighted Solidity} \equiv \sigma_P = \frac{b}{\pi R}\left[\frac{\int_{xc}^{1} c_x x^4 dx}{\int_{xc}^{1} x^4 dx}\right].$$

It is worth noting that propeller designers rarely use a thrust-weighted solidity, but they do use a form of power-weighted solidity, which they call blade Activity Factor (AF), that is calculated as

$$\text{AF per blade} = \frac{100,000}{16}\int_{root}^{tip} (b/D)(r/R)^3\, d(r/R).$$

Thus, a proprotor power-weighted solidity is calculated from a propeller Activity Factor with the correspondence being

$$\sigma_P = \frac{128}{100,000\pi}(\text{Number of Blades})(\text{AF per blade}).$$

When the Bell–Boeing team embarked on what was to become the U.S. Marines MV-22B, they began with a tiltrotor aircraft designated as the Joint Vertical Experimental (JVX), which was later designated by the U.S. Navy as the V-22. When development was completed, this third-generation tiltrotor became the MV-22B (ref. 2). Because the NASA OARF test stand was primarily built with power for testing rotors, proprotors, and propellers up to about 25 feet in diameter, the 38-foot-diameter full-scale JVX proprotor was tested at 0.6579 scale. The "model" JVX was tested at the OARF (fig. 11) in June of 1984, and experimental hover performance was reported in reference 12 and included in this report in Appendix C. More recent attention was paid to this experimental data by Acree (refs. 13, 14). The hover performance of these first three proprotors, along with blade geometry, was reported to the rotorcraft industry in May 1985 by Fort Felker, Marty Maisel, and Mark Betzina with reference 11.

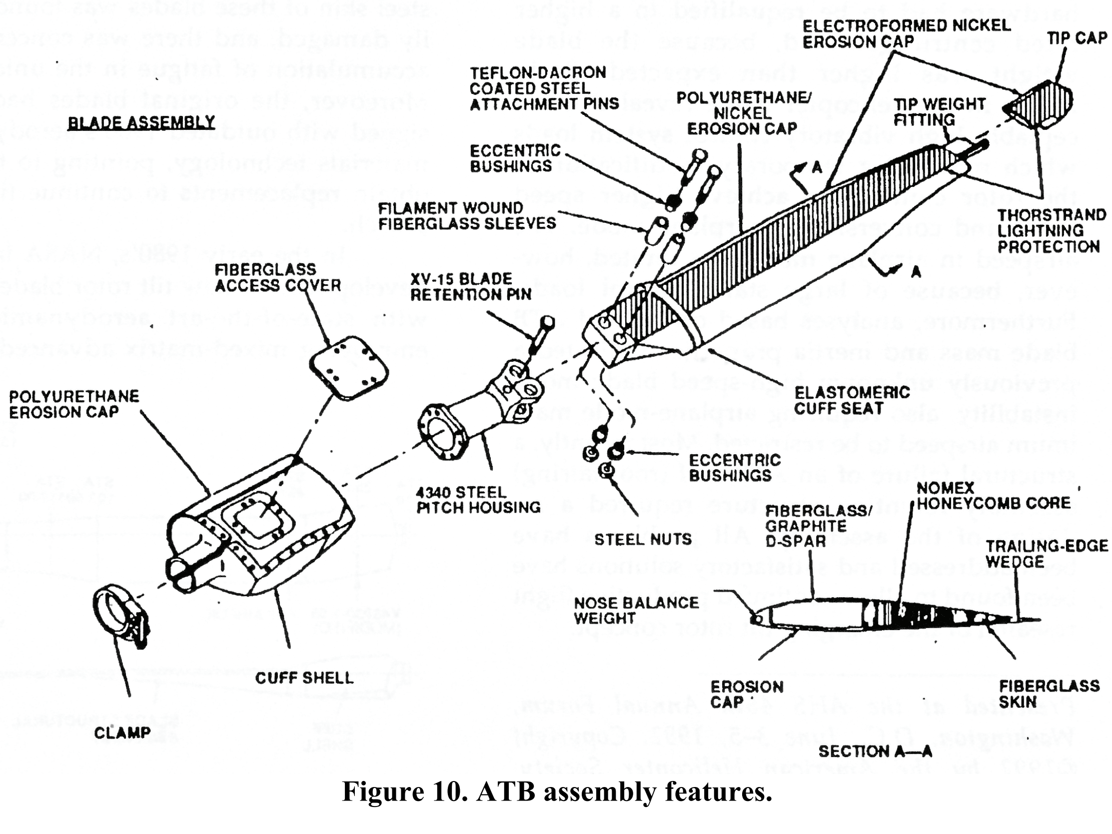

Figure 10. ATB assembly features.

Figure 11. The 0.658-scale JVX composite-bladed proprotor tested in hover at the NASA OARF.

Development of propellers for the U.S. Air Force XC-142A, a tiltwing, occurred in two stages because the *initial* Hamilton Standard propeller (configuration 4 on the preceding list and Appendix D) was found in flight testing to be inadequate. Hamilton Standard's redesign and the *final* configuration (configuration 5 on the preceding list and Appendix E) proved satisfactory after flight testing in hover (refs. 15–19). Both the initial and the final propellers were 15.625 feet in diameter and both were four-bladed. Both propellers were tested on the WADC test stand. It should be noted in passing that Hamilton Standard's VTOL propeller designs (fig. 12) were quite different from rotorcraft proprotor designs (fig. 10) The thrust- and power-weighted solidities of the final design were much greater than for the initial design as table 1 shows.

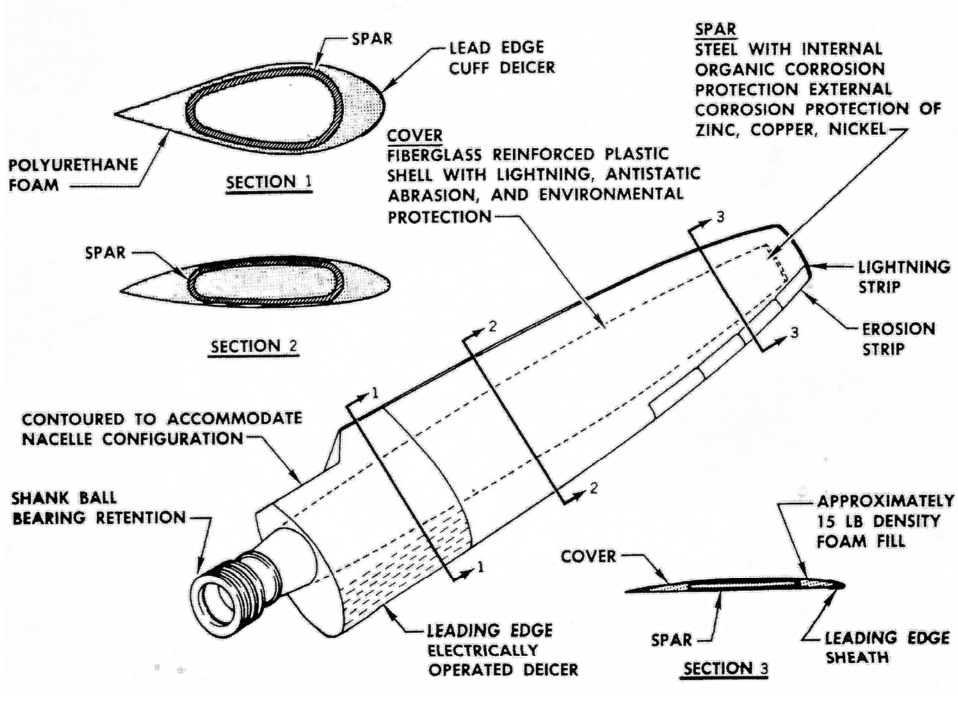

Figure 12. XC-142A blade assembly features.

Table 1. Summary of Design Parameters for Primary Configurations Studied

Parameter	XV-15	ATB	0.658-Scale JVX	Initial XC-142A	Final XC-142A
Prop/proprotor designations	n/a	n/a	n/a	2FE	2FF
Number of propellers	2	2	2	4	4
Number of engines	2	2	2	4	4
Gross weight full-scale (lb)	13,000	13,000	52,600	41,500	41,500
Installed engine	LTC1K-41K	LTC1K-41K	LTC1K-41K	T64-GE-1	T64-GE-1
T.O. power per engine (shp)	1,550	1,550	1,550	3,080	3,080
Diameter full-scale (ft)	25.0	25.0	38.0	15.625	15.625
Diameter test (ft)	25.0	25.0	25.0	15.625	15.625
Blades	3	3	3	4	4
Blade material	Metal	Composite	Composite	Composite	Composite
Thrust weighted solidity, σ_T	0.0892	0.1016	0.1142	0.1522	0.1790
Power weighted solidity, σ_P	0.0891	0.0961	0.1116	0.1420	0.1712
Nominal design, V_t (fps)	771	771	821	1,008	1,008

Note: Key data is for just one proprotor/propeller.

Performance Comparisons of Primary Configurations

There are several graphical coordinate forms on which hovering performance can be examined. Therefore, rather than choose just one form, this examination of hovering performance of the five primary configurations makes the comparison with graphs of:

1. C_P vs. C_T
2. C_P vs. Ideal C_P
3. C_P/σ_P vs. C_T/σ_T
4. C_T/C_P vs. C_T
5. FM vs. C_T
6. FM vs. C_T/σ_T
7. C_T vs. $\theta_{0.75R}$
8. C_T/σ_T vs. $\theta_{0.75R}$

Note that $\text{Ideal } C_P = C_T^{3/2} / \sqrt{2}$.

Of course, each graphical form has its place when making a configuration choice. But, from a practical engineering point of view, the fundamental form is power coefficient (C_P) plotted versus thrust coefficient (C_T) for any given propeller or proprotor configuration and tip Mach number. In this form, and given the design tip speed, shaft horsepower versus thrust can be immediately obtained at any given density altitude and temperature. Therefore, the first comparison of C_P versus C_T is shown on figure 13. This graph shows that an envelope to the *proprotors* appears to be a Figure of Merit (FM) of 0.80 while that for the two XC-142A *propellers* is somewhat lower, say closer to a Figure of Merit of 0.75. The hover performance data for the five configurations appears (with such a small-sized graph) to not be a decision making chart. What helps, of course, is to enlarge the graph and add a mathematically faired curve through each configuration's data. This enlarged C_P vs. C_T graph with one data set curve fitted using Microsoft Excel's Trendline tool is shown on figure 14.

The other presentation forms are provided in figures 15 through 21 without discussion.

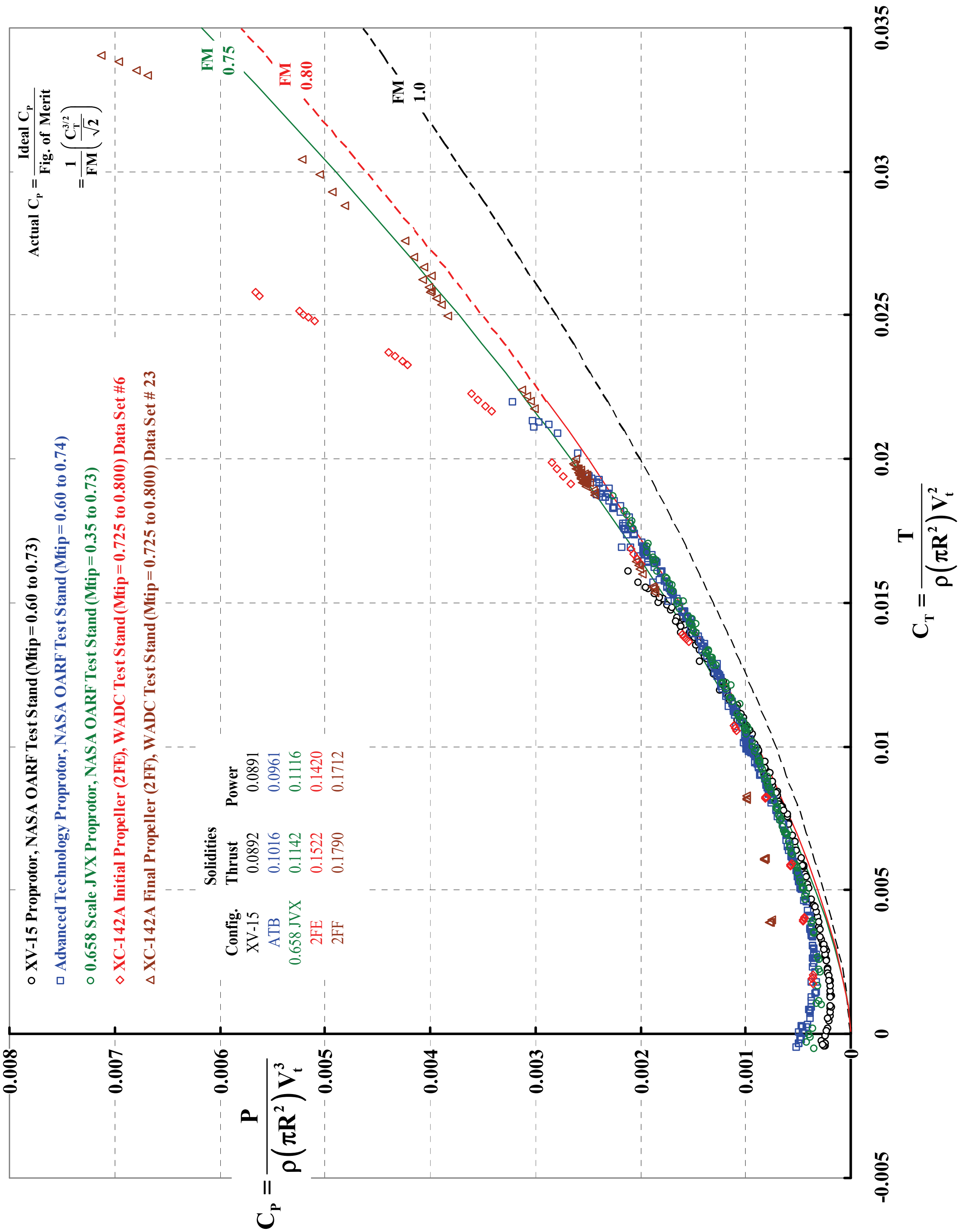

Figure 13. At small-graph scale, the performance of these three proprotors and two propellers appears, for practical purposes, to be virtually the same over a wide range of thrust coefficients.

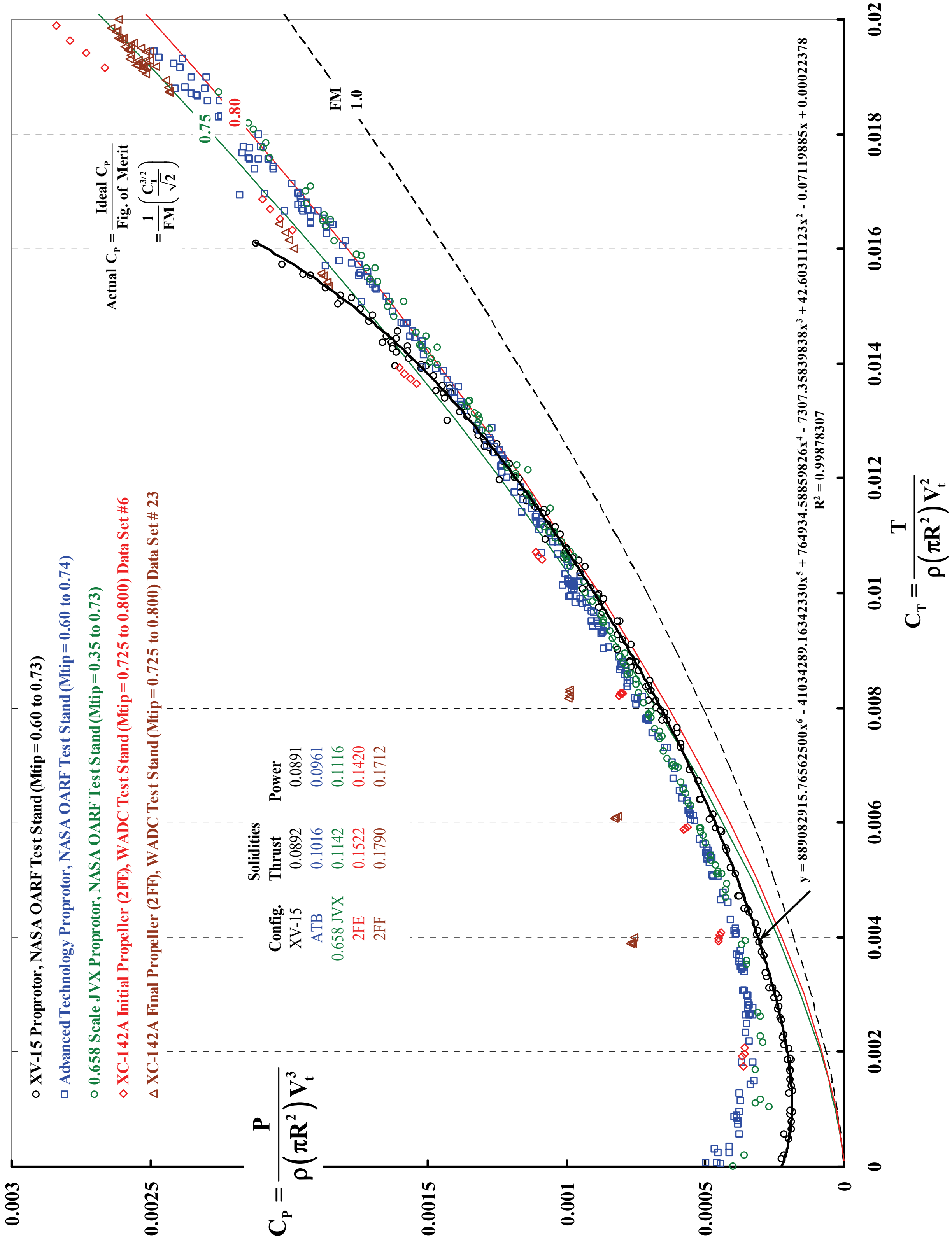

Figure 14. At enlarged graphical scale, the thrust coefficient required to obtain optimum performance increases as solidity increases. It appears that an envelope of the optimums could be drawn.

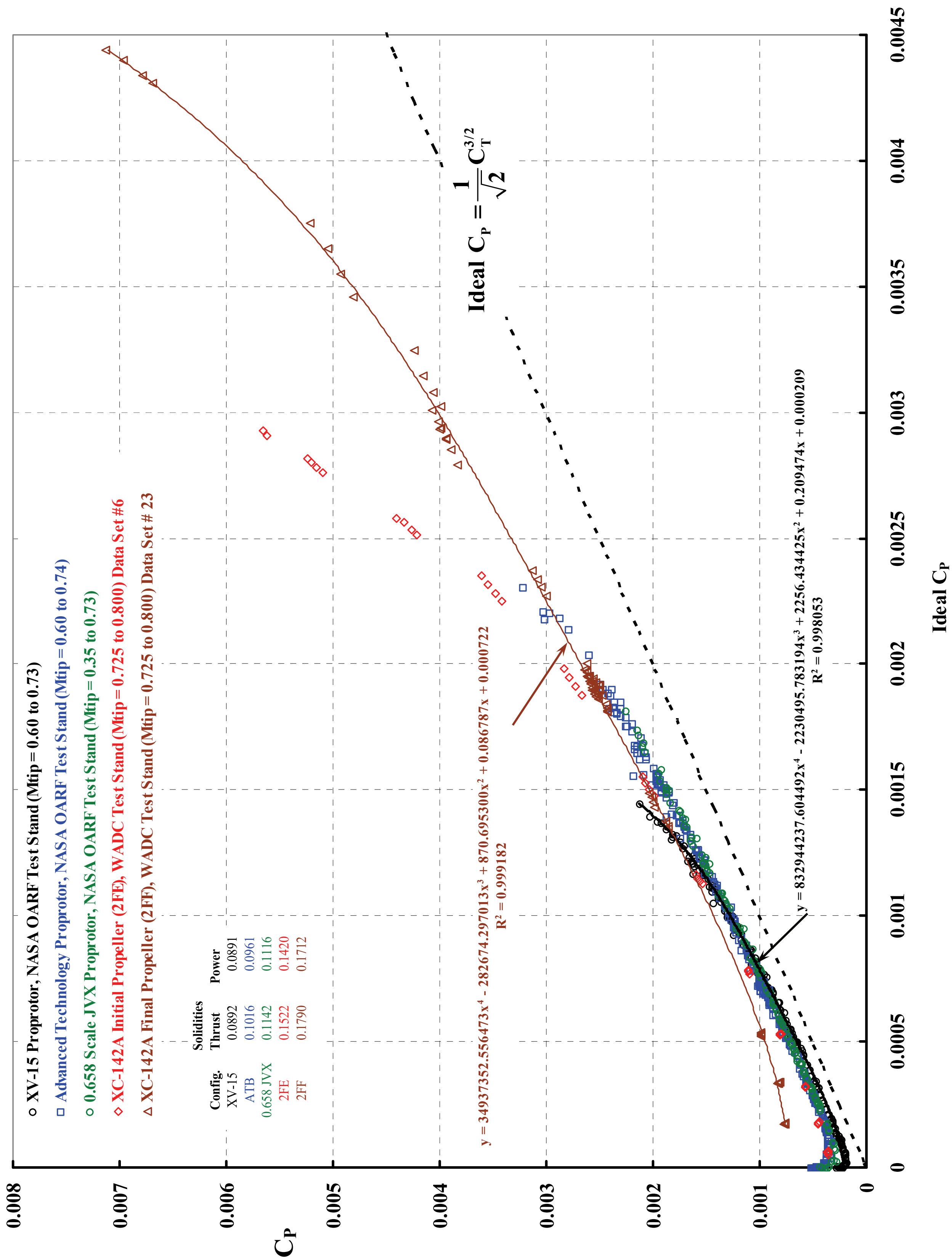

Figure 15. Actual power coefficient varies nearly linearly with the ideal power coefficient.

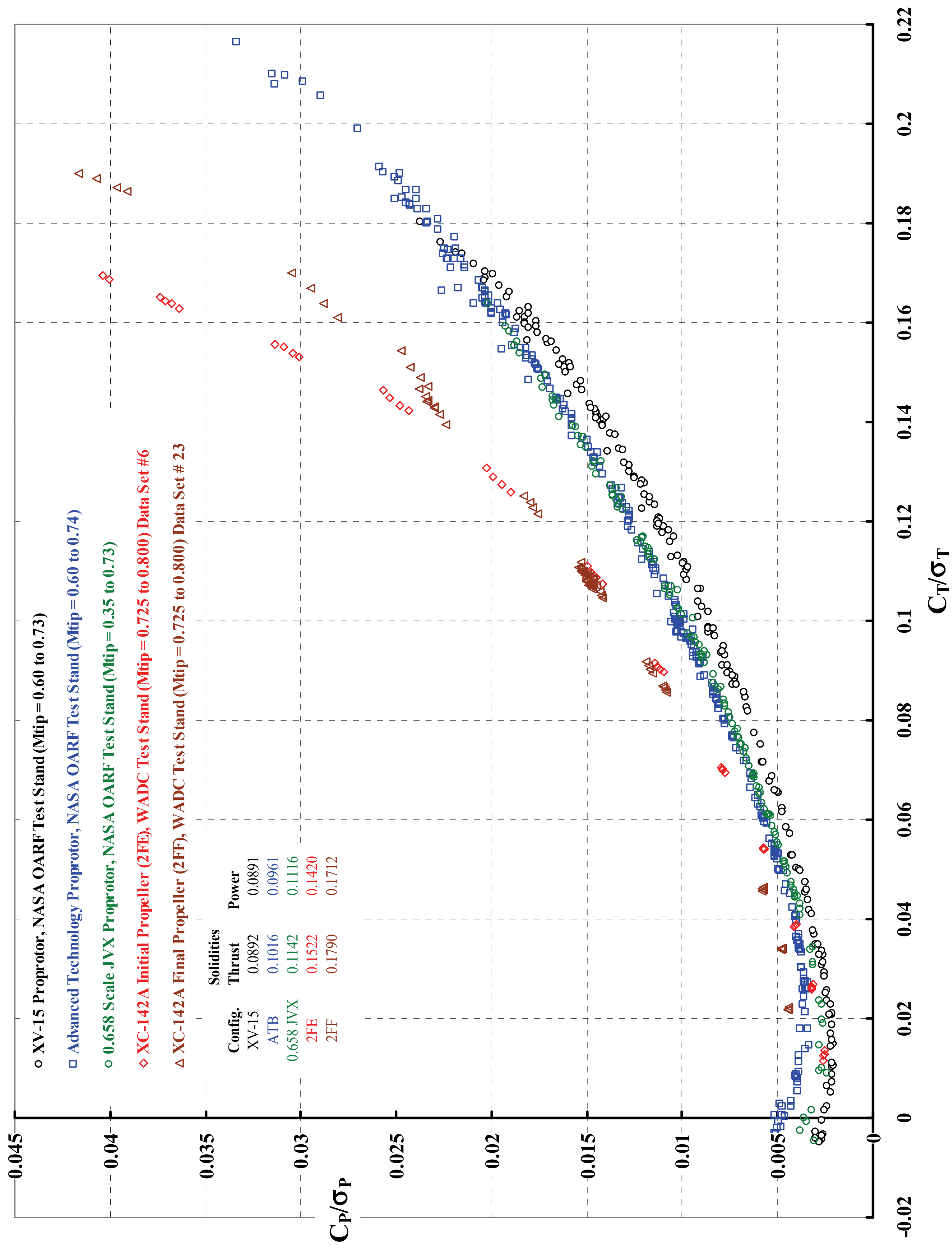

Figure 16. Including solidity does not collapse performance curves to a single universal curve.

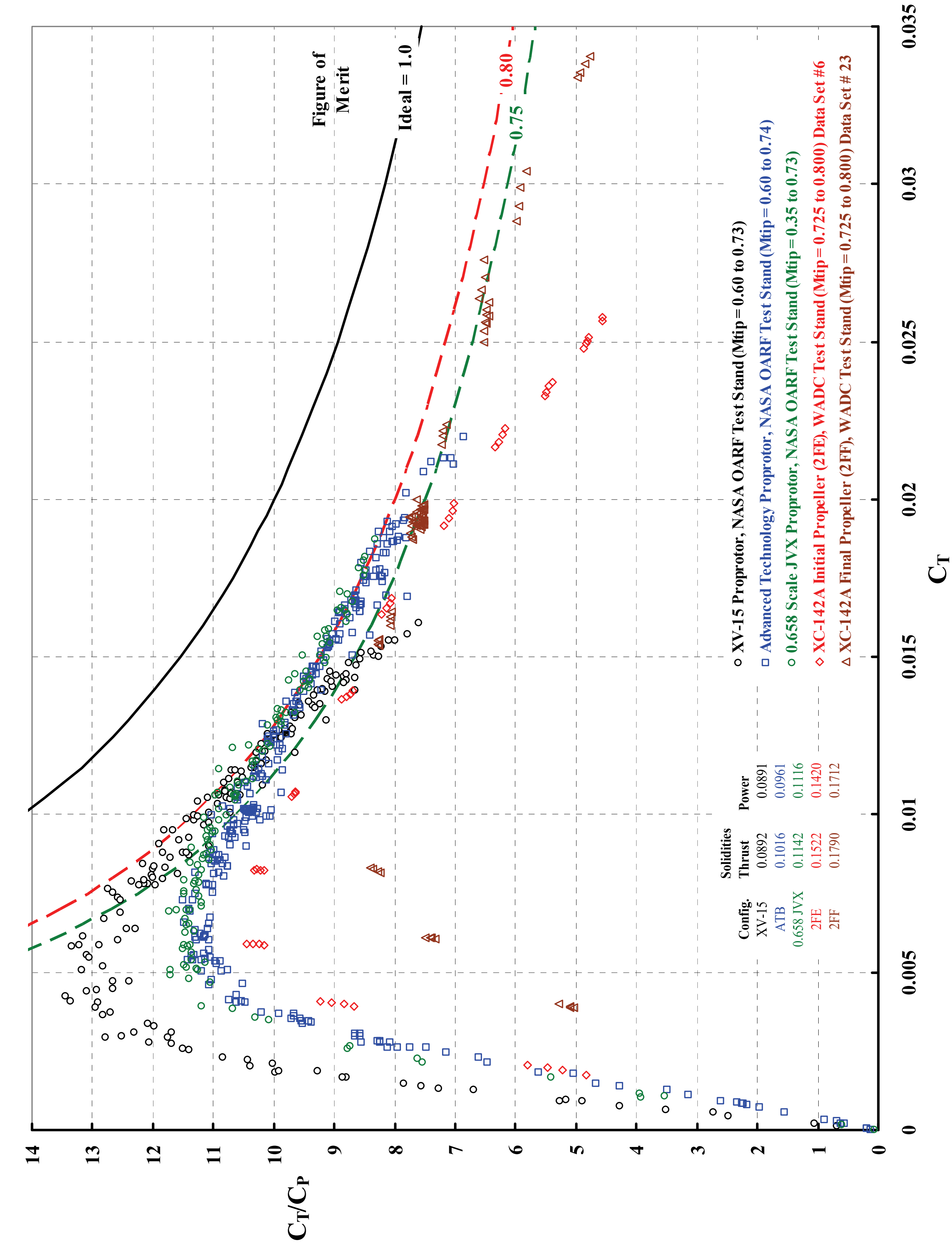

Figure 17. Up to a point, lowering thrust coefficient improves the thrust-to-power-coefficient ratio.

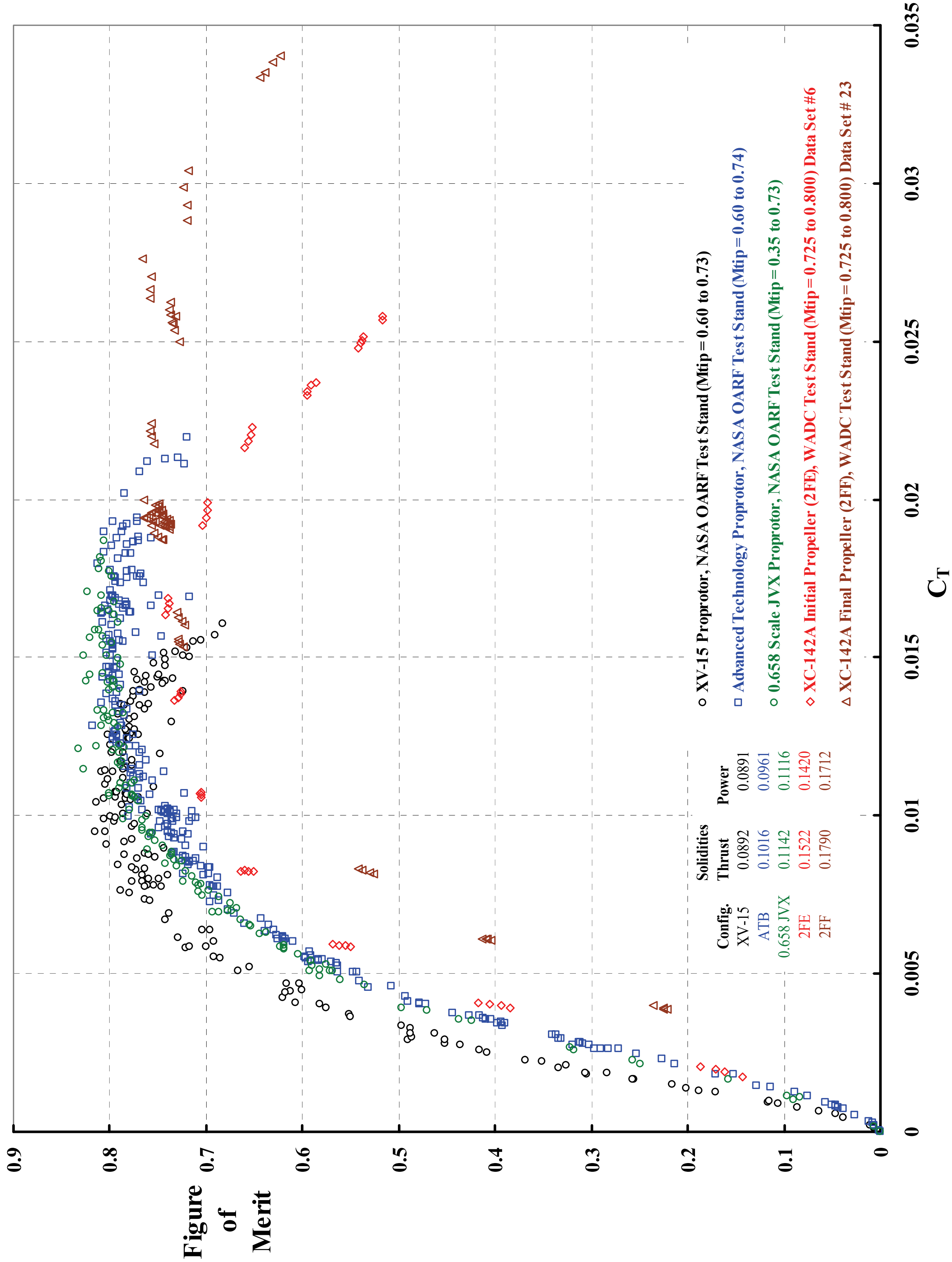

Figure 18. The “optimum” Figure of Merit occurs over a fairly wide range of thrust coefficients.

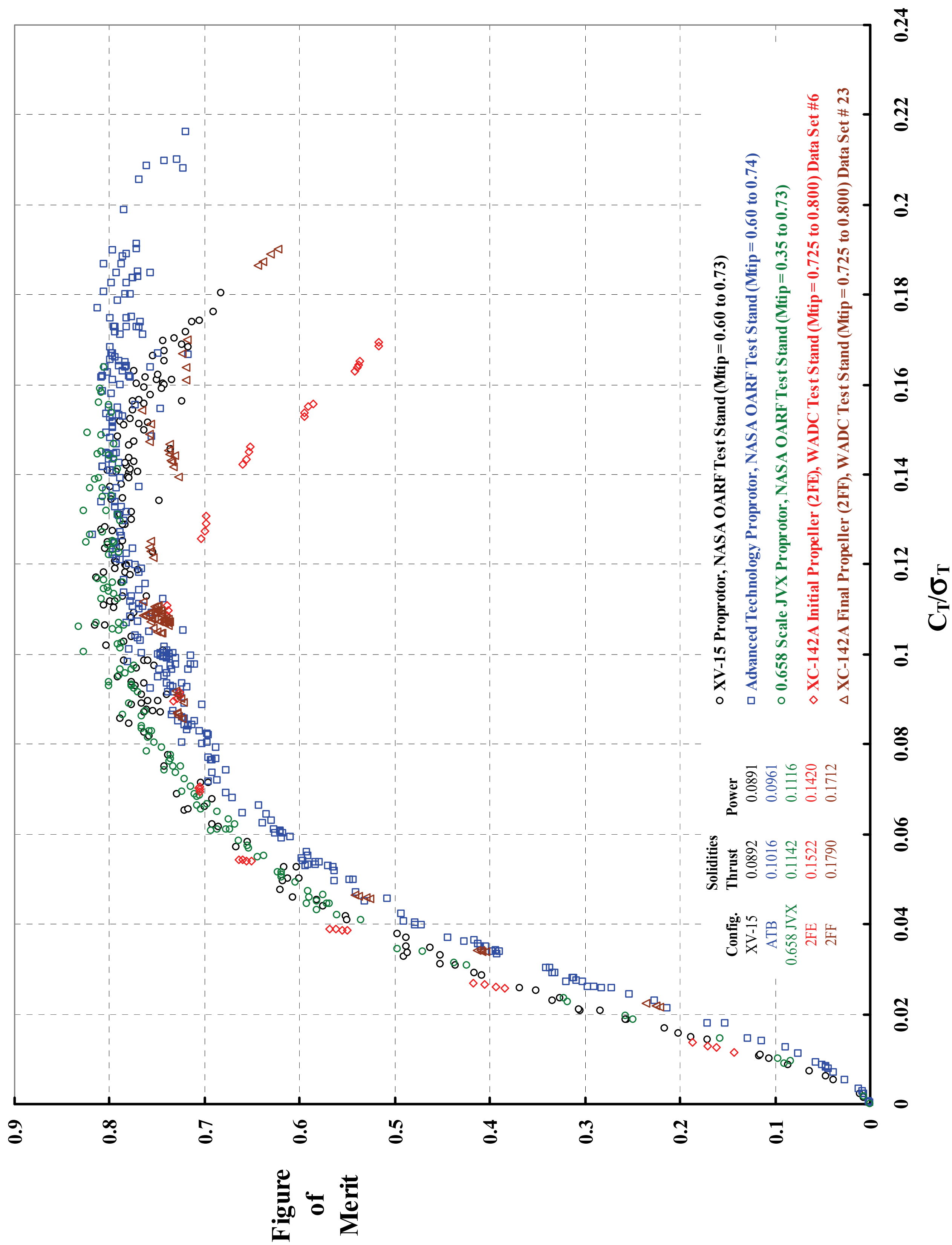

Figure 19. The blade loading coefficient at which blade stall begins is not well defined.

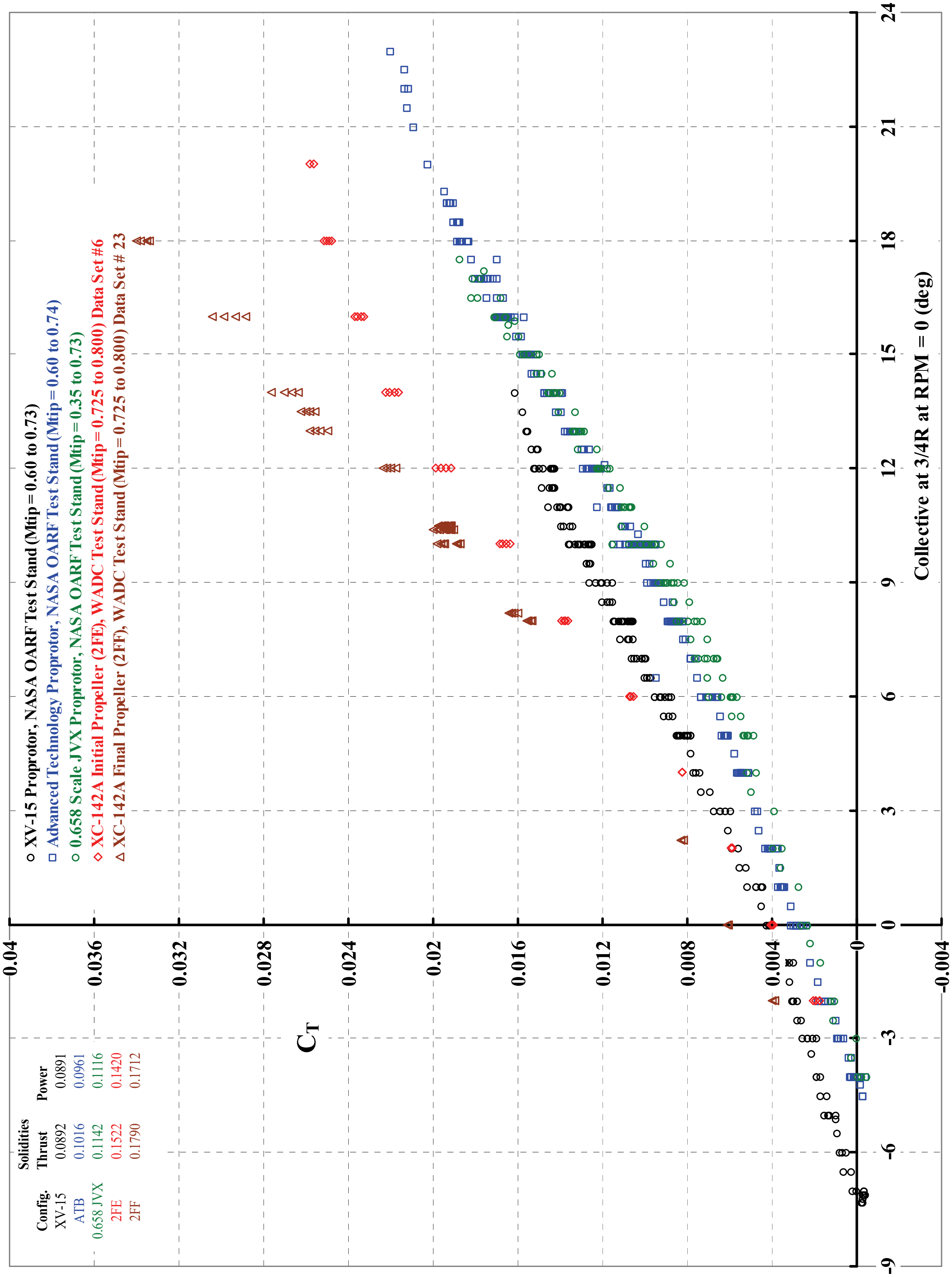

Figure 20. The slope of thrust coefficient with collective pitch is not independent of solidity.

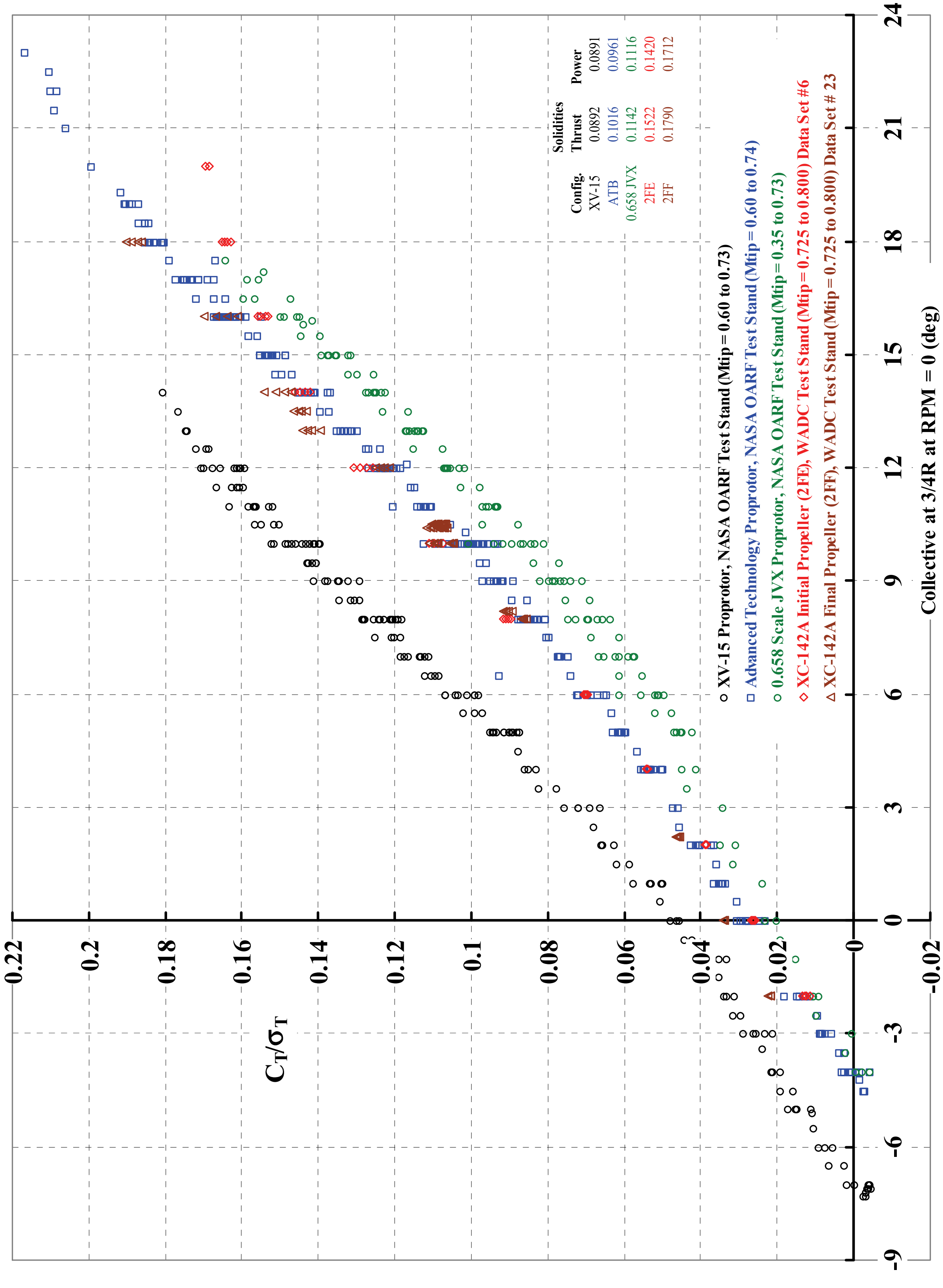

Figure 21. The slope of the blade loading coefficient with collective pitch does appear to remove the effect of solidity—at least to the first order.

Blade Number at Equal Solidity

During May of 1994, Bell Helicopter Textron Inc. (BHTI) conducted checkout of two 0.15-Mach-scaled JVX model proprotors. This initiated subsequent testing in the NASA Langley Research Center 14- by 22-Foot Subsonic Wind Tunnel from June 13 to July 29, 1994. The purpose of the wind tunnel test was to quantify and compare acoustic, aerodynamics, and Blade Vortex Interaction (BVI) characteristics of two similar tiltrotor rotor systems with different numbers of blades but of equal solidity.

The debugging and checkout of BHTI's Power Force Model was conducted at Bell's facility. This provided hover performance data for both the three- and the four-bladed configurations (fig. 22 and table 2), which was included in the complete data report (ref. 20). The performance data is provided in Appendices F and G and shown in figures 23 to 25 herein.

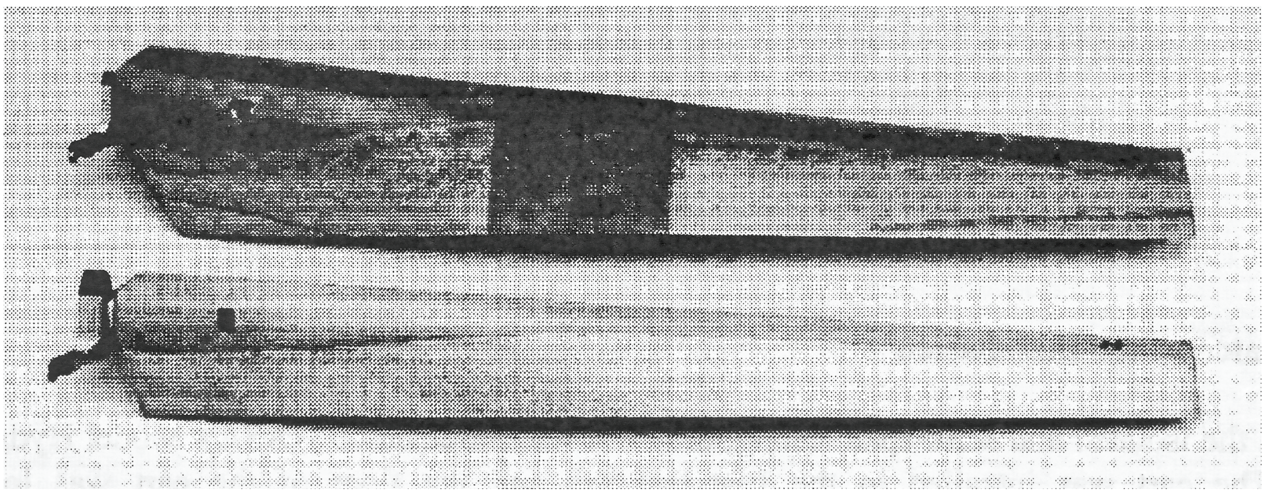

Figure 22. Three wide-chord blades versus four narrow-chord blades were tested at small scale (5.7 feet diameter).

Table 2. Blade Properties of the Three- Versus Four-Blade Experiment

Parameter	Value
Rotor Diameter	68.4 inch
Blade Twist	-47.5 degrees
Blade Airfoils	0.15 Scaled JVX
Thrust Weighted Solidity	0.114 (JVX)
Blade Planform	Linear Tapered Swept
Blade Chord at tip:	
3-Bladed Rotor	3.60 inch
4-Bladed Rotor	2.70 inch
Aerodynamic Reference Blade Chord:	
3-Bladed Rotor	4.09 inch
4-Bladed Rotor	3.07 inch
Hub Precone	2 degrees
Blade Pitch Flap Coupling	45 degrees
Maximum Control System Travels	+15 to -5 deg F/A Cyclic
(3/4 radius)	-9 to +10 deg Lateral Cyclic
	-5 to +24 deg Collective
Maximum Rotor Flapping Angle	12 degrees
Operating Rotor Speed	2647 RPM
Operating Tip Speed	790 ft/sec
Maximum (110%) Rotor Speed	2911 RPM
Maximum Power (at 2650 RPM)	150 HP
Maximum Design Thrust (Ct = 0.023)	1053 lb

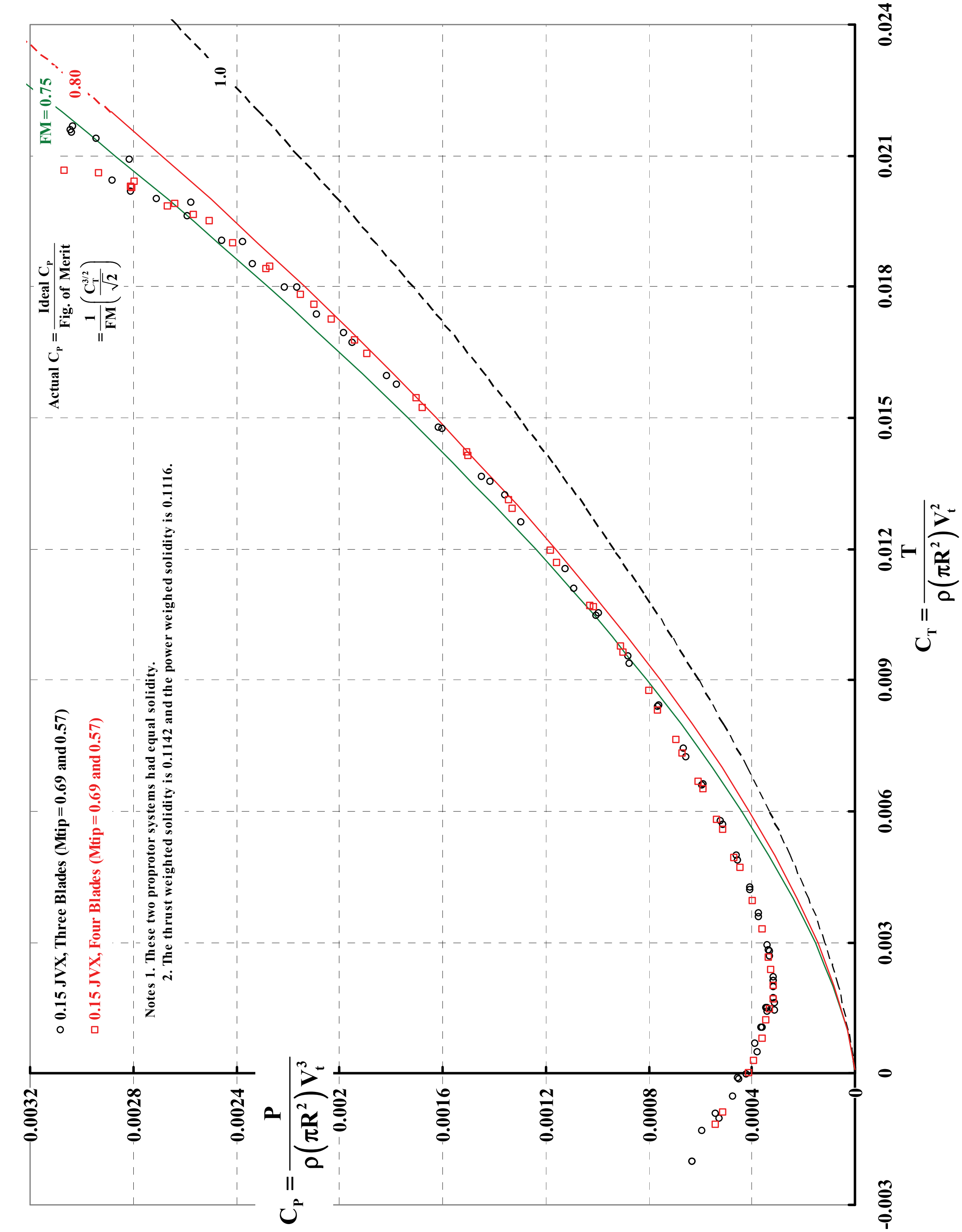

Figure 23. The influence of blade number at equal solidity appears to be relegated to the region of blade stall.

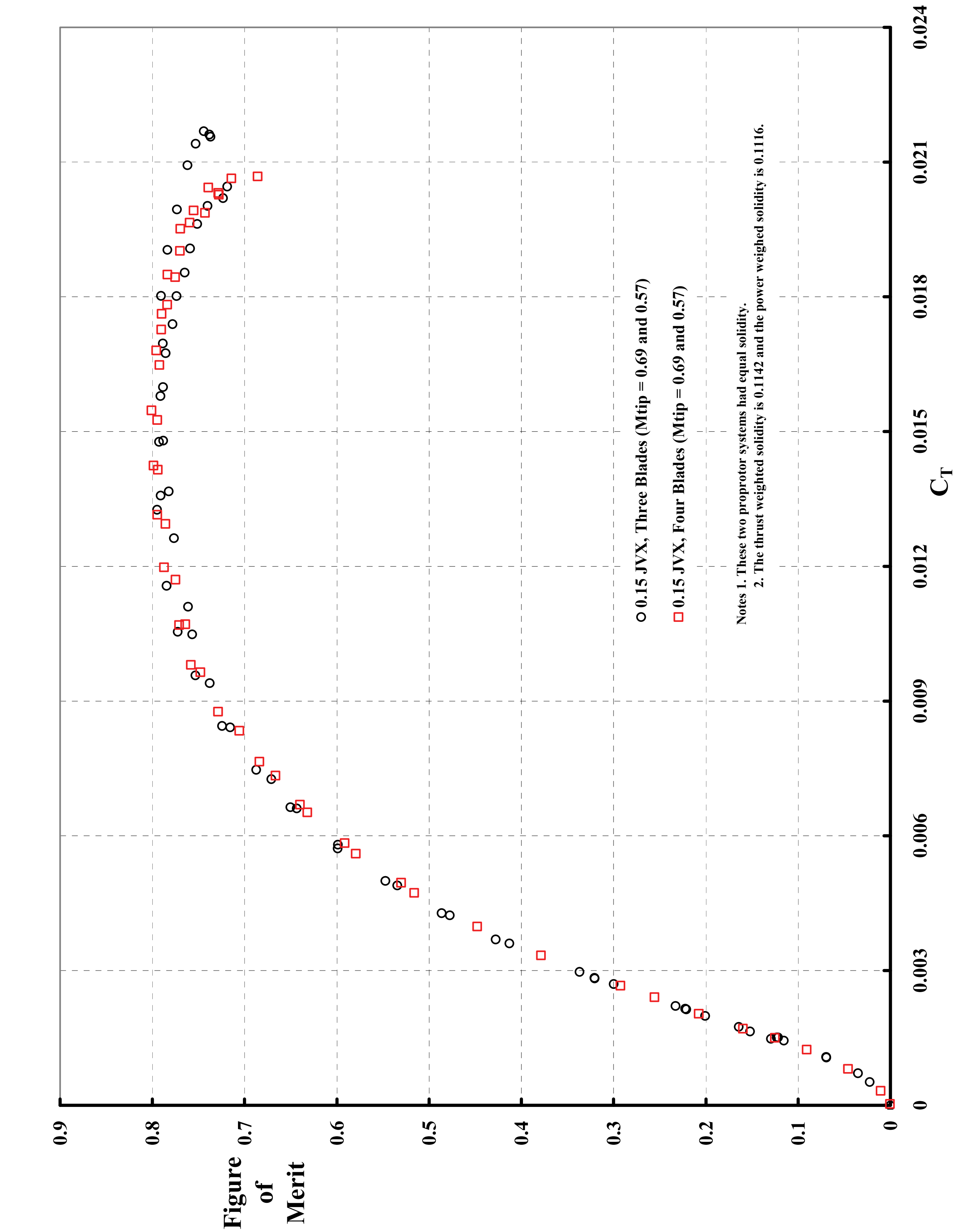

Figure 24. Both Mach number and Reynolds number appear to influence performance in the blade stall region.

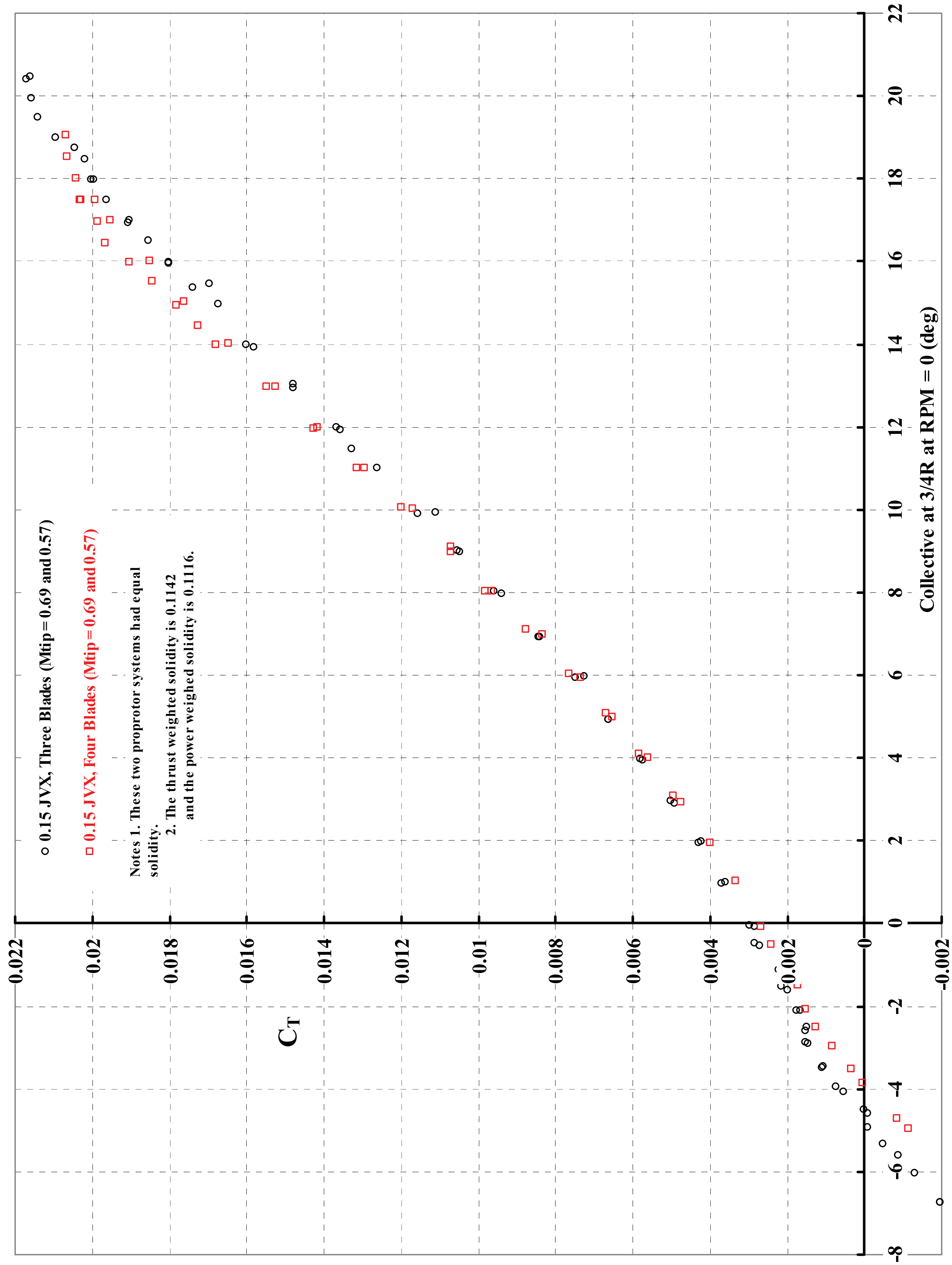

Figure 25. Aerodynamic loads and resulting structural deformations influence blade twisting.

Twist Effect With Other Blade Properties Constant

In the mid-1960s, Boeing Vertol was actively studying large, low disc loading tiltrotor aircraft. They focused on a configuration designated as the Model 160 (ref. 22). Their VTOL aircraft was deemed a competitor to the LTV XC-142A during the Tri-Service Competition and had a design gross weight of 46,200 pounds and a disc loading of 9.7. The configuration looked like a CH-47 fuselage with a tiltrotor wing and tip-mounted proprotor assemblies added. The two proprotors were 55 feet in diameter and each had three blades. The proprotors were designed with a normal tip speed of 750 feet per second in hover and 525 feet per second for cruise flight. A wide scoped 0.2364-scaled (13-foot-diameter) model proprotor test program aimed at experimentally determining the "optimum" twist for *the* proprotor was carried out with six twist geometries (blade sets A through F). The first three geometries are shown in figure 26 and are sufficient examples for this report. All blade sets were tested in hover (ref. 23) on the WADC test stand using Rig #3 (figs. 27 and 28). Then testing for cruise performance measurement was later conducted using Onera's large, high-speed wind tunnel in Modane, France (refs. 24, 25).

The C_P versus C_T performance at the design tip speed of 750 feet per second is shown in figure 29. Based on this examination of all the hover data in several graphical forms (figs. 29 through 36), Vertol engineers selected a twist of –36 degrees as the preferred twist for hover.

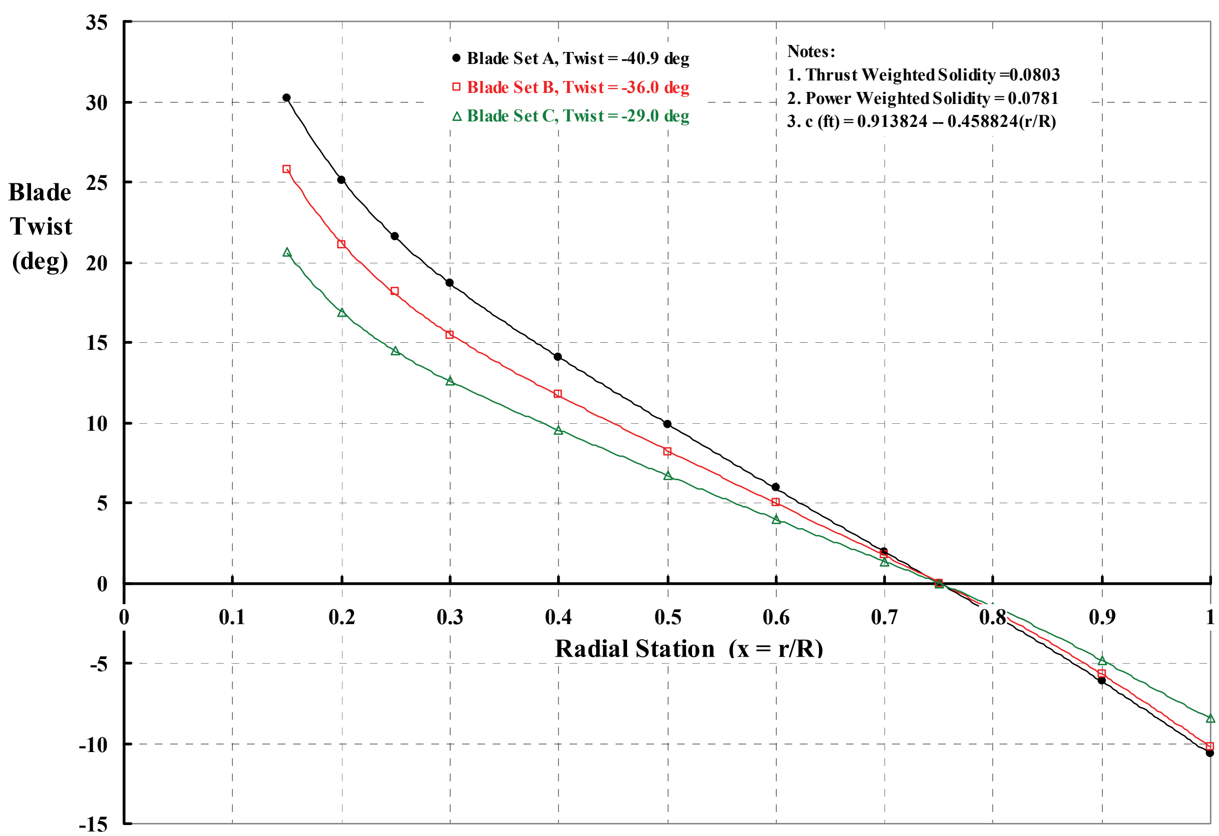

Figure 26. The static twist range of blades tested was from –40 to –29 degrees.

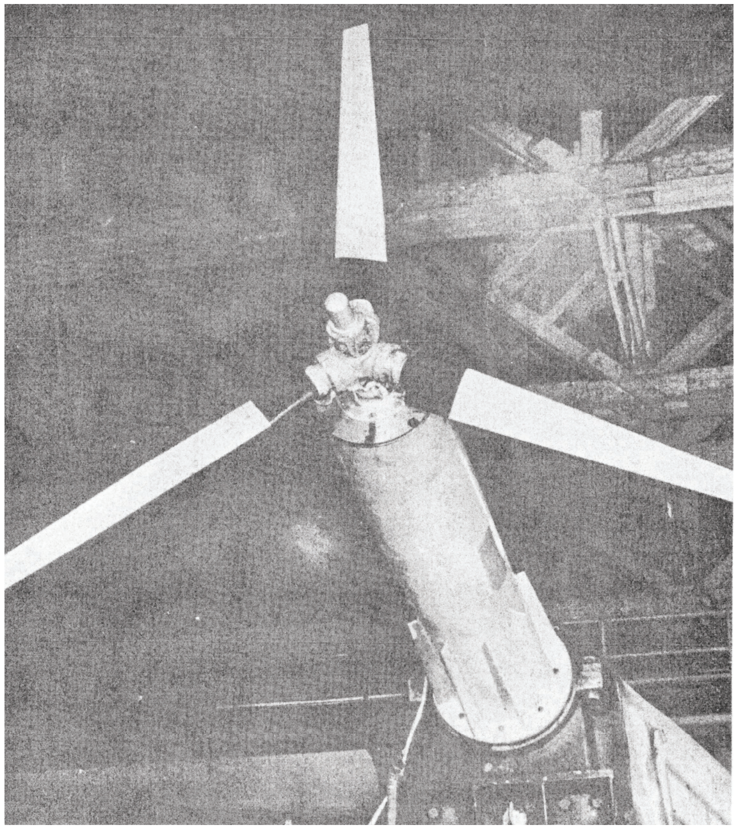

Figure 27. A 13-foot-diameter Model 160 proprotor mounted to WADC Rig #3.

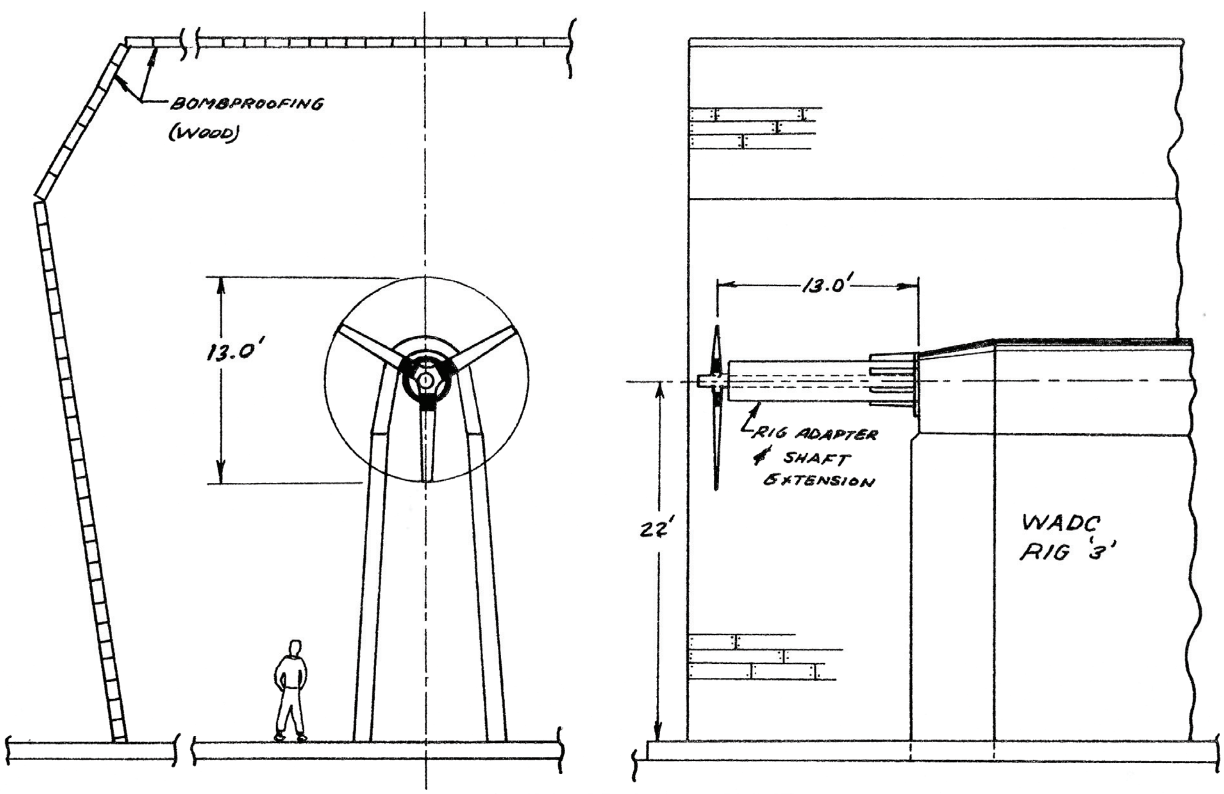

Figure 28. WADC Rig #3 propeller test stand with 13-foot shaft extension.

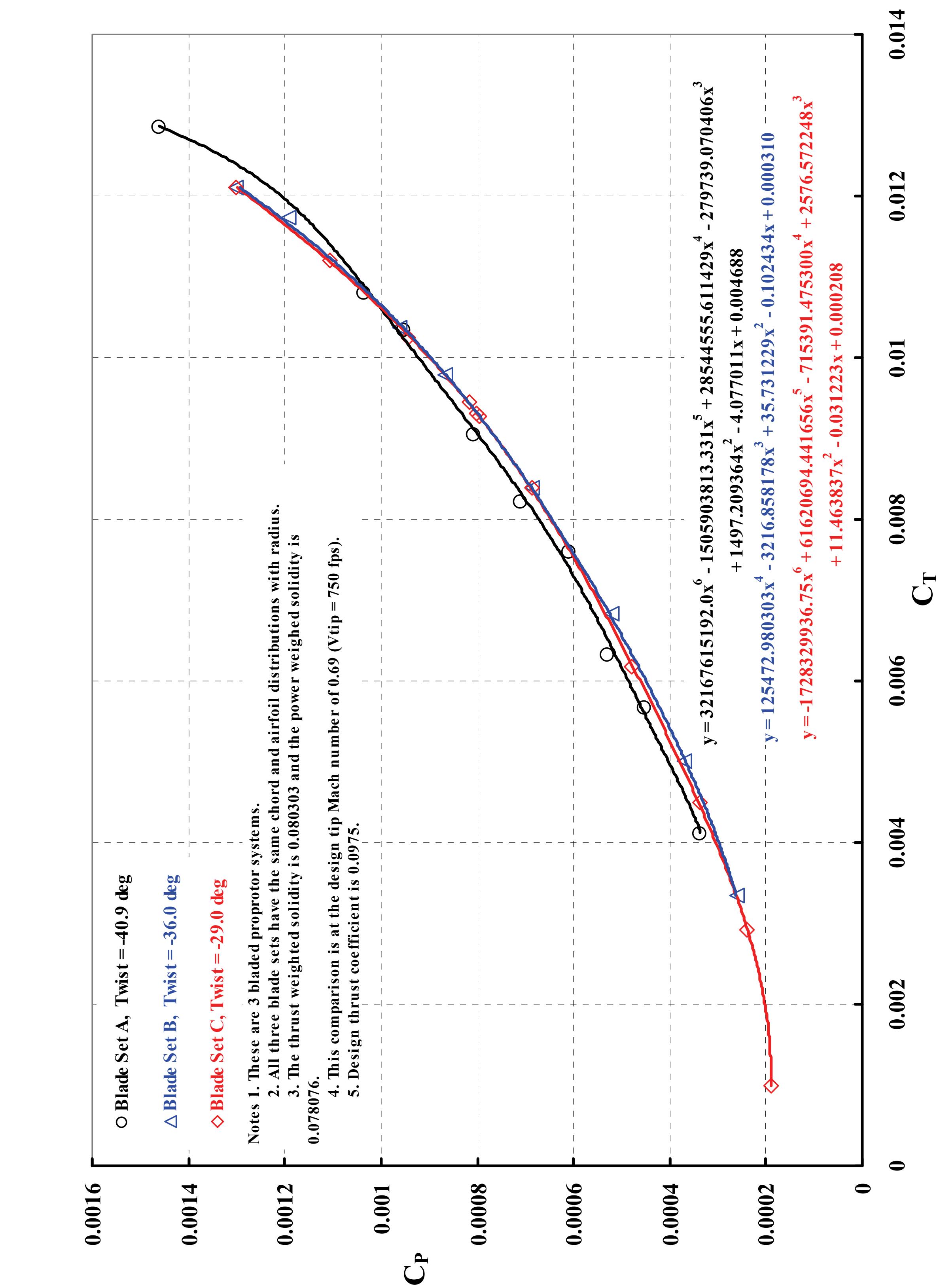

Figure 29. Blade design twist is not as influential as solidity in maximizing hover performance. Note that this comparison is made at only one tip Mach number of 0.69 for clarity.

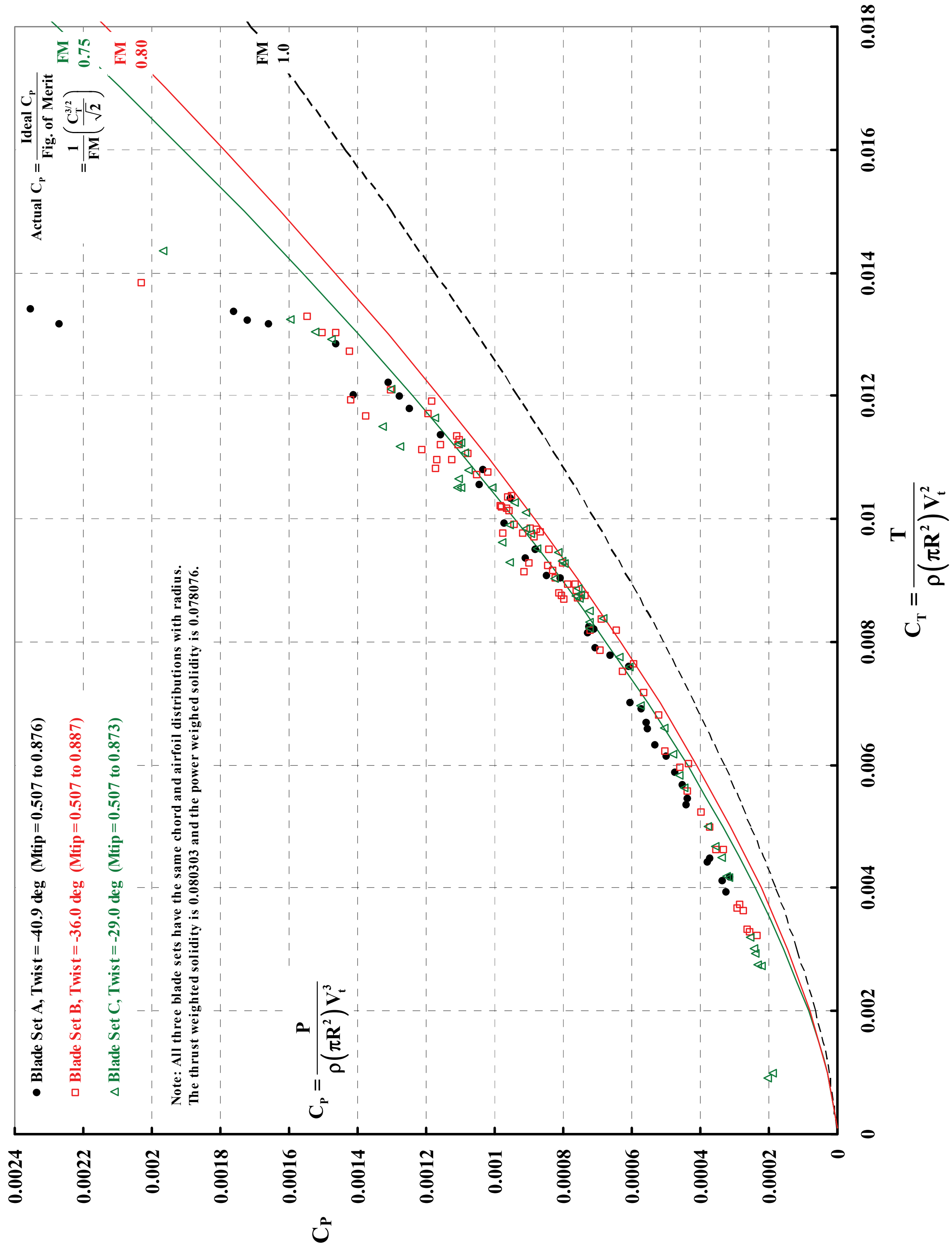

Figure 30. A design twist in the range of –36.0 degrees for a solidity of 0.1 appears satisfactory if the required thrust coefficient is on the order of 0.008 to 0.012.

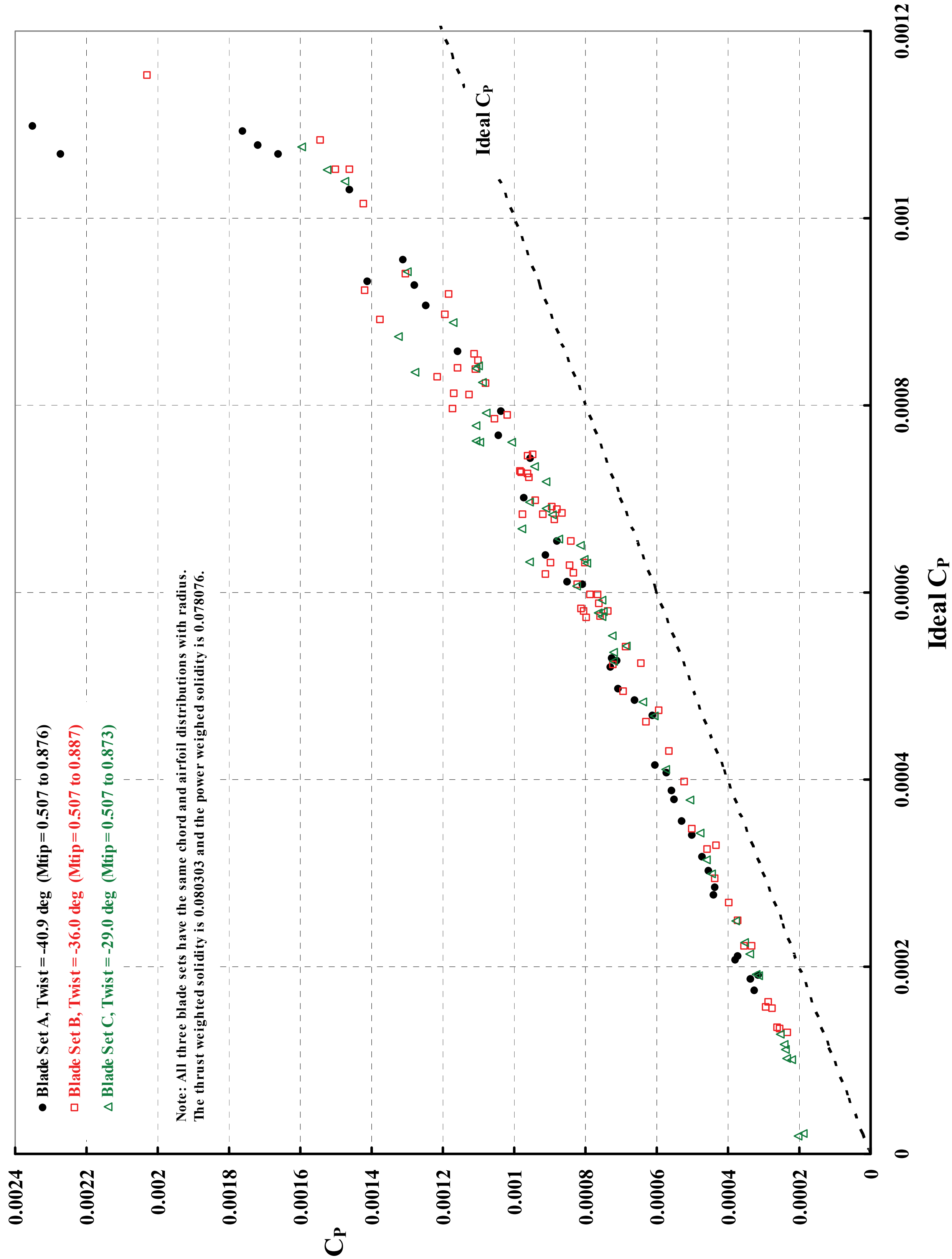

Figure 31. Power coefficient varies nearly linearly with ideal power coefficient.

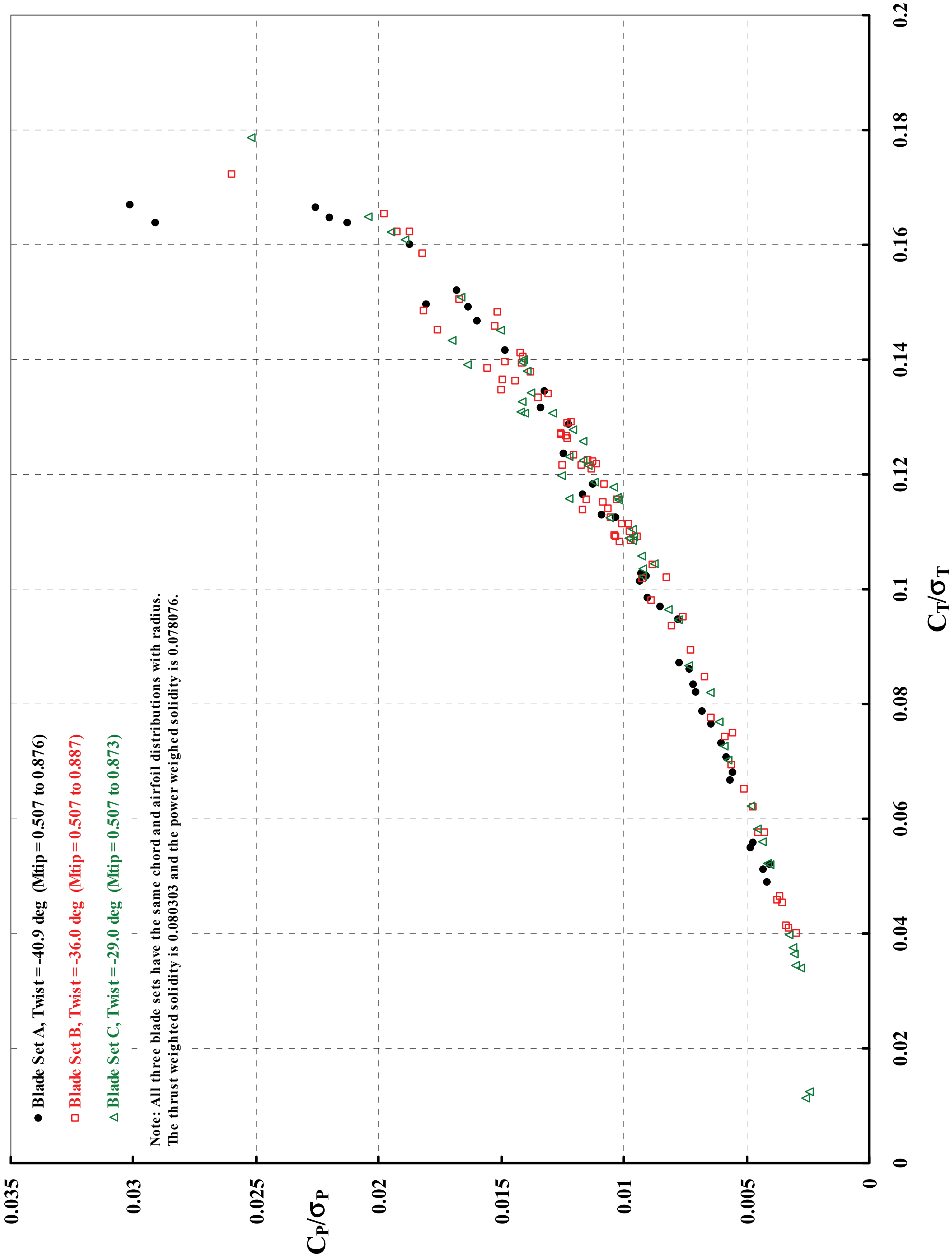

Figure 32. The data is too sparse in the blade stall region to draw a conclusion about the maximum blade loading coefficient.

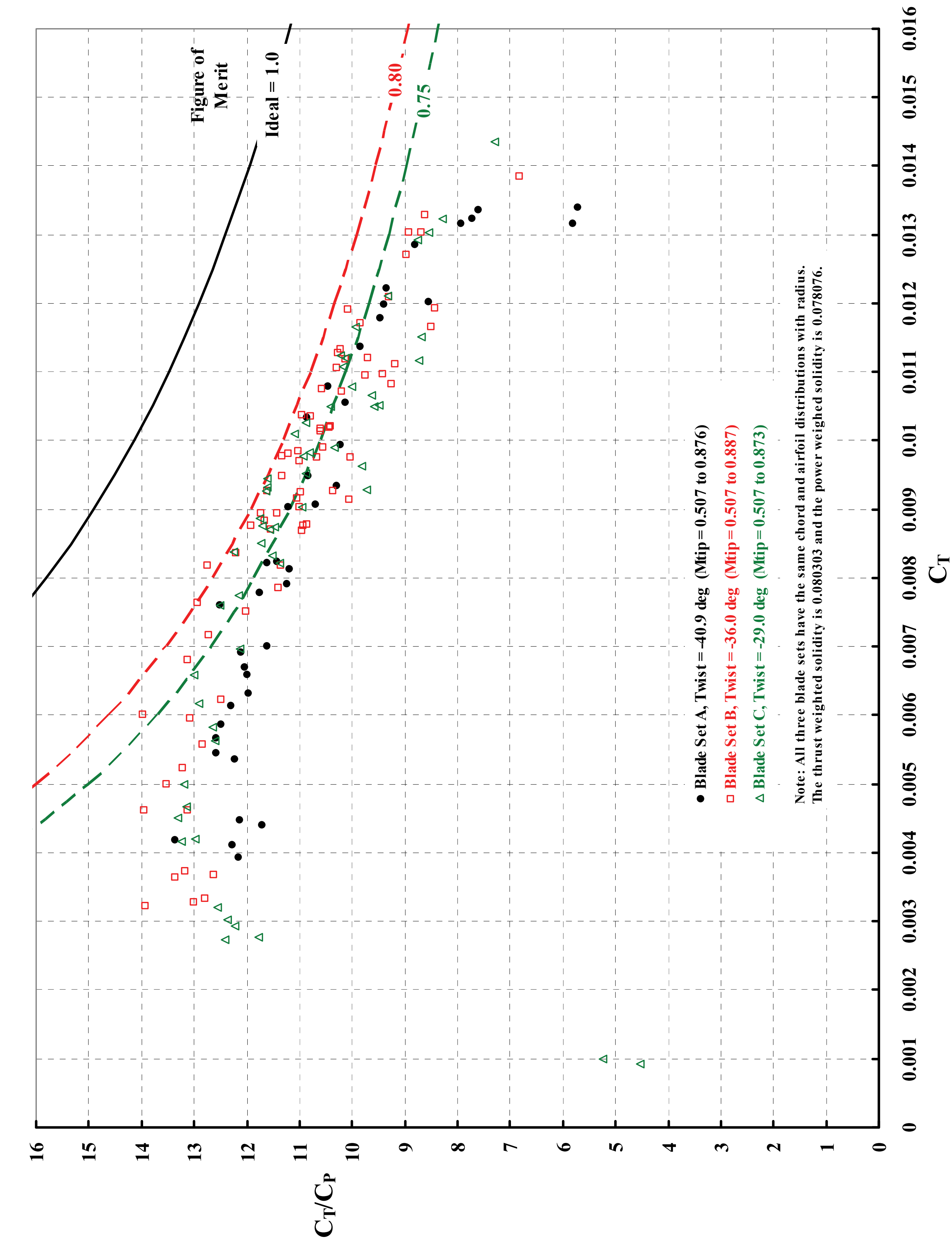

Figure 33. Blade design twist is not as influential as solidity in maximizing hover performance.

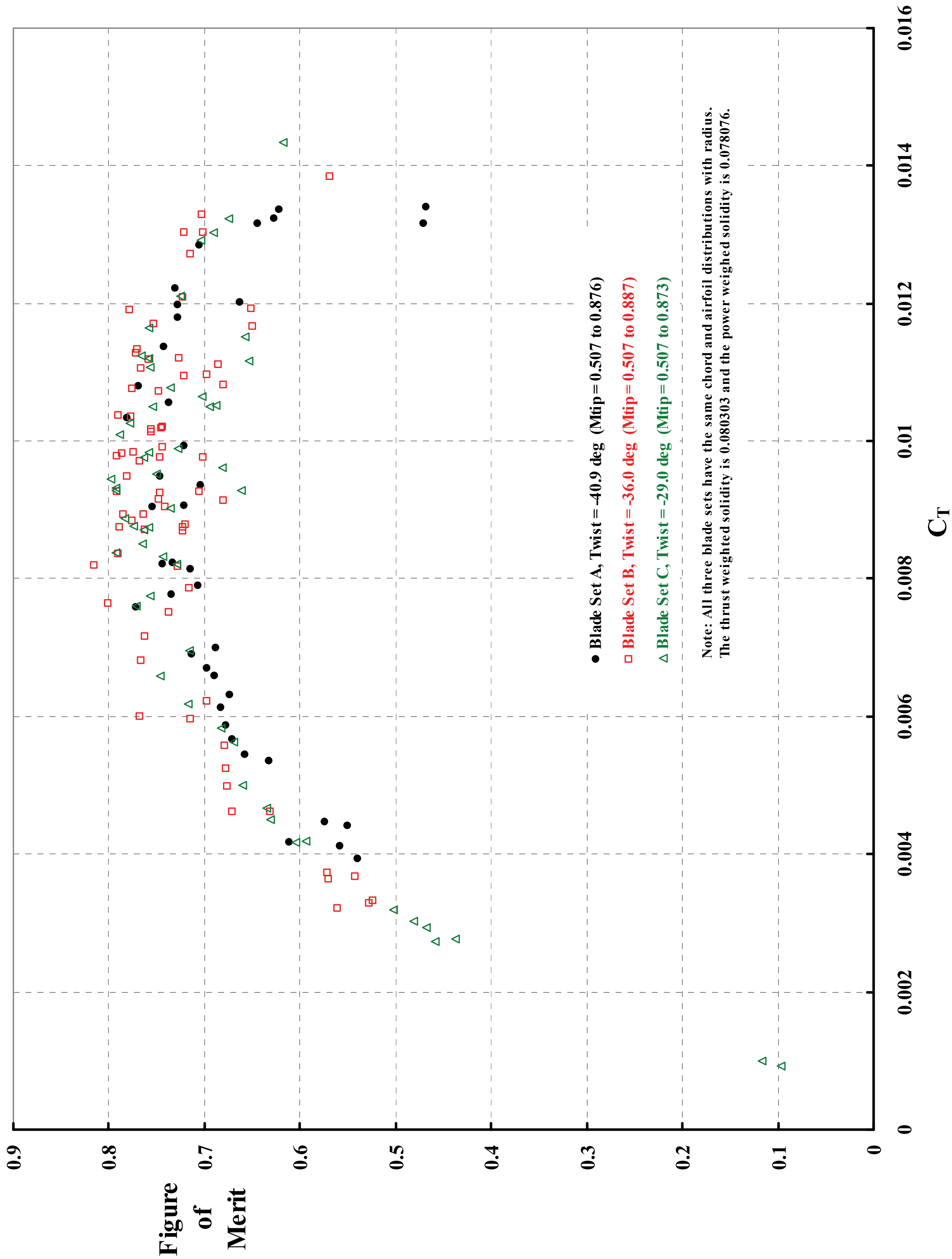

Figure 34. Blade design twist is not as influential as solidity in maximizing hover performance. While not singled out in this figure, tip Mach number is more important than twist.

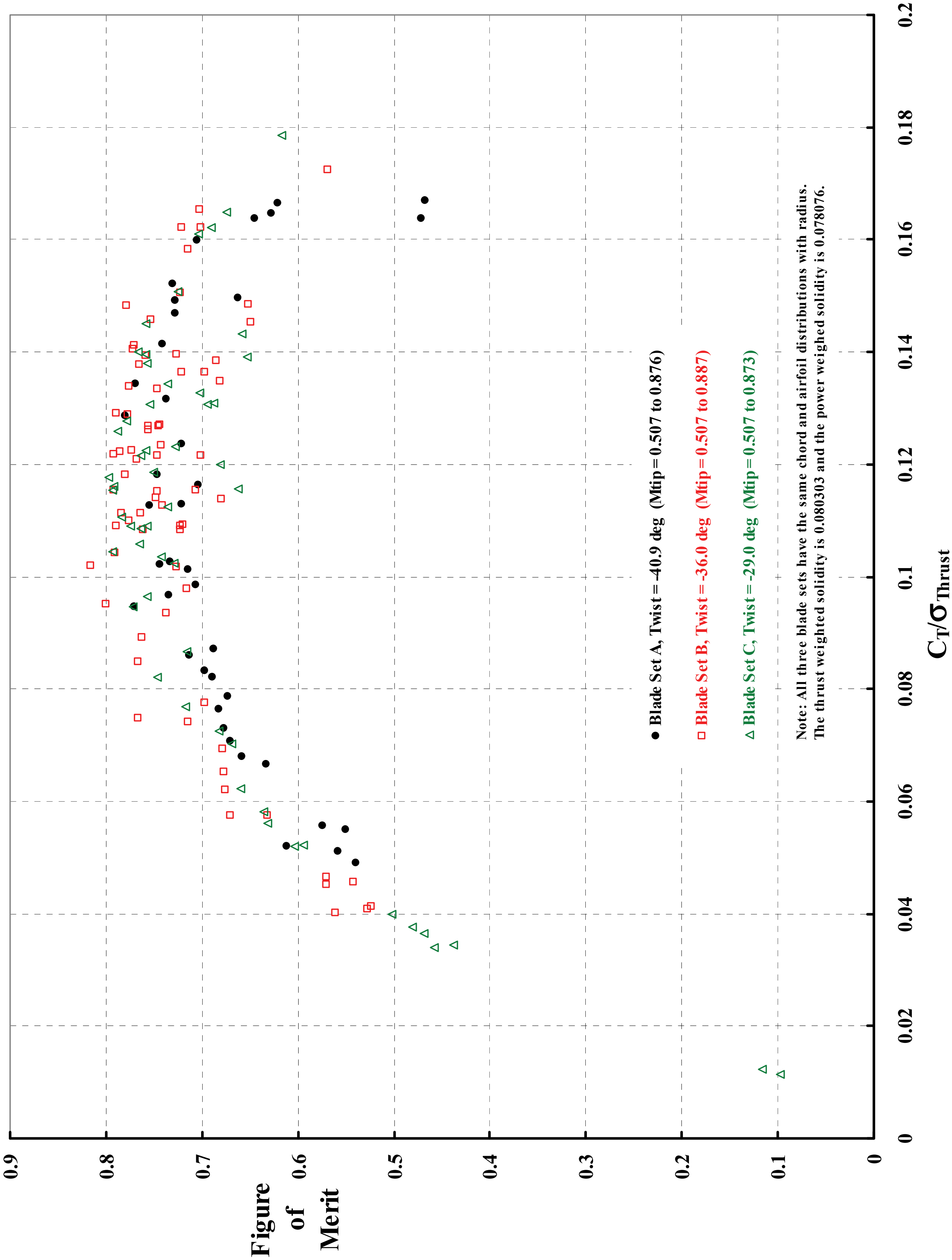

Figure 35. The data is too sparse in the stall region to draw a conclusion about maximum blade loading.

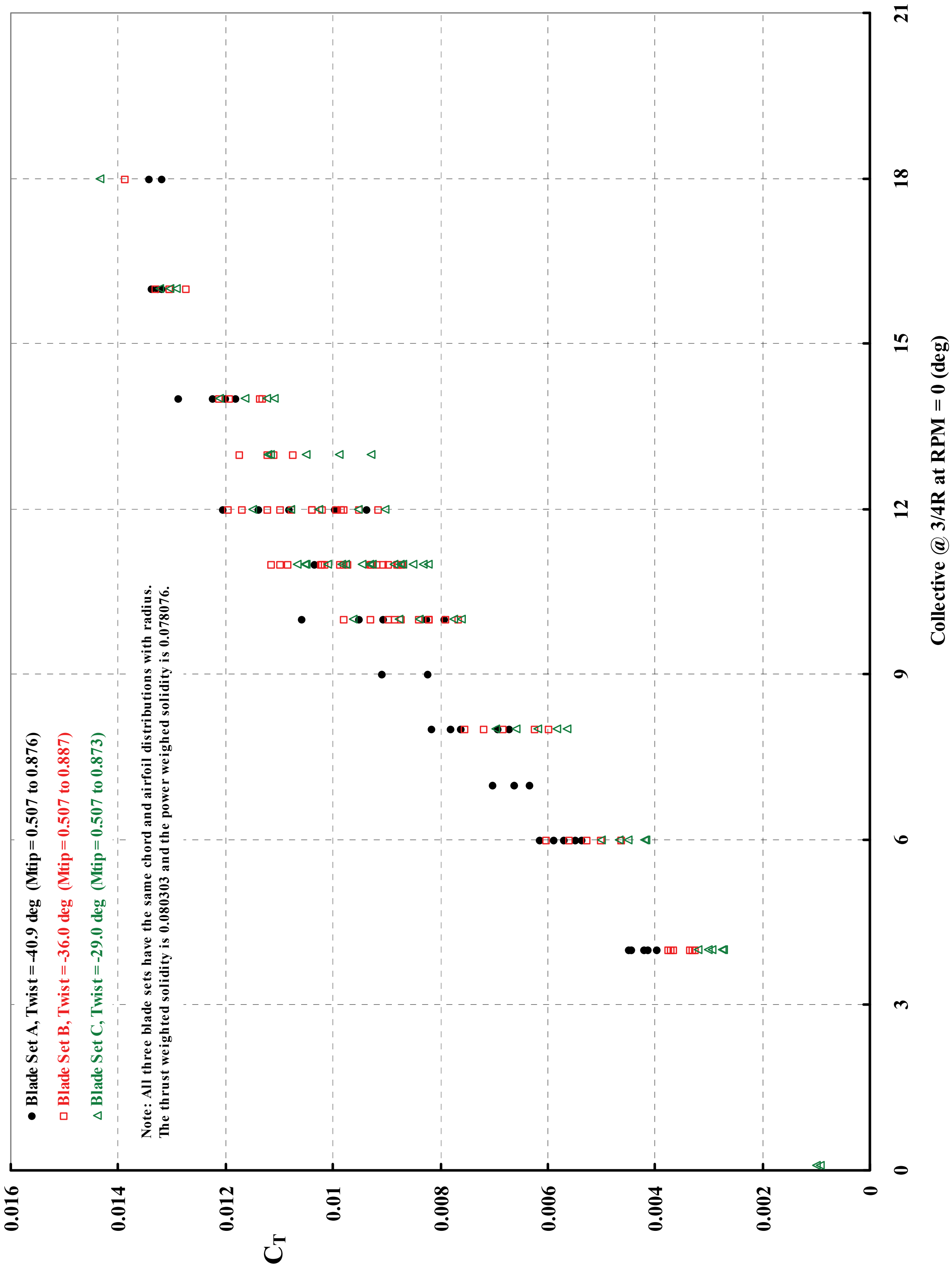

Figure 36. Tip Mach number and tip speed are very influential as to how thrust coefficient varies with collective pitch at the 3/4 radius.

Scale Effects on Hover Performance

The extensive testing program carried out in support of the JVX/V-22 tiltrotor included a large-scale version having a 25-foot diameter (Appendix C), and later, the 5.7-foot-diameter version (Appendix F). Both sizes were Mach-scaled to the 38-foot-diameter proprotor design as it existed during the early design phase of the MV-22B tiltrotor. The resulting experimental data for hover performance allows an example of “small” versus “large” to add to the data base. The hover performance comparison of these two configurations—in several graphical forms—is shown in figures 37 to 41.

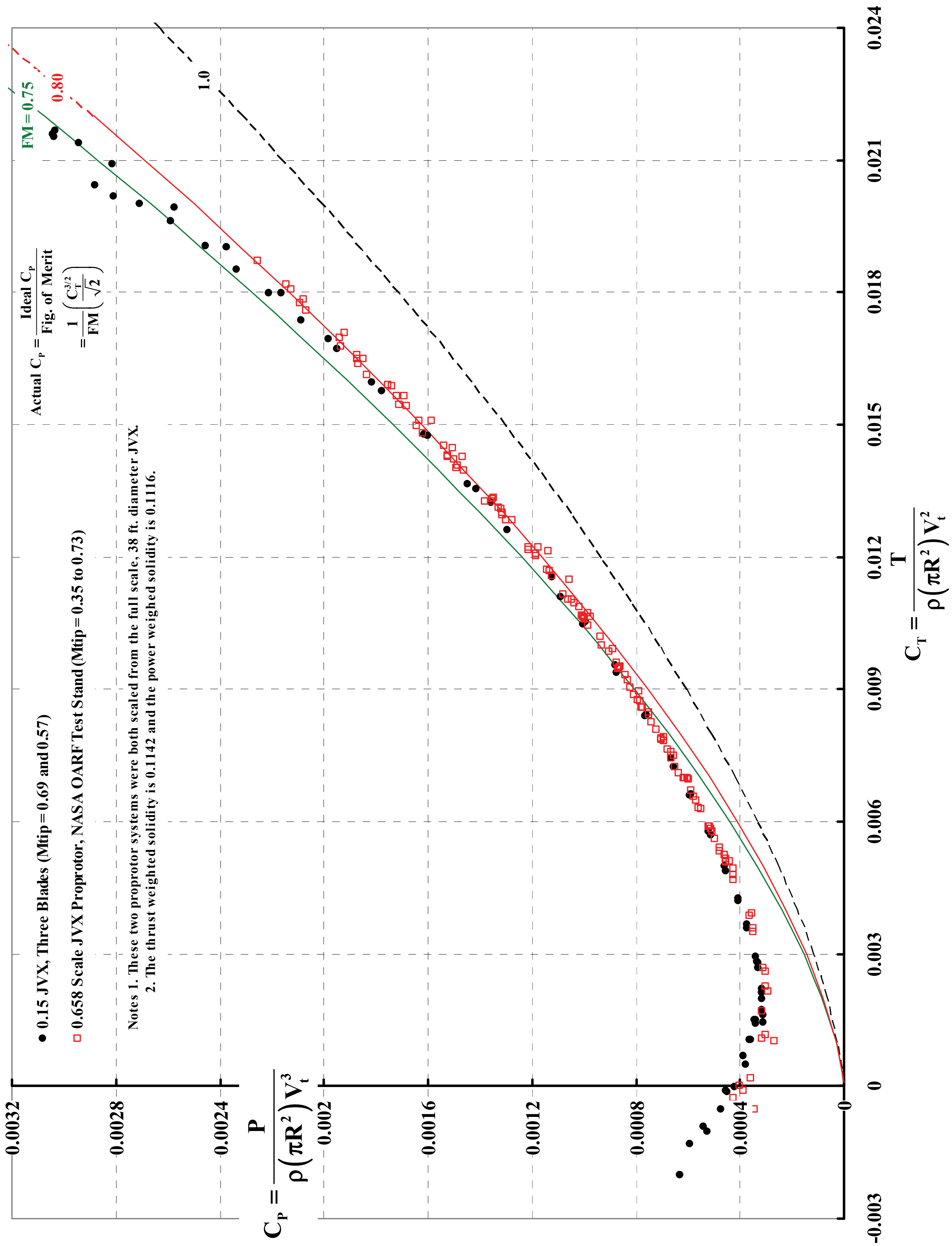

Figure 37. The larger-scaled (25-foot-diameter) JVX proprotor shows a performance improvement over the smaller-scaled (5.7-foot-diameter) JVX proprotor.

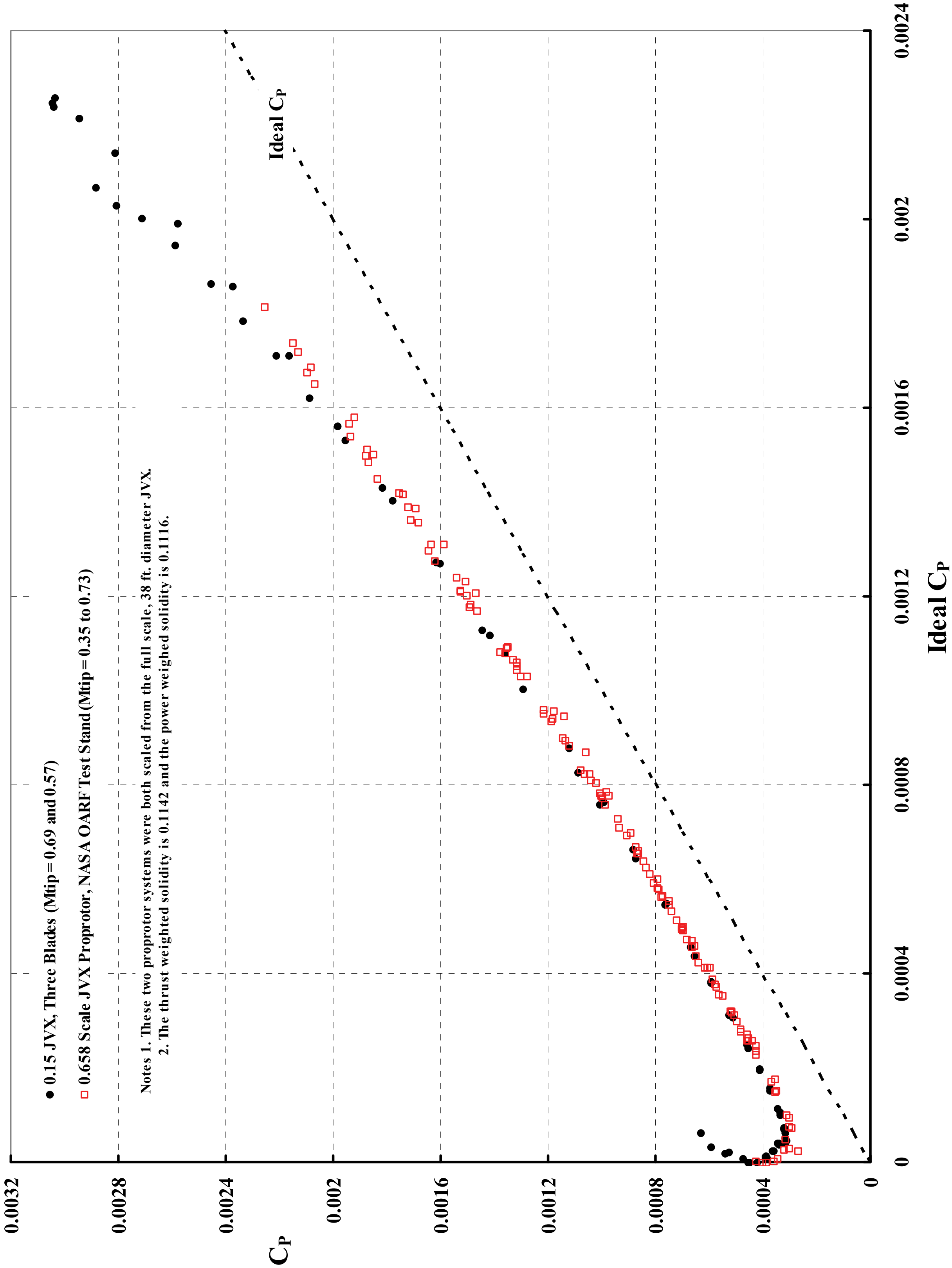

Figure 38. The lower Reynolds number of the smaller-scaled JVX proprotor appears to be influential on hover performance.

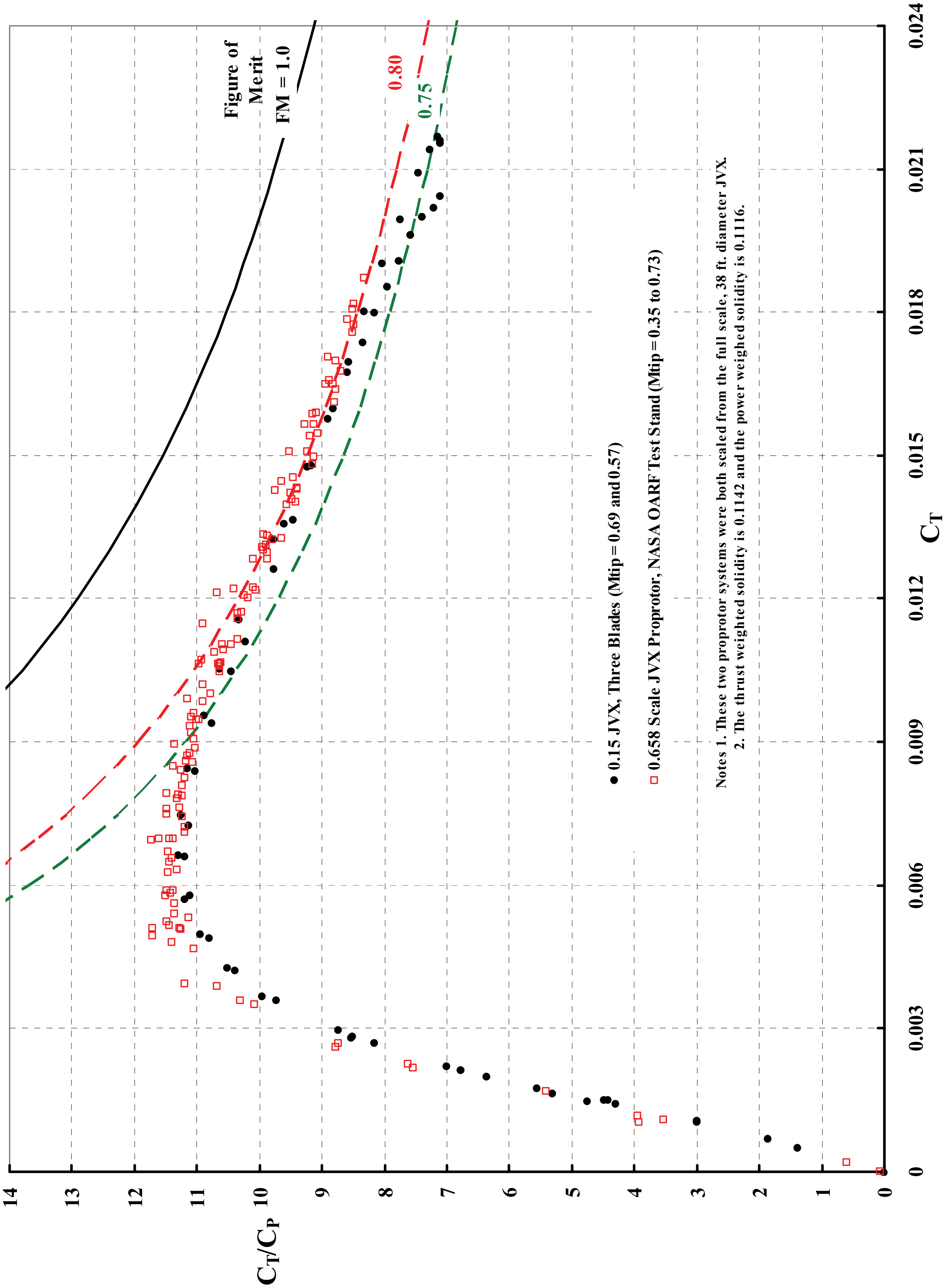

Figure 39. The lower Reynolds number of the smaller-scaled JVX proprotor appears to be influential on hover performance because of excessive profile power.

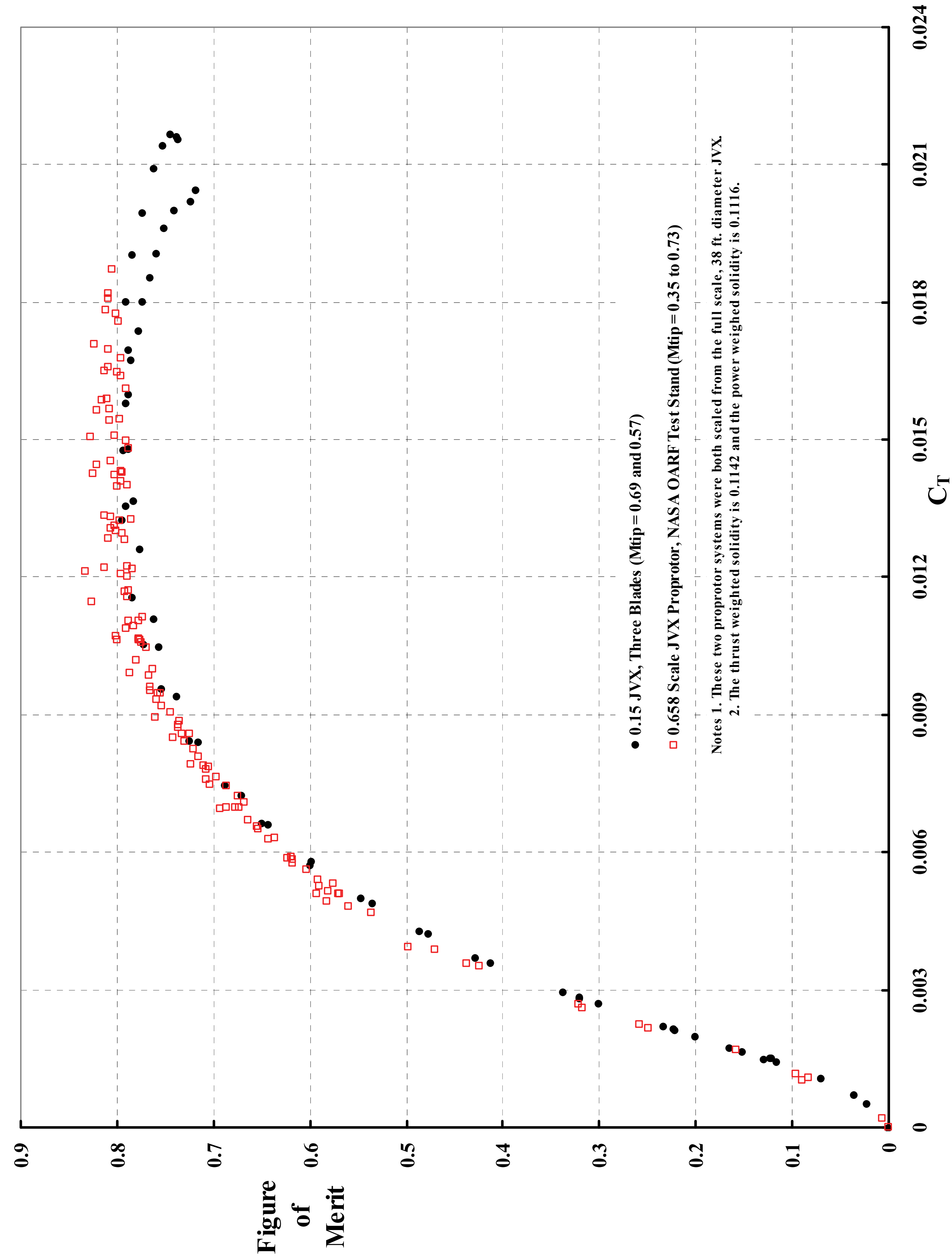

Figure 40. Figure of Merit appears to be about 0.003 higher with the larger-scaled JVX proprotor.

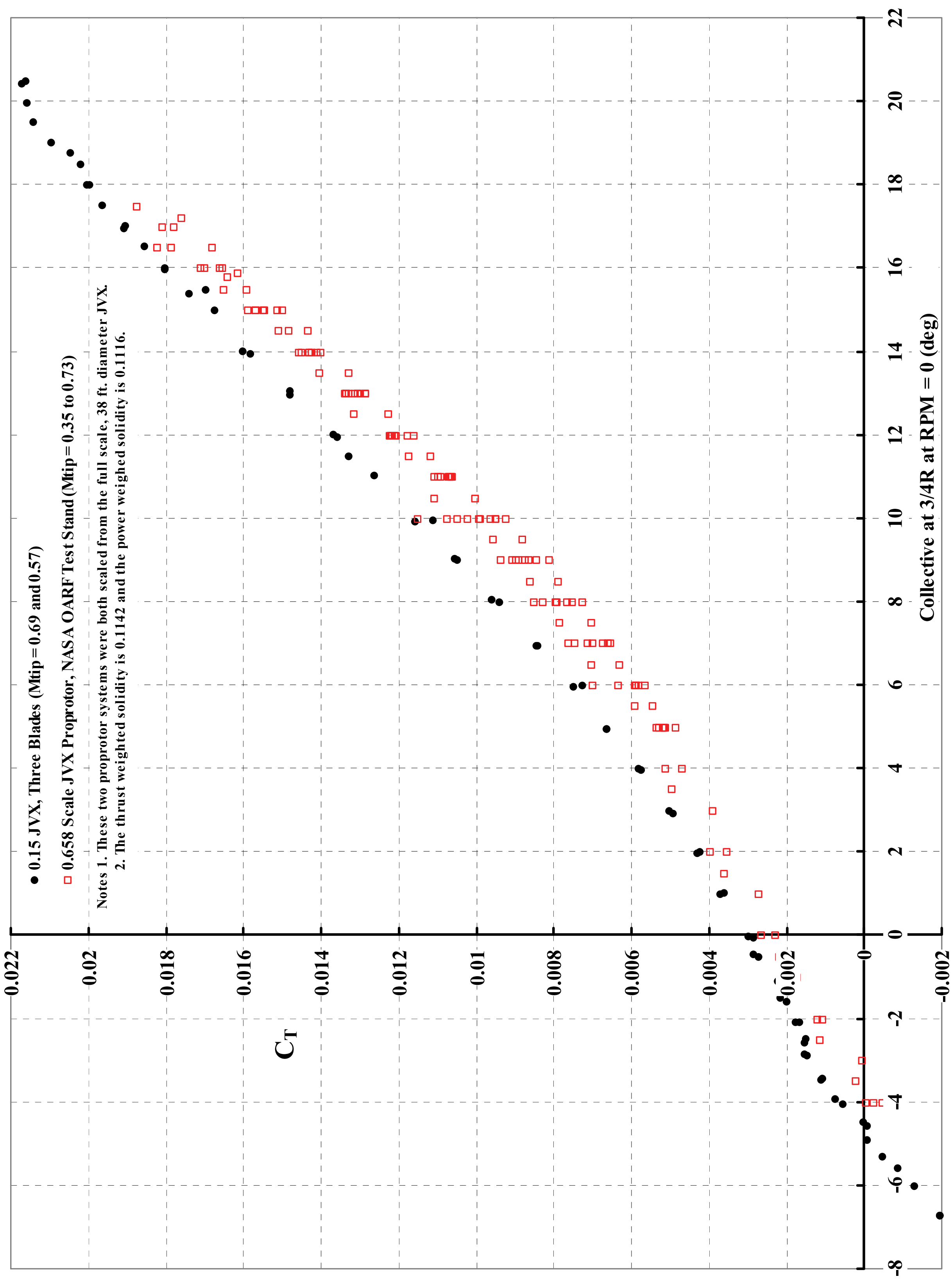

Figure 41. Mach number, Reynolds number, and elastic deformation due to airloads are very important factors affecting how thrust coefficient varies with collective pitch.

Six, 5-Foot-Diameter Propellers

Six, 5-foot-diameter, four-bladed propeller configurations were tested in hover as part of a U.S. Air Force–sponsored program titled Advanced V/STOL Propeller Technology. The Program Summary Report was published (AFFDL-TR-71-88 Volume XIV) in April of 1974. It was the last volume of a 14-volume set of reports dealing with a comprehensive experimental and theoretical research activity to define a propeller using *monocyclic as a tiltwing pitch control device.* The monocyclic approach to tiltwing pitch control would replace the tail-mounted, pitch control propeller used on the XV-142A.

Hamilton Standard was awarded the go-ahead monocyclic propeller configuration contract in May of 1969 (some 20 months after the XC-142A program was cancelled). The contract itself was titled "Design, Fabrication and Test of Hardware to Obtain Propeller and Cyclic Control Technology." Canadair Limited, with their CL-84 tiltwing experience and test facilities, was an associate contractor.

The intended V/STOL aircraft, figure 42, was aimed at the troop transport mission. A thorough mission analysis established that the optimum mid-mission gross weight would be about 82,000 pounds with a total installed horsepower of about 33,000. This aircraft design dictated that each of the four 26.4-foot-diameter propellers should be designed to absorb 5,150 propeller shaft horsepower, and for an expected output thrust in excess of 21,500 pounds at a tip speed of 850 feet per second. The ambient condition was to be 93^{o}F at 2,500 feet altitude. Roughly speaking, the propeller was being designed for a four-propeller tiltwing about twice the size of the XC-142A. It was expected that this tiltwing would takeoff from the base (93^{o}F at 2,500 feet) in STOL mode at a gross weight of 91,660 pounds using four engines rated at 8,505 horsepower (sea level, standard).

The small-scale (5-foot-diameter) testing led to selection of a four-bladed design with an Activity Factor of 150 per blade (power weighted solidity of 0.24446) and NACA 65 series cambered airfoils with an integrated design lift coefficient of 0.5. The airfoil camber (with its associated airfoil design lift coefficient, CL_{design}) varied along the blade span. It is worth noting that propeller design engineers calculate a propeller blade's integrated design lift coefficient as

$$(C_L) = 4\int_{x_c}^{1} CL_{design}\, x^3 dx \,,$$

which is a rarely seen parameter in rotorcraft literature.

The small-scale model testing was followed by testing with a 1/2-scale (13.2-foot-diameter) model, and feasibility of cyclic control was established by testing on the Air Force Aero Propulsion Laboratory (AFAPL) test Rig #2 located at WADC in Dayton, Ohio. Later, an LTV XC-142A propeller (15.625-foot-diameter Hamilton Standard 2FF16A1-4A) with a collective and cyclic pitch control system was tested in the NASA Ames 40- by 80-Foot Wind Tunnel during January and September 1970. This test gathered data for propeller operation simulating transition from hover to low-speed forward flight at a tip speed of 845 feet per second (1030 RPM). Cyclic pitch varied from 0 to ± 6 degrees.

The final step in the Hamilton Standard (plus Canadair Limited) R&D program was the design, manufacturing, and static testing of the 26.4-foot-diameter, cyclic pitch controllable propeller—the largest propeller Hamilton Standard had ever designed and manufactured. This test was conducted on the Hamilton Standard Whirl Test Rig for about 20.5 hours, of which nearly 6 hours were under cyclic operation. Two key summary performance graphs were obtained. The first, shown here as figure 43, indicates that *at constant propeller shaft horsepower* there is considerable loss in steady thrust as cyclic pitch control is applied. At full cyclic control of 6 degrees, the available steady thrust is reduced from 22,600 pounds at zero cyclic pitch to 20,000 pounds where the propeller is producing about 57,000 foot-pounds of pitching moment. The second key graph is figure 44, which shows that performance from the three different diameter (but equal blade geometry) propellers, at a test tip speed of 850 feet per second, was virtually identical—at least within experimental error.

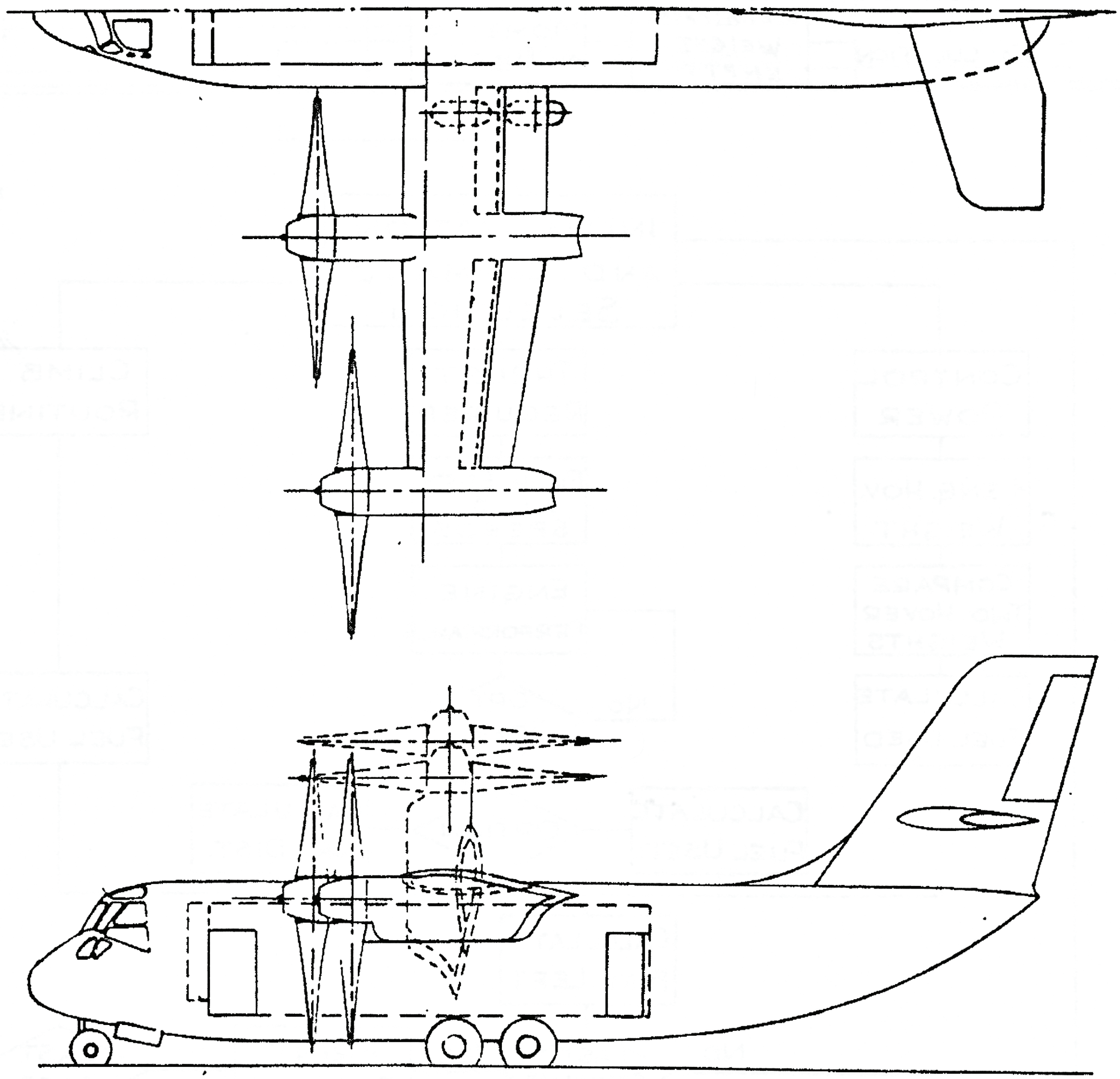

Figure 42. The U.S. Air Force initiated an Advanced V/STOL Propeller Technology program aimed at a 90,000-plus-pound takeoff gross weight machine. The conceptual tiltwing was envisioned as being about twice the size of the LTV XC-142A. The four, 26.4-foot- diameter propellers were designed to use *monocyclic as a tiltwing pitch control device.* This monocyclic approach to tiltwing pitch control would replace the tail-mounted, pitch control propeller used on the XV-142A.

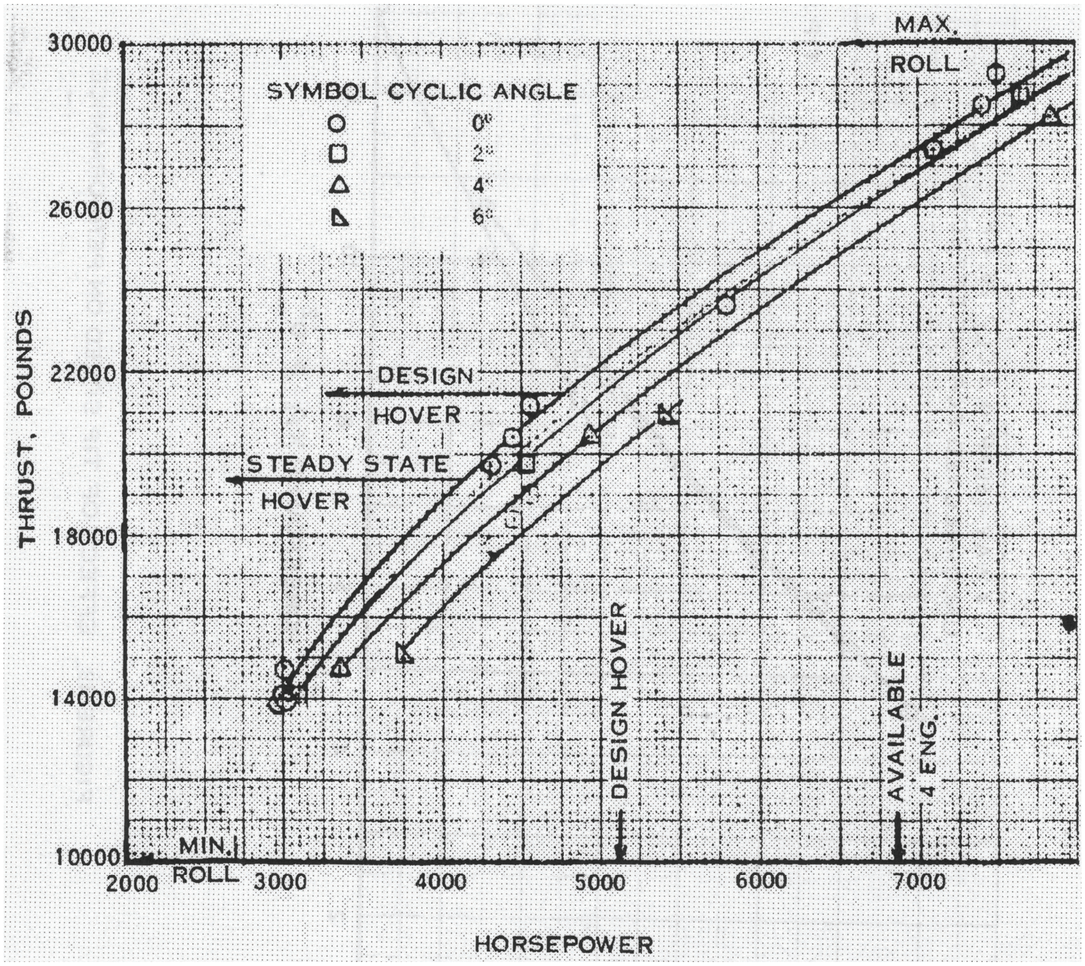

Figure 43. Effect of cyclic input on hover performance.

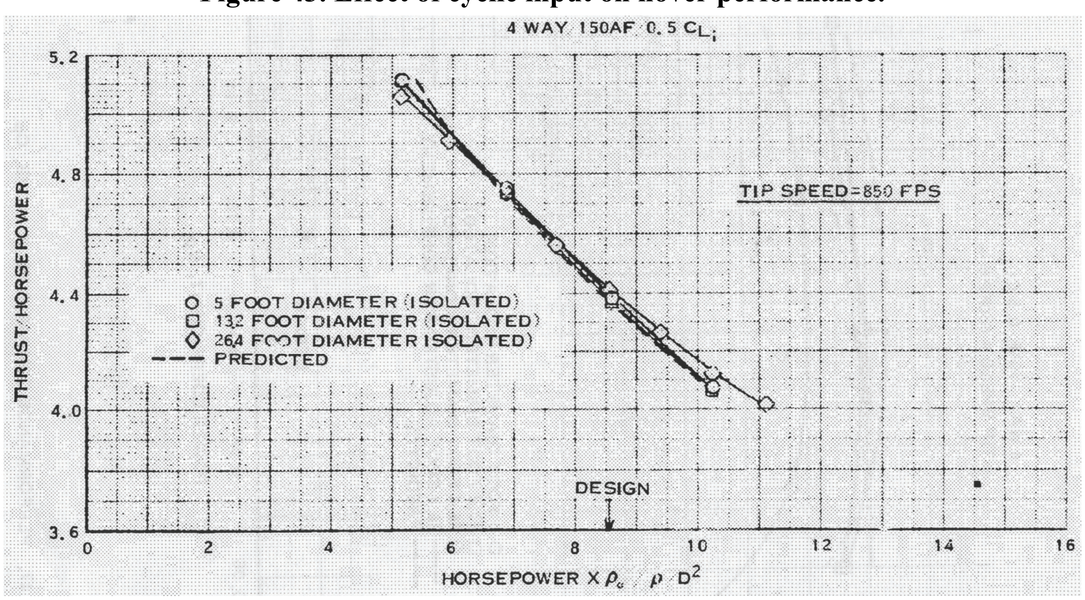

Figure 44. Small- and medium-diameter Mach-scale propellers demonstrated hover performance virtually identical to full-scale performance—at least within experimental error.

Table 3. Parameter Summary for Primary Configurations Studied

Propeller	Data Bank Number	Power Weighted Solidity	Propeller Design C_L
HS 212x-14	K	0.244462	0.50
HS 47x-478	L	0.275427	0.50
HS 47x-486	M	0.210237	0.50
CL 1968-1E14	N	0.162975	0.67
CL240-3C14	O	0.162975	0.90
CL 240-2C14	P	0.203718	0.67

Note: All model propellers had four, 5-foot-diameter blades, machined out of solid aluminum. Tests were conducted at tip speeds of 450, 550, 650, 750, and 850 fps (nominal tip Mach number from 0.40 to 0.74). However, blade chord and twist geometry were different for each model propeller. The NACA 95A series airfoil was used outboard of the 0.4R radius station.

The test results for the six, 5-foot-diameter, four-bladed, Mach-scale propellers are a valuable data bank. As table 3 shows, these initiating efforts carefully searched, experimentally, for a design well suited to a 91,660-pound takeoff gross weight, tiltwing V/STOL. These six propeller configurations were chosen from a group of 46 propellers tested before and during the Hamilton Standard contract. The propellers were tested on the Canadair Limited static test rig shown in figure 45. The enclosed space for the static testing was in a corner of a very large hanger shown in figure 46.

The performance of the six, 5-foot-diameter propellers is displayed in standard rotorcraft coefficients (C_P versus C_T) in figure 47. Based on this hover performance, hover noise measurements, and cruise performance considerations, Hamilton Standard engineers chose the 212X-14 design for the full-scale, 26.4-foot-diameter propeller. Coupled with the other hover performance discussed in this report, it is concluded that conceptual design of proprotors and propellers for V/STOL aircraft should be expected to achieve an isolated hover Figure of Merit of 0.80 for any density weighted disc loading between 5 and 40 pounds per square foot provided the tip Mach number is less than 0.75. The key design variables are tip speed, power weighted solidity, and blade airfoil camber. The secondary variables are the radial distributions of blade airfoil thickness ratio, chord, and twist. Figures 48 through 54 also substantiate this conclusion.

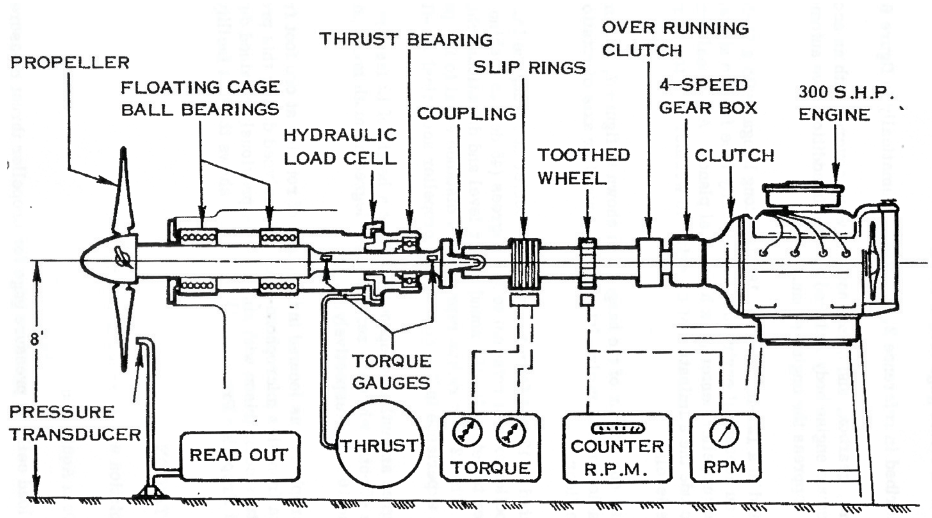

Figure 45. The Canadair Ltd. propeller static test rig was ideal for the 5-foot-diameter scale-model testing used to sort out promising configurations.

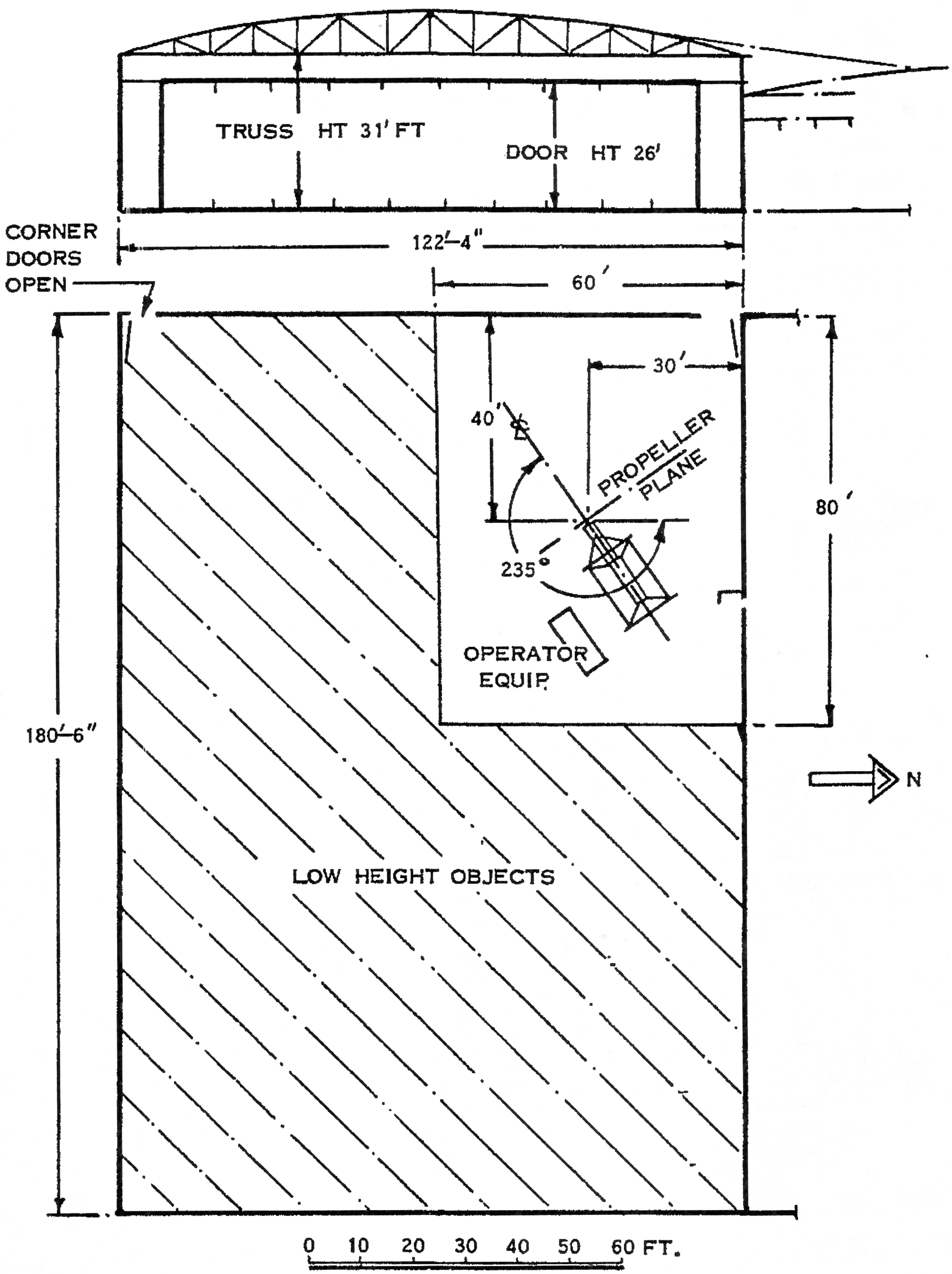

Figure 46. Canadair conducted model propeller static testing in a very large enclosure that reduced wall interference to a minimum.

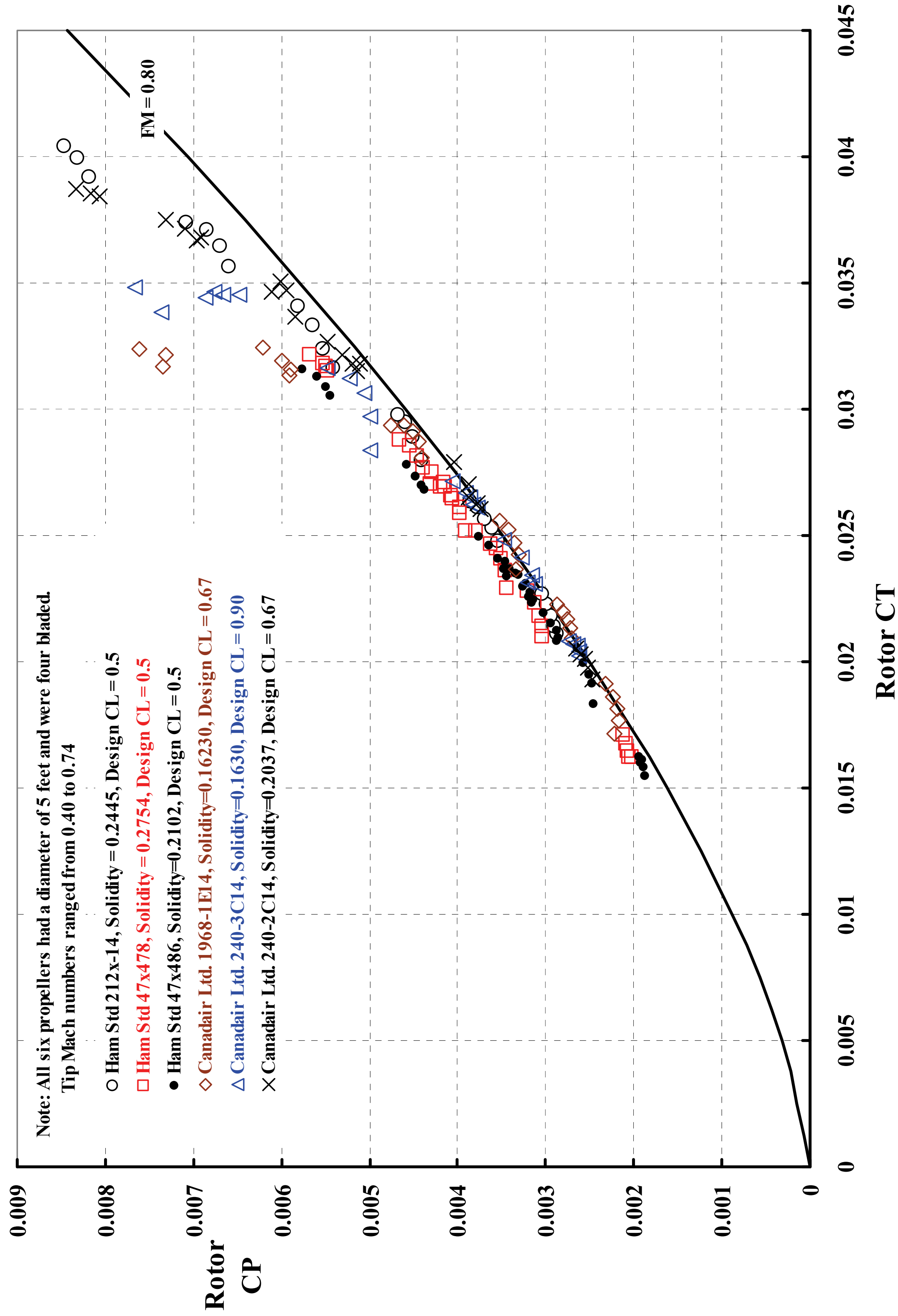

Figure 47. Hamilton Standard chose their 212X-14 configuration for the full-scale, 26.4-foot-diameter design. While the Canadair Ltd. 240-2C14 was seriously considered, cruise performance testing showed that propeller integrated lift coefficient above 0.50 was too much airfoil cambering.

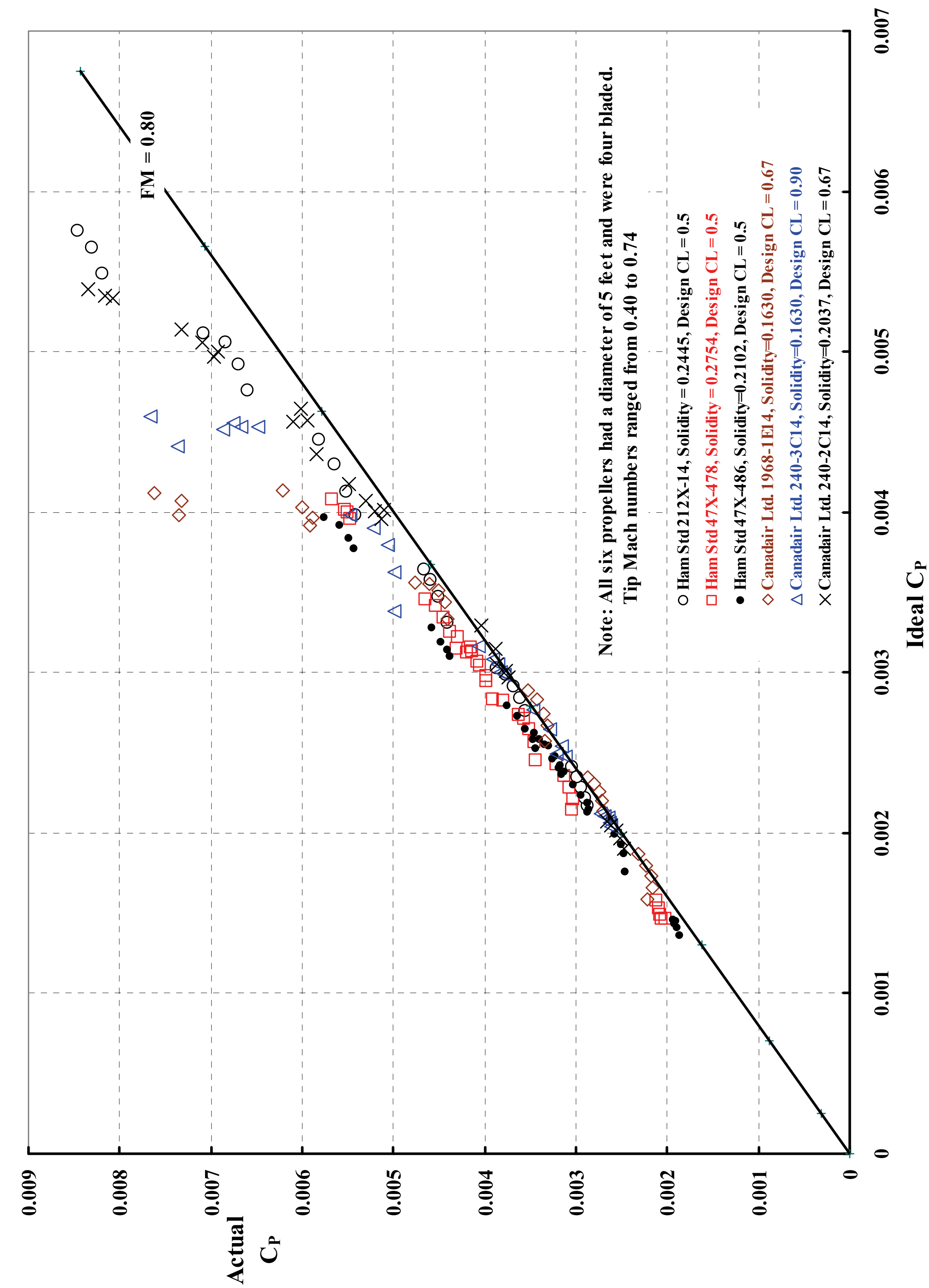

Figure 48. Several propeller configurations demonstrated a Figure of Merit at, or slightly above, 0.80.

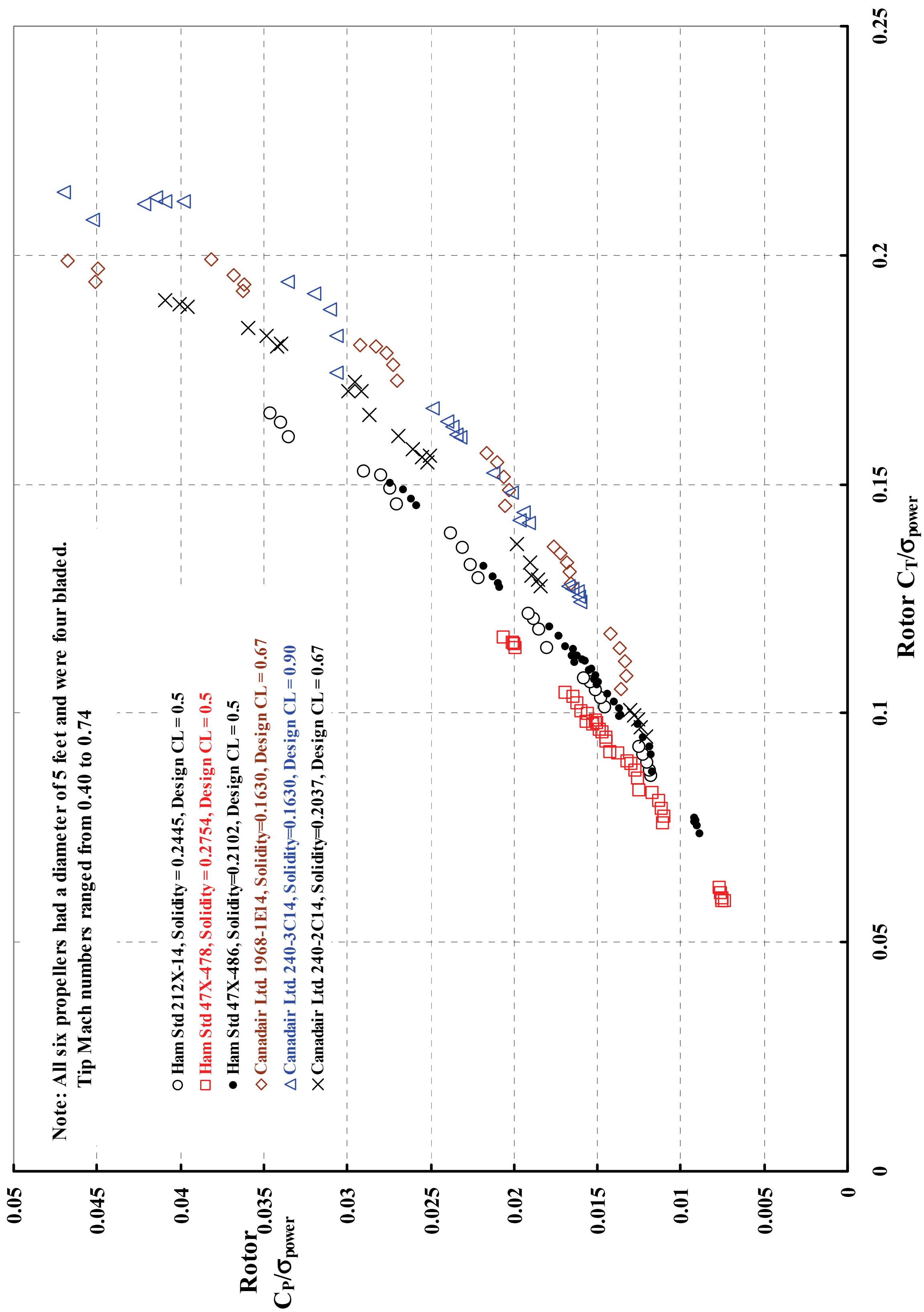

Figure 49. The influence of solidity is not removed with this coordinate system.

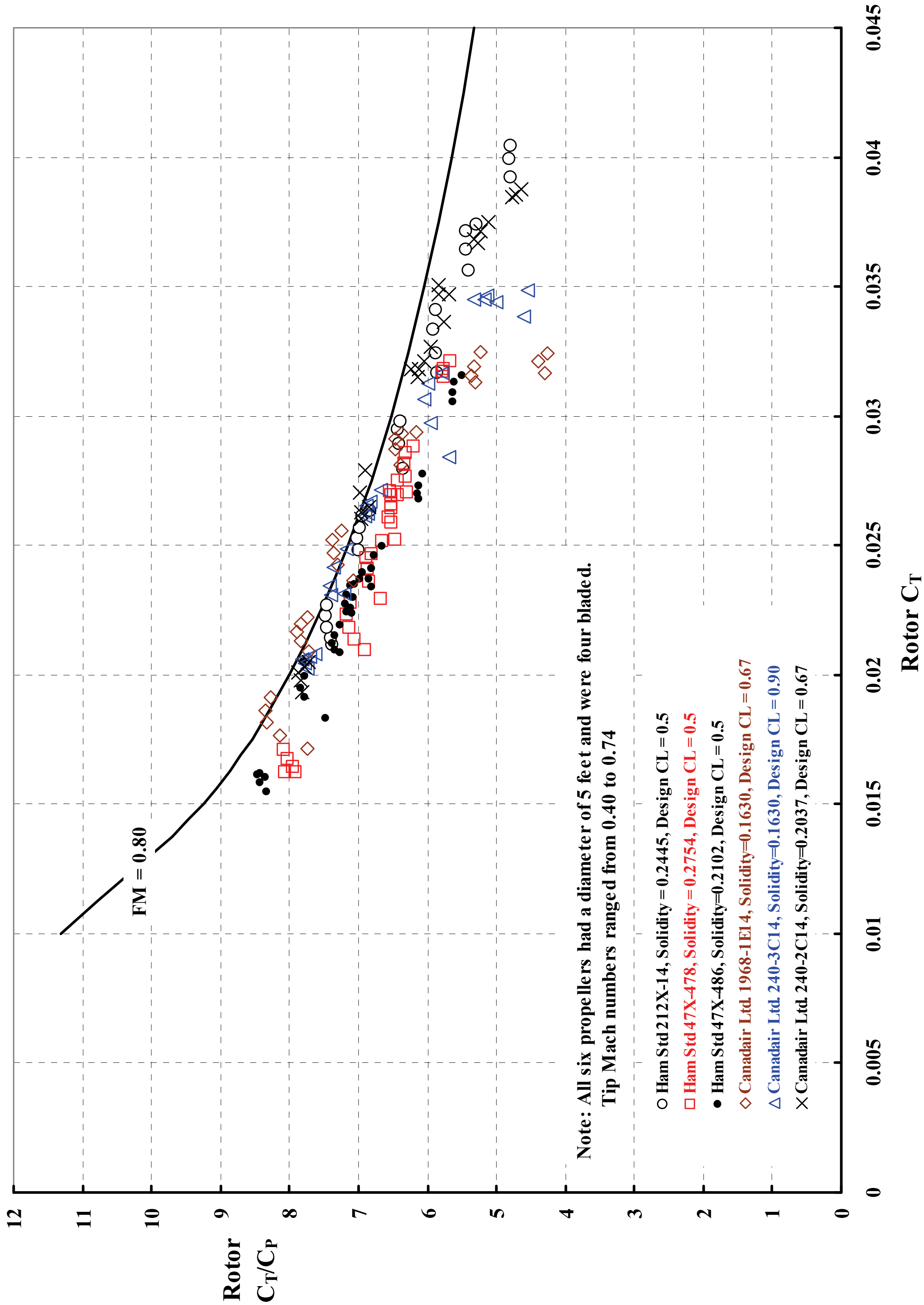

Figure 50. Several propeller configurations demonstrated a Figure of Merit at, or slightly above, 0.80.

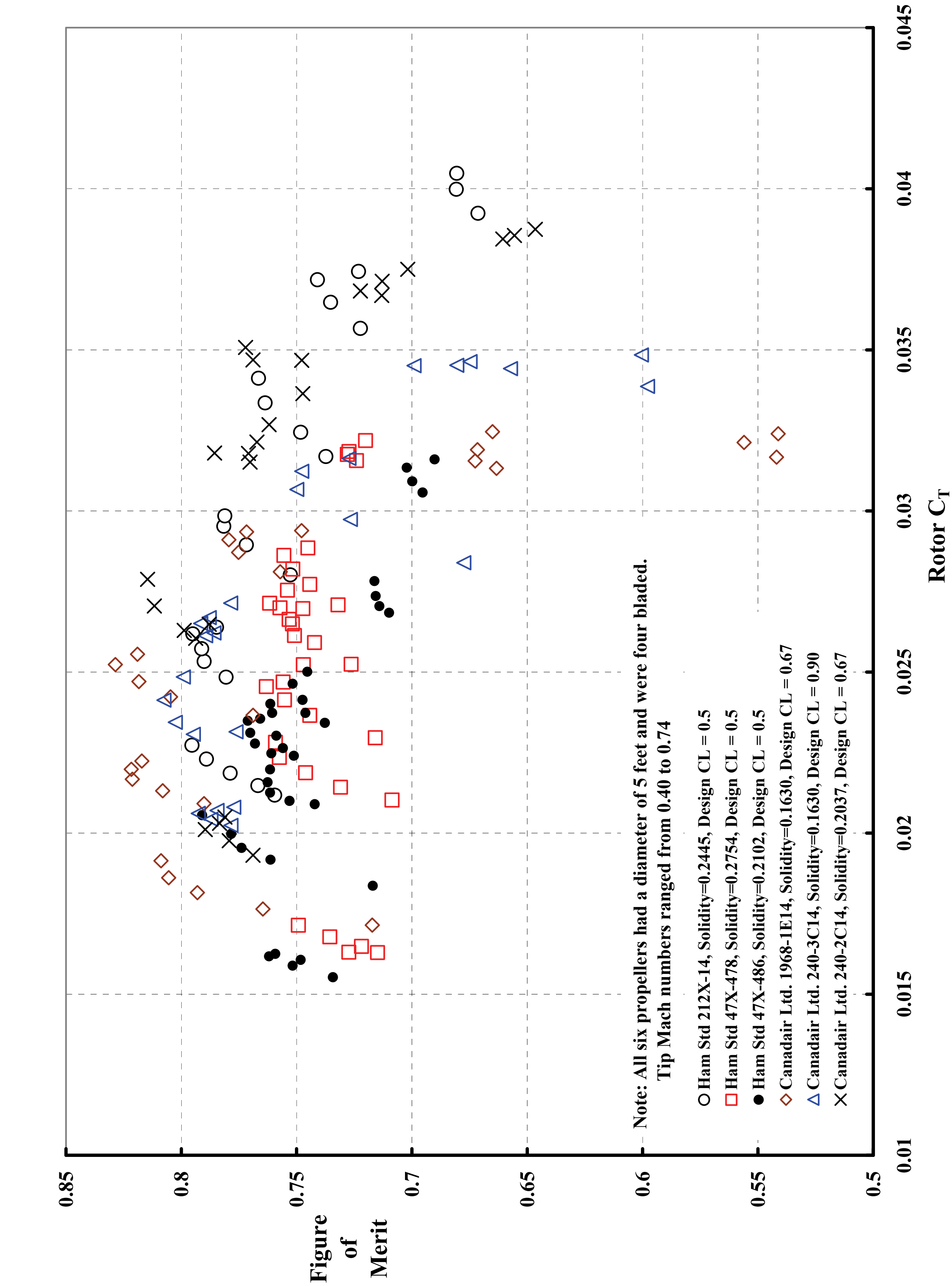

Figure 51. The Hamilton Standard 212X-14 and Canadair Ltd. 240-2C14 were clearly the two best performing propeller configurations.

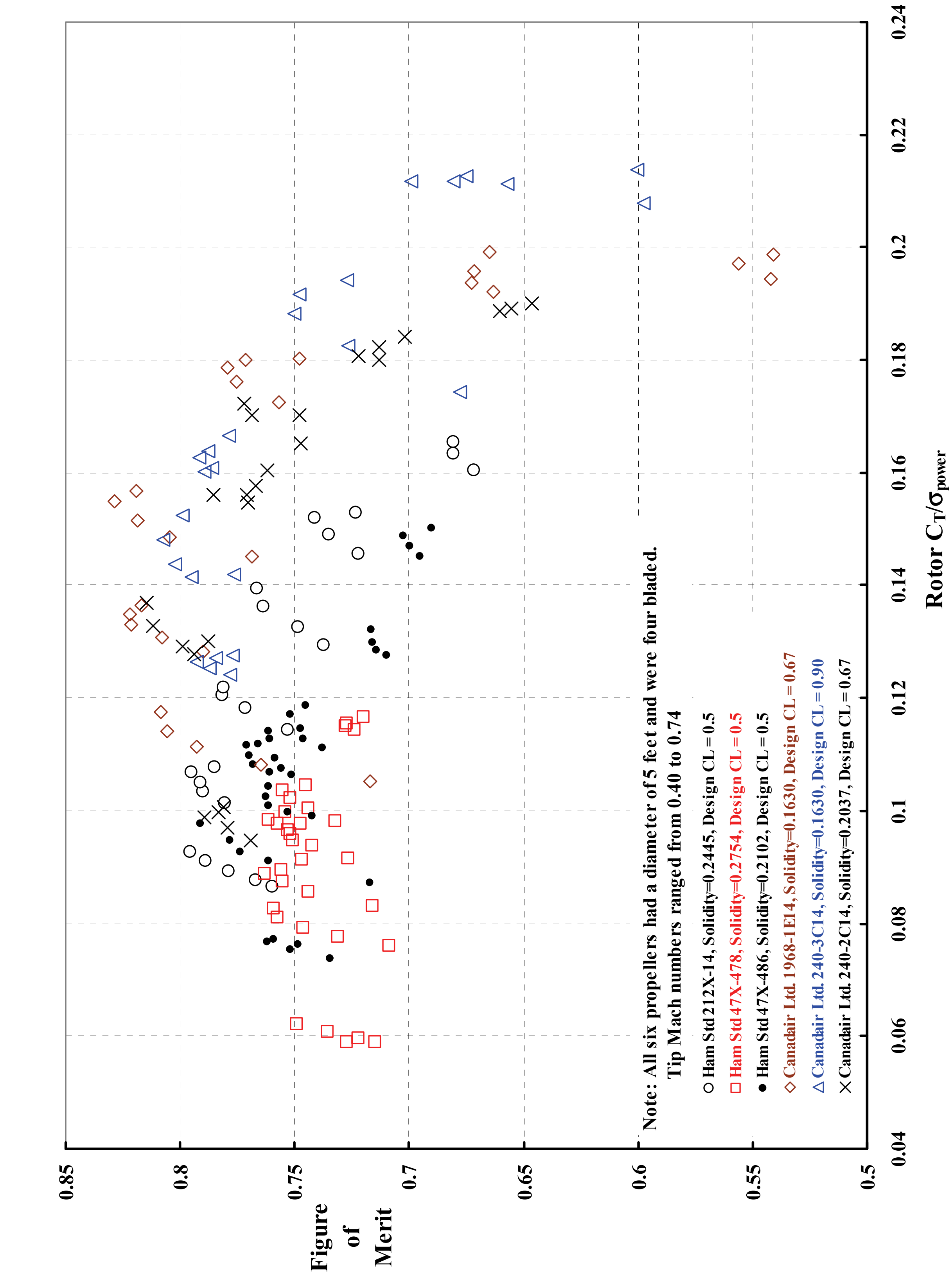

Figure 52. Canadair Ltd. explored the influence of propeller blade integrated design lift coefficient as a means of improving the onset of blade stall.

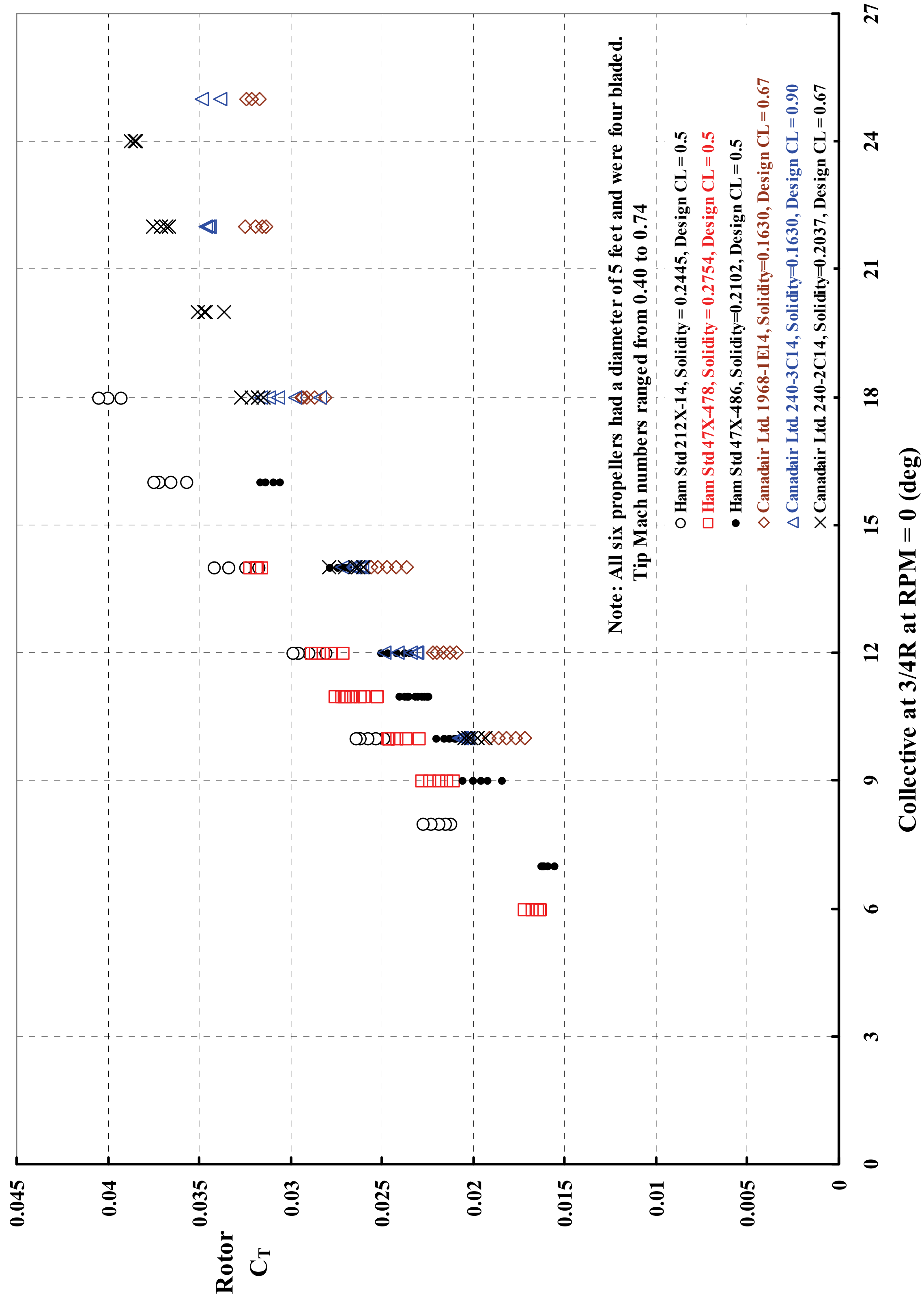

Figure 53. Thrust coefficient versus collective pitch at the 3/4 radius shows solidity is an influential parameter. It also shows that the reference zero value associated with zero thrust is subject to test setup, and experimental error and elastic twisting differences between 0 and test RPM.

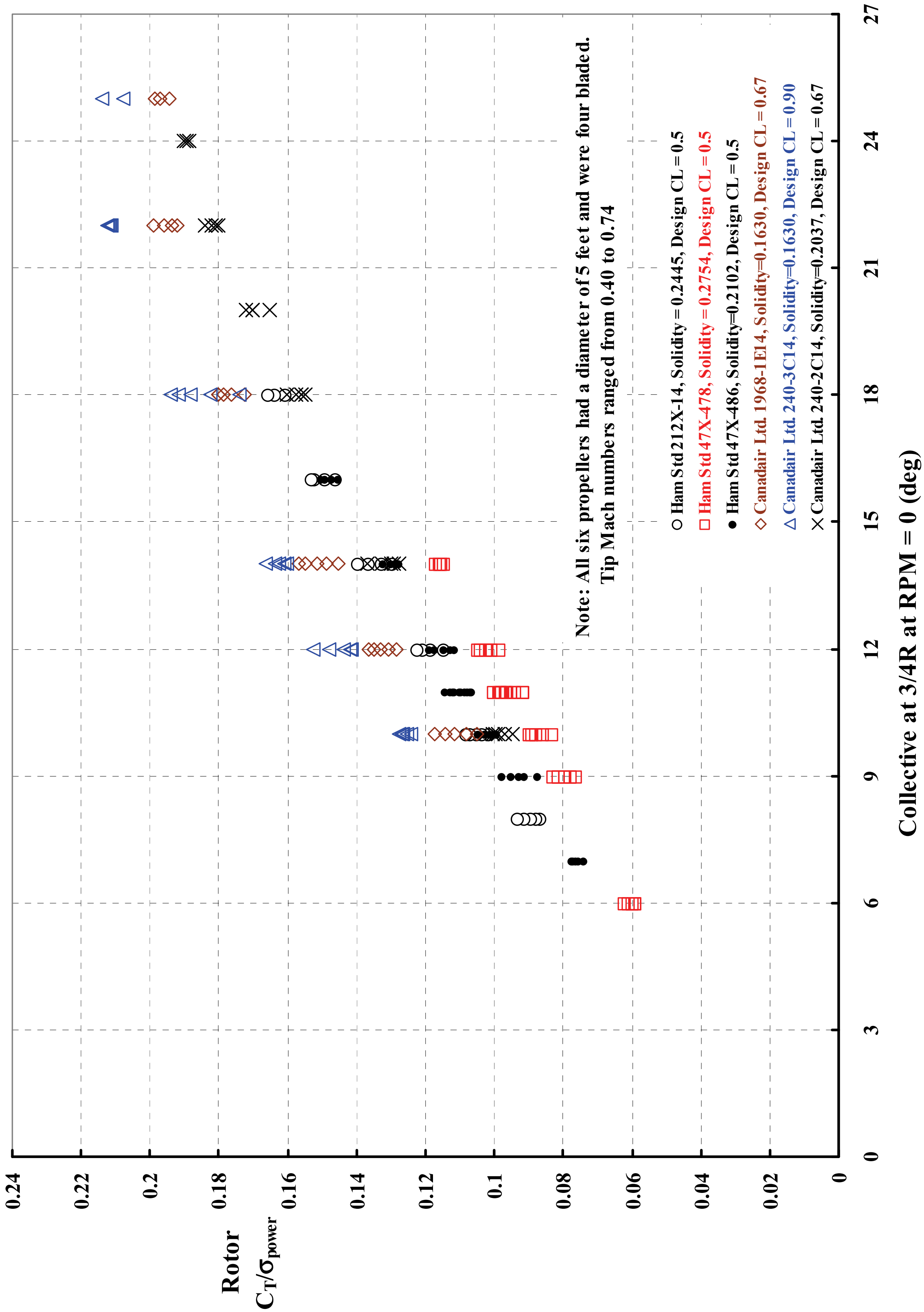

Figure 54. Solidity influences can be removed by plotting C_T/σ_{power} versus collective pitch. However, the actual collective pitch associated with zero thrust seems always in doubt.

CLOSING REMARKS

Available proprotor and propeller experimental performance data obtained in hover conditions confirms that solidity is the major design parameter once diameter and tip Mach number have been decided. A Figure of Merit up to 0.80 at a selected design thrust coefficient appears to be the maximum possible based on the experimental data included in this report. This conclusion is summarized in figures 55 and 56.

Figure 55 collects measured hover performance data, in the standard graphical form of C_P versus C_T, from each of the 16 examples. A maximum Figure of Merit equal to 0.80 (shown with the heavy black line) provides a lower bound to this available data. It appears that for any C_T in the range between 0.0075 to 0.0275, a proprotor/propeller can be found having a Figure of Merit equal to 0.80 (providing the tip Mach number is above 0.40 and below 0.775). These 16 examples show that the current state of isolated proprotor/propeller hover performance technology is quite simply

$$C_P = \frac{C_T^{3/2}}{\sqrt{2}\ \mathrm{FM}} = \frac{C_T^{3/2}}{\sqrt{2}\ (0.80)} = 0.884\, C_T^{3/2}\,.$$

Figure 56 summarizes hover performance with a graph of Figure of Merit versus C_T/σ_{power}. This coordinate form quantifies how severely the onset blade stall degrades hover performance. While not all of the 16 proprotor/propeller examples were tested to the region of maximum lift, it is clear from the configurations in Appendices B, E, and O that a maximum C_T/σ_{power} of 0.21 is obtainable with current technology.

RECOMMENDATIONS

Comparisons of currently available theories to all of the data provided in this report should be made. Comparisons of any given theory to the proprotors and propellers discussed in the primary configuration study must be the goal. This is absolutely required if the practicing engineer is to be convinced that any of several theories are worth using.

However, it is recommended that immediate theory-versus-test comparisons (and correlations and validations) be obtained for:

(a) the example of three versus four blades at equal solidity and twist (data in Appendices F and G)

(b) the example of three different twists holding all other blade properties constant (data in Appendices H, I, and J) and,

(c) the three examples of clearly defined blade stall (data in Appendices B, E, and O) be studied quite thoroughly.

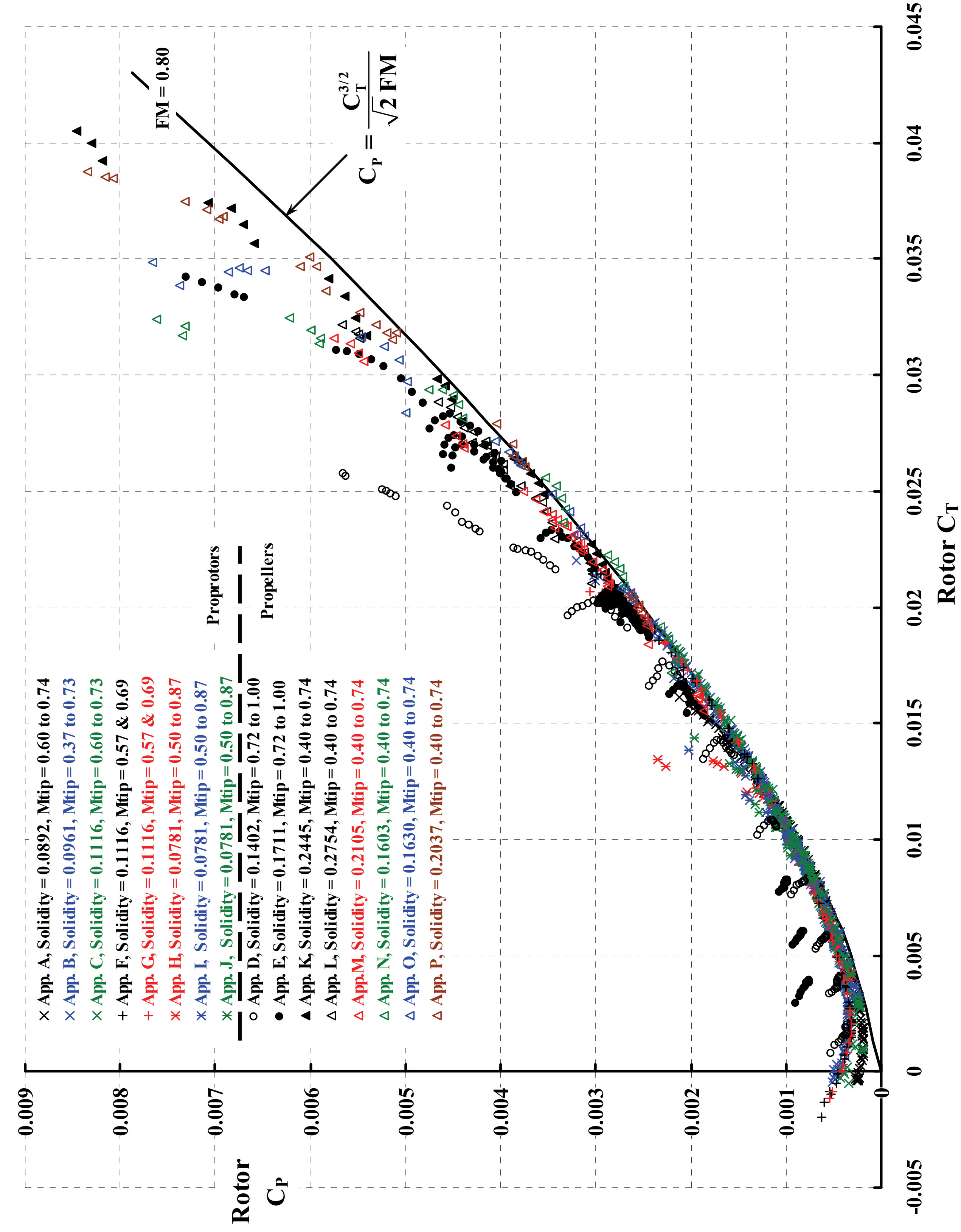

Figure 55. It appears that for any C_T in the range between 0.0075 to 0.0275, a proprotor/propeller can be found having a FM = 0.80 (providing the tip Mach number is above 0.40 and below 0.775).

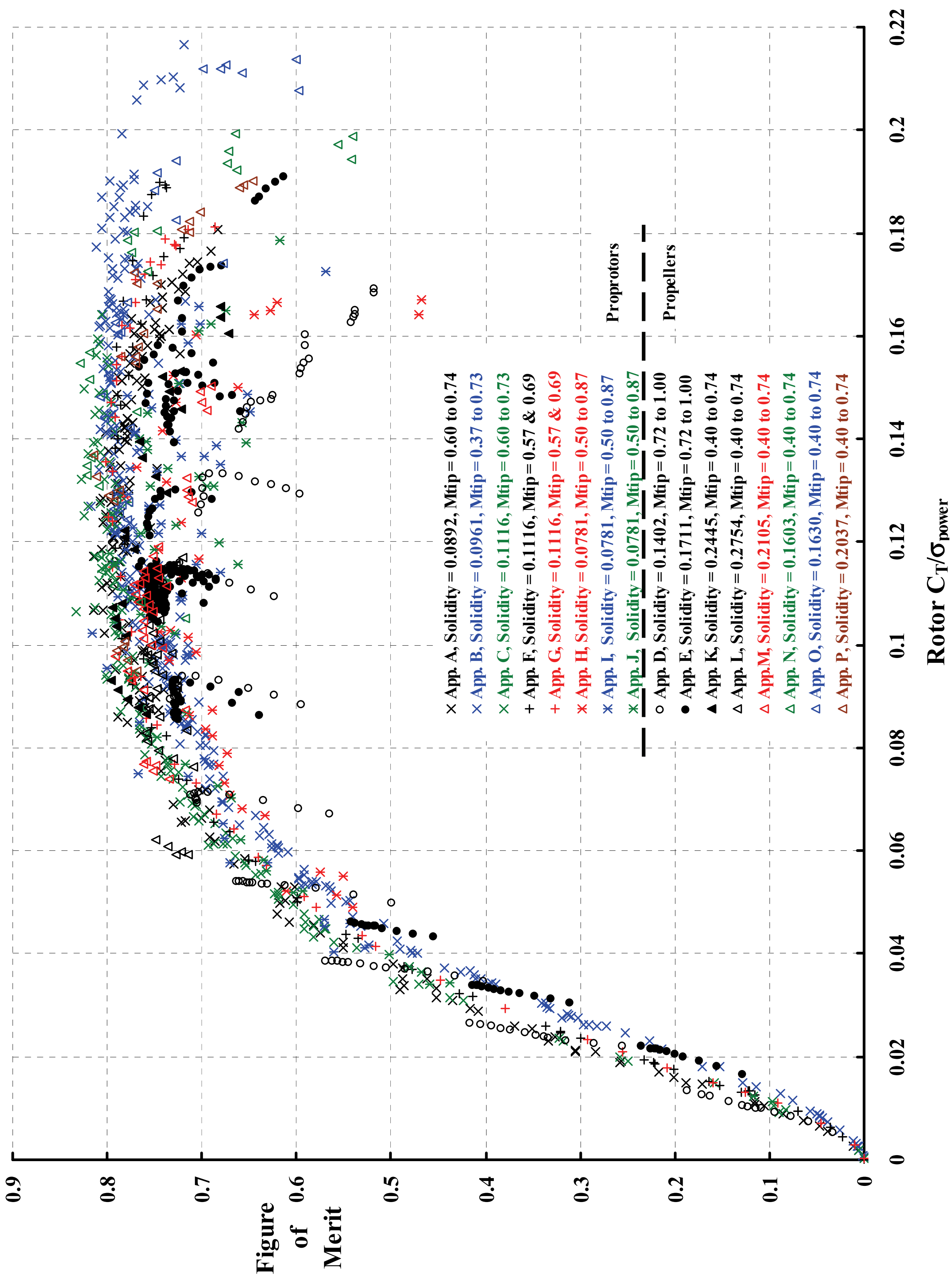

Figure 56. The onset of blade stall degrades hover performance. Appendices B, E, and O configurations show that a maximum C_T/σ_{power} of 0.021 is obtainable with current technology.

Appendix A

XV-15 Metal Blade Proprotor (NASA OARF and WADC Tests)

This appendix contains:

1. Proprotor configuration (table A-1 and figs. A-1 to A-5).
2. Performance data of C_P versus C_T and C_T versus 3/4 radius collective for the NASA OARF test (figs. A-6 and A-7, and table A-2) and for WADC test (figs. A-8 and A-9, and table A-3).

1. Proprotor Configuration

The XV-15 proprotor was well described in reference 3 as follows:

The 25-foot three-bladed proprotor used for these tests is semi-rigid, with the hub gimbal mounted to the mast to provide blade flapping freedom. The all-bonded blades are made with high-strength, heat-treated 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 as is discussed in Subsection III.A.2 of reference 3.

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, 27-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, thereby saving weight and minimizing performance losses.

An elastomeric hub spring is utilized to increase the control and damping moment capability of the proprotor. The hub spring is located in the nonrotating system to eliminate fatigue loading on this component. The spring is attached directly to the top case of the transmission and to the hub yoke through a bearing.

Cyclic control is achieved through a monocyclic (fore and aft) swashplate below the proprotor. A rise-and-fall collective head assembly above the proprotor moves three walking beams thereby providing collective control. Hydraulic actuators position the cyclic and collective controls. The servo valves of the 1500-psi hydraulic actuators were positioned by a 28-volt electromechanical actuator to provide remote control for these tests. In the event of hydraulic pressure loss, the electric actuator provided a mechanical backup to carry the control loads until the tunnel could be shut down.

Table A–1. Summary of Full-Scale XV-15 Proprotor Geometry

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 (C_L Mast)	NACA 64-935 a = 0.3	
Tip	NACA 64-208 a = 0.3	
Blade Twist (See Figure IV-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)
Helicopter	740	565
Conversion	700	534
Airplane	600	458

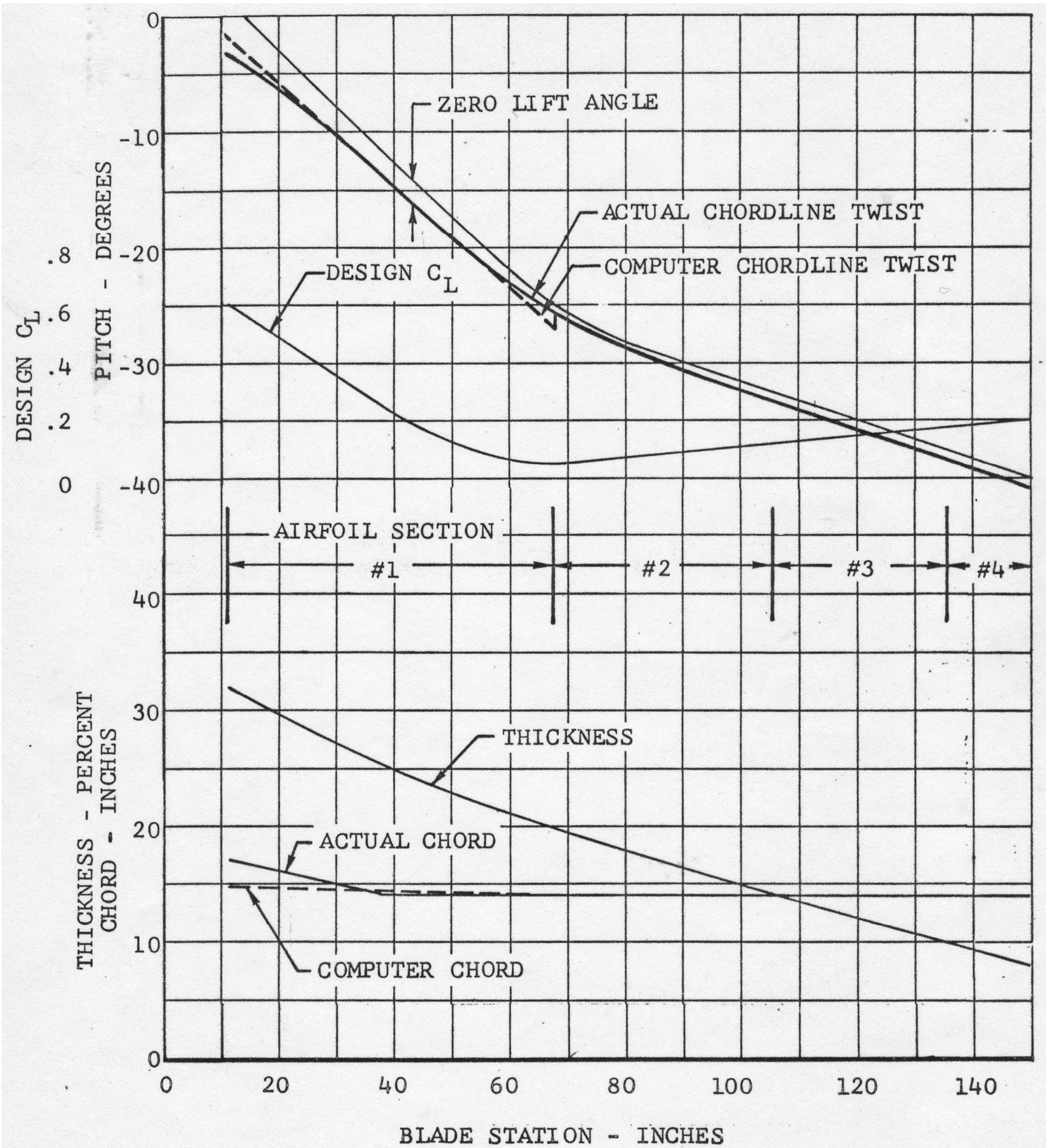

Figure A-1. XV-15 blade geometry. Note: The airfoil sections numbered 1 through 4 only define which airfoil tables of C_d versus C_l for several Mach numbers were used in the theory calculations shown in reference 3.

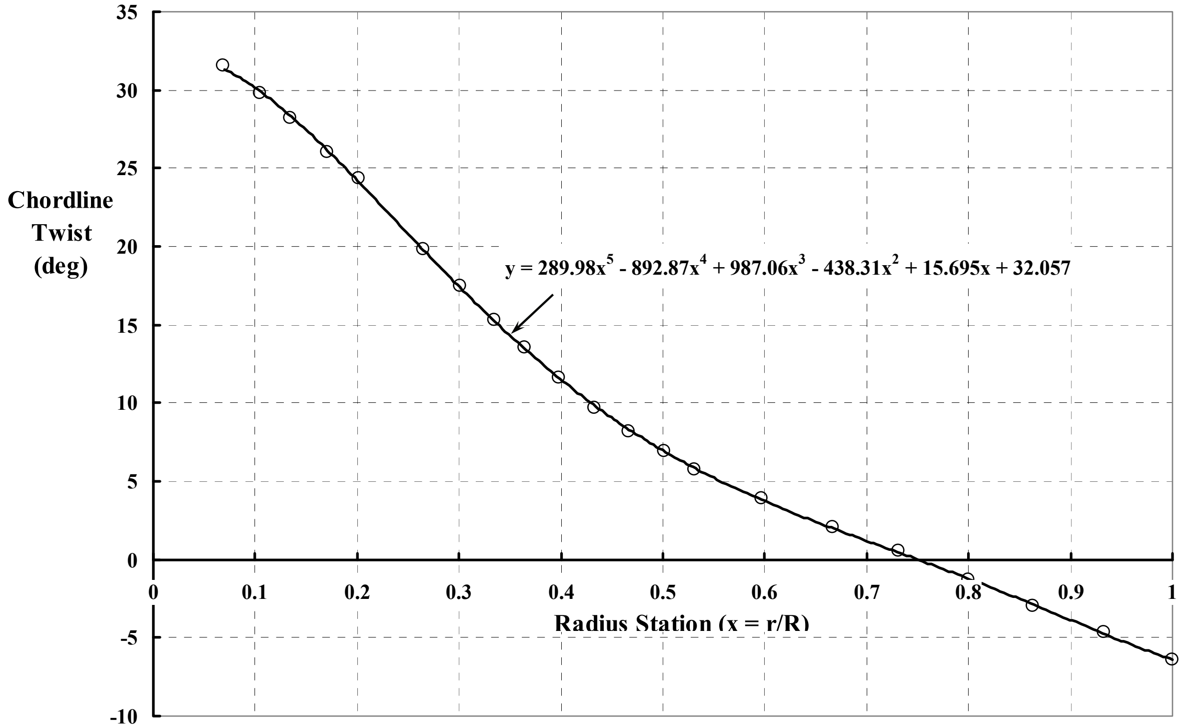

Figure A-2. XV-15 metal-bladed proprotor—twist vs. radius station.

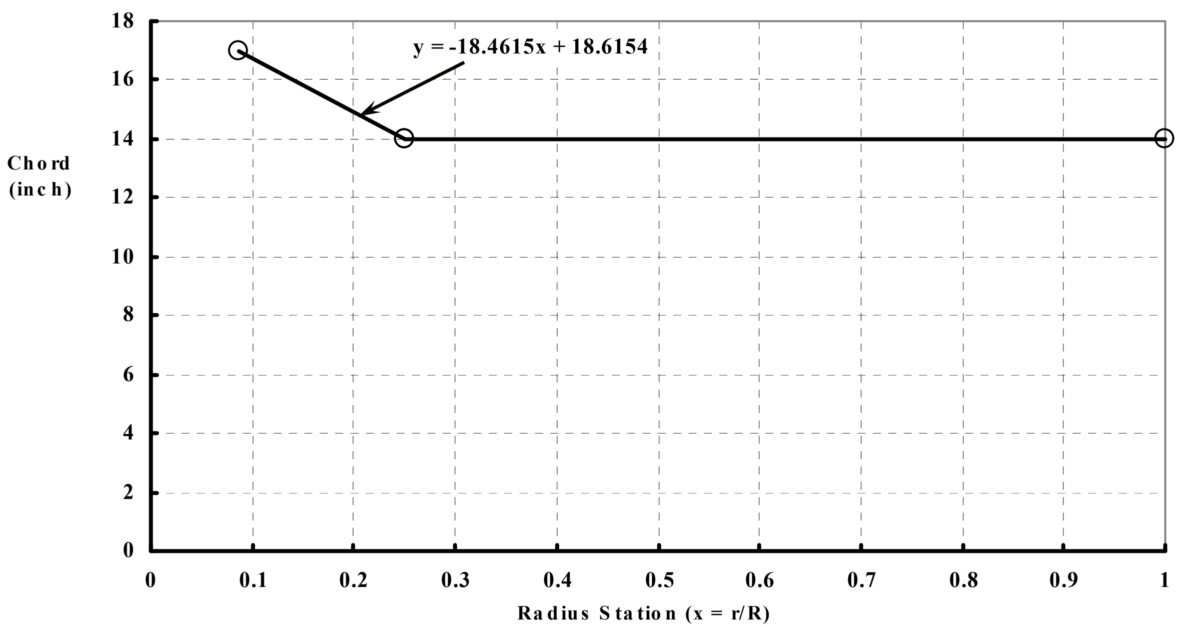

Figure A-3. XV-15 metal-bladed proprotor—chord vs. radius station.

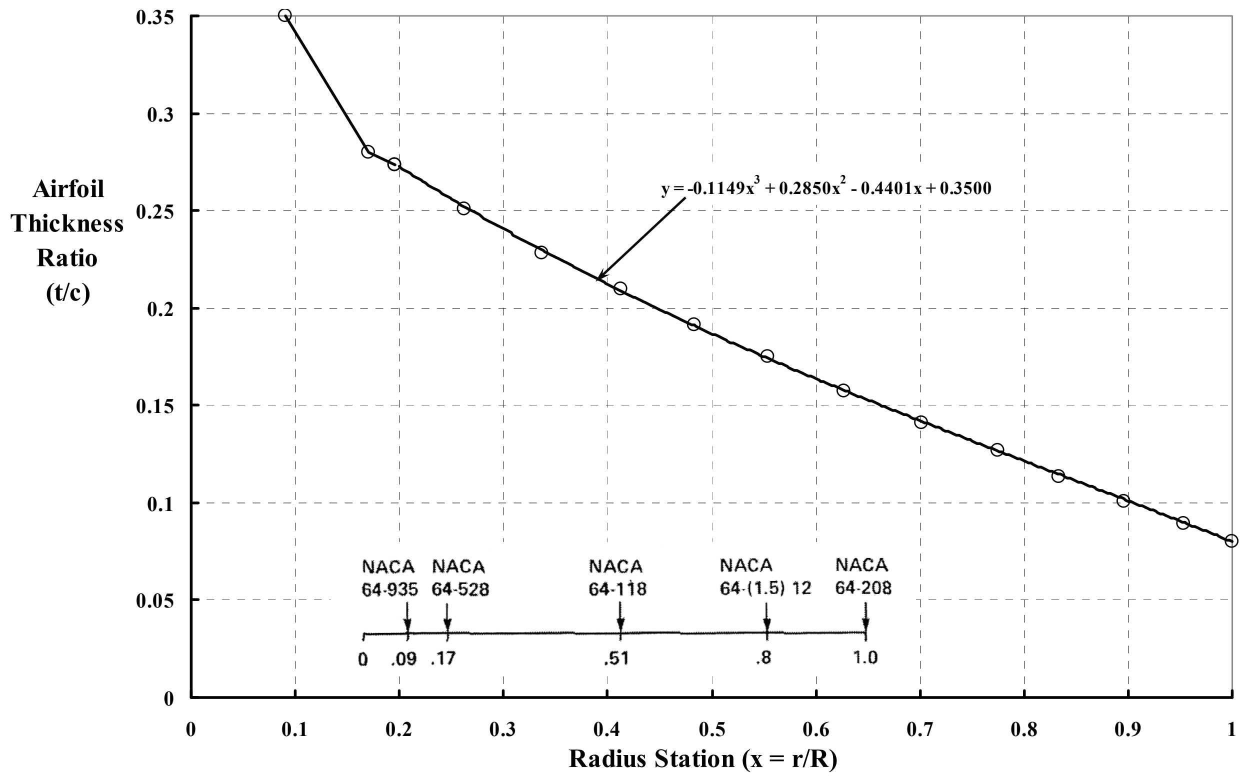

Figure A-4. XV-15 metal-bladed proprotor—airfoil thickness ratio vs. radius station.

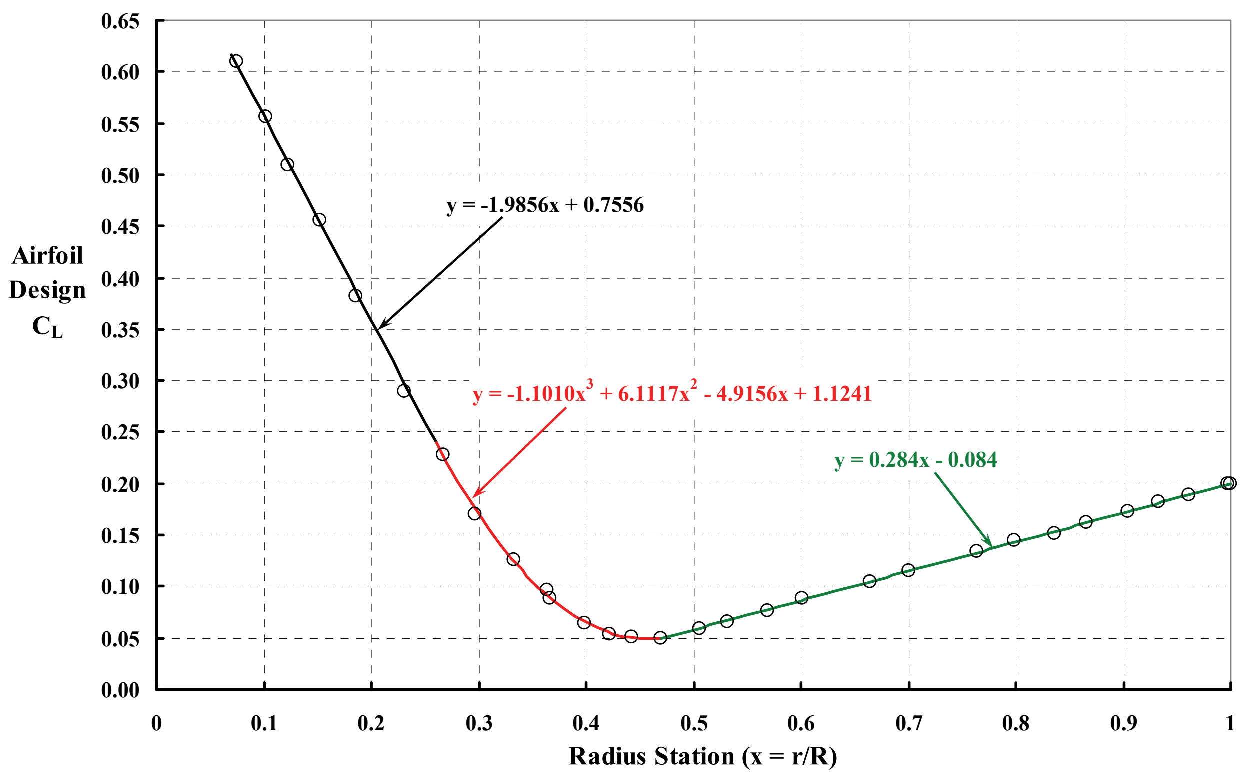

Figure A-5. XV-15 metal-bladed proprotor—airfoil design C_L vs. radius station.

2. Performance Data

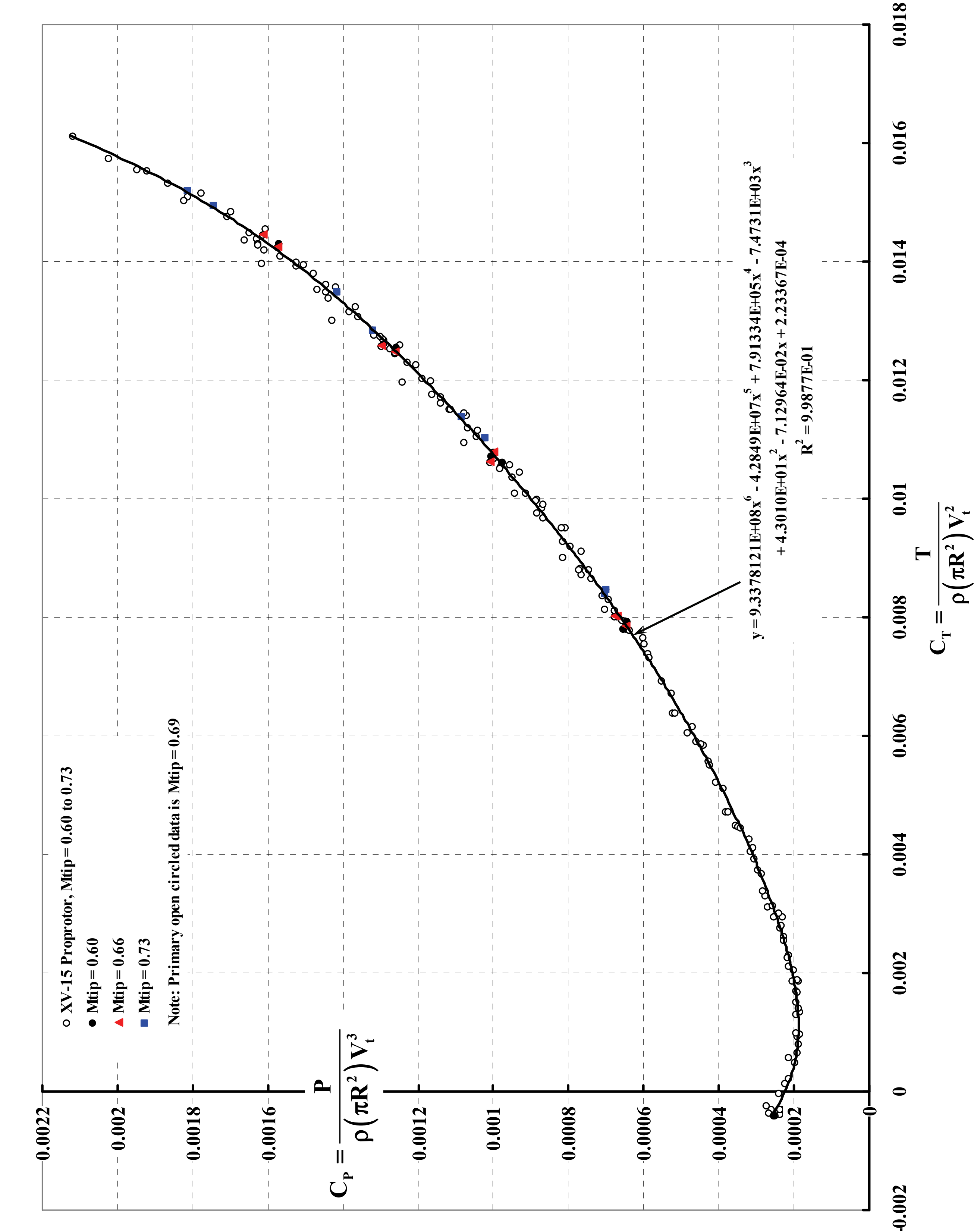

Figure A-6. XV-15 metal-bladed proprotor test results from the OARF.

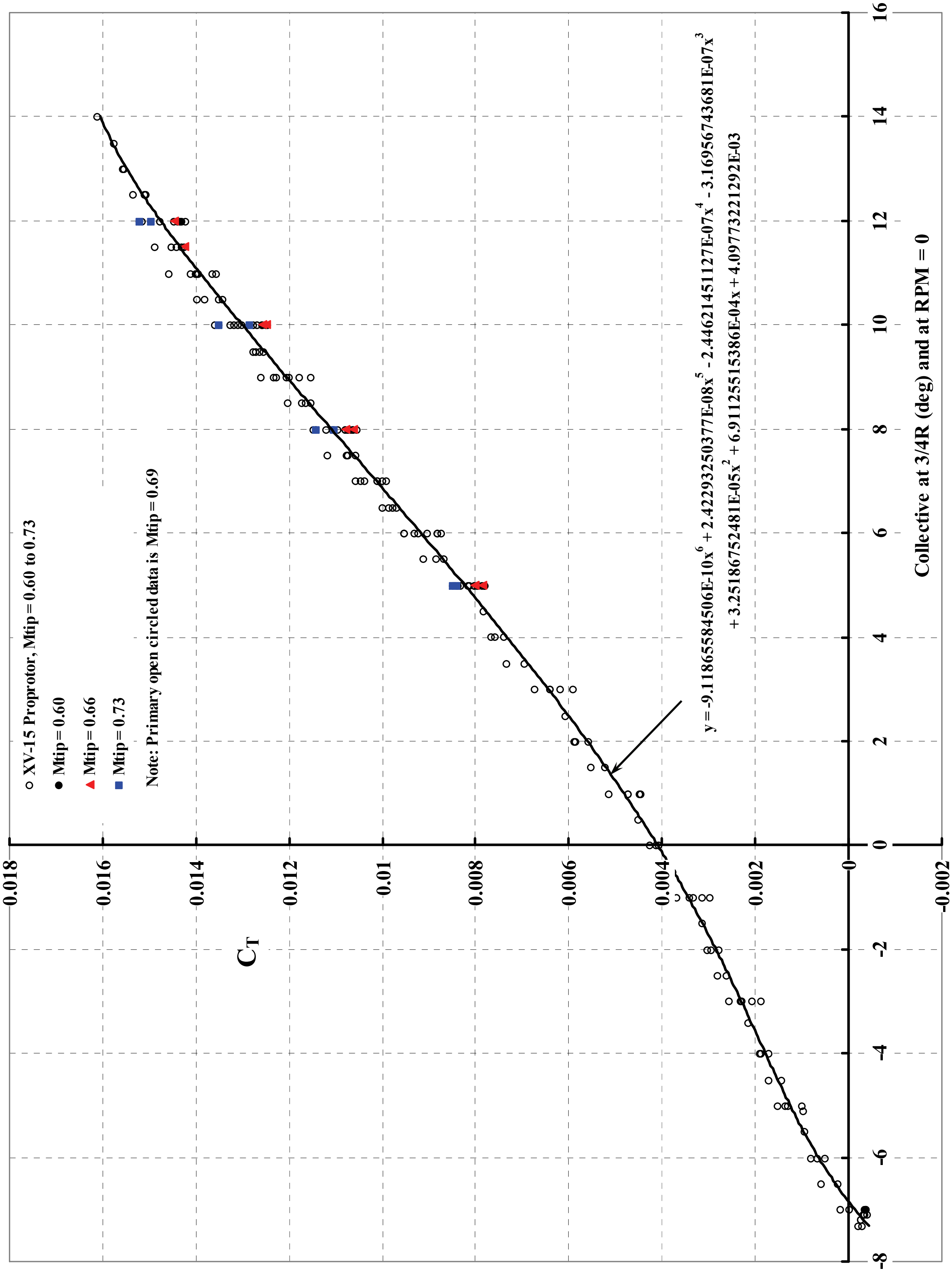

Figure A-7. XV-15 proprotor—thrust coefficient vs. collective pitch.

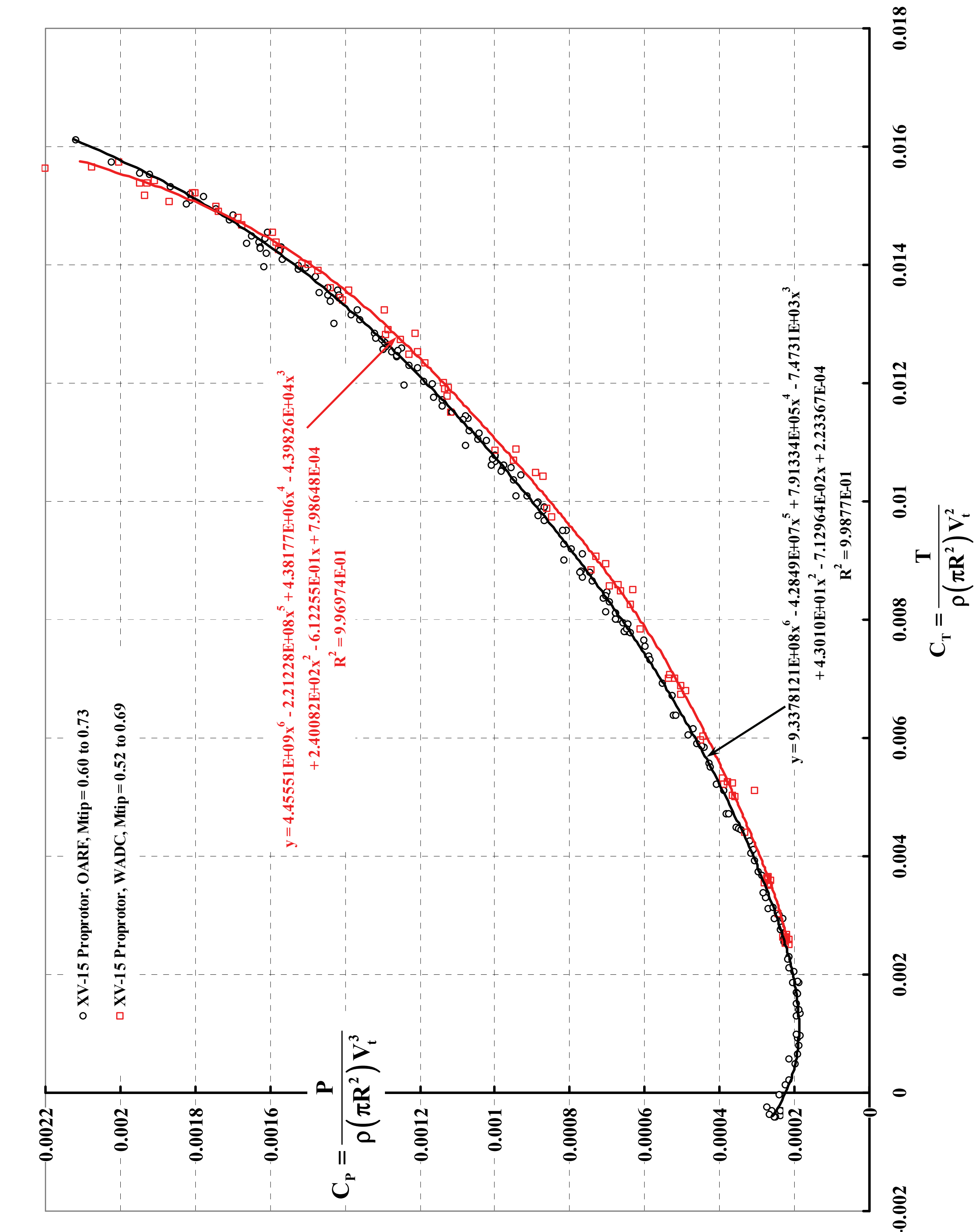

Figure A-8. XV-15 proprotor test results from the OARF and at WADC.

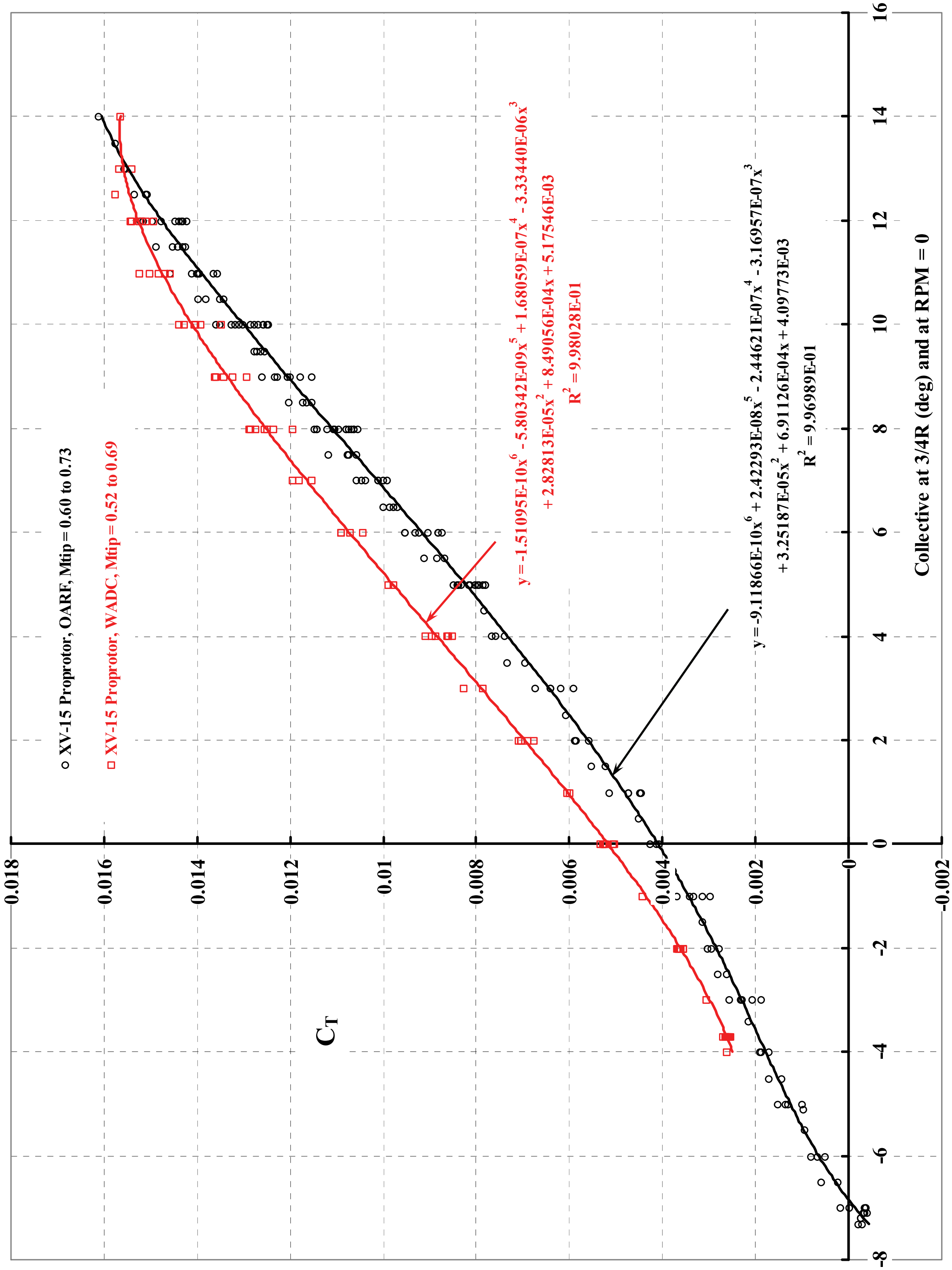

Figure A-9. XV-15 proprotor test results from the OARF and at WADC show that thrust vs. collective pitch trends are quite similar.

Table A–2. XV-15 Metal-Blade Proprotor Test Results From the OARF

RUN	Point	Vtip (fps)	M tip	Coll.	CT	CP	Ideal CP	FM	CT/CP
14	15	769.4	0.6922	-7.00	-0.000027	0.000241	0.000000	0.0004	-0.11
14	16	769.4	0.6922	-5.00	0.001344	0.000185	0.000035	0.1883	7.26
14	17	769.4	0.6922	-3.00	0.002319	0.000214	0.000079	0.3690	10.84
14	18	769.4	0.6921	-1.00	0.003320	0.000277	0.000135	0.4883	11.99
14	19	769.4	0.6917	1.00	0.004732	0.000382	0.000230	0.6025	12.39
14	20	769.0	0.6914	3.00	0.006405	0.000521	0.000362	0.6957	12.29
14	21	769.0	0.6911	5.00	0.008148	0.000703	0.000520	0.7398	11.59
14	22	768.7	0.6911	6.00	0.009022	0.000815	0.000606	0.7435	11.07
14	23	768.7	0.6907	7.00	0.010095	0.000942	0.000717	0.7614	10.72
14	24	768.4	0.6904	8.00	0.010960	0.001076	0.000811	0.7540	10.19
14	25	768.4	0.6903	9.00	0.011985	0.001242	0.000928	0.7470	9.65
14	26	768.0	0.6899	10.00	0.013014	0.001427	0.001050	0.7357	9.12
14	27	767.7	0.6896	11.00	0.013978	0.001615	0.001169	0.7236	8.66
15	3	769.0	0.6907	-7.10	-0.000332	0.000246	0.000004	0.0174	-1.35
15	4	769.0	0.6907	-6.00	0.000491	0.000198	0.000008	0.0389	2.48
15	5	769.0	0.6907	-4.00	0.001698	0.000193	0.000049	0.2564	8.80
15	6	769.0	0.6907	-2.00	0.002772	0.000237	0.000103	0.4354	11.70
15	7	769.0	0.6905	0.00	0.004063	0.000315	0.000183	0.5814	12.90
15	8	768.7	0.6904	2.00	0.005581	0.000426	0.000295	0.6921	13.10
15	9	768.4	0.6902	4.00	0.007391	0.000588	0.000449	0.7641	12.57
15	10	768.4	0.6901	6.00	0.009208	0.000796	0.000625	0.7849	11.57
15	11	768.4	0.6899	7.00	0.010104	0.000913	0.000718	0.7866	11.07
15	12	768.4	0.6898	8.00	0.011063	0.001044	0.000823	0.7881	10.60
15	13	768.0	0.6896	9.00	0.012035	0.001188	0.000934	0.7858	10.13
15	14	768.0	0.6894	10.00	0.013089	0.001358	0.001059	0.7797	9.64
15	15	767.7	0.6893	11.00	0.013929	0.001523	0.001162	0.7632	9.15
15	16	769.0	0.6903	-7.10	-0.000347	0.000248	0.000005	0.0184	-1.40
15	17	769.0	0.6903	-6.50	0.000225	0.000213	0.000002	0.0112	1.06
15	18	769.0	0.6903	-4.50	0.001421	0.000188	0.000038	0.2015	7.56
15	19	769.0	0.6903	-2.50	0.002621	0.000228	0.000095	0.4162	11.50
15	20	769.0	0.6900	-0.50	0.003760	0.000296	0.000163	0.5508	12.70
15	21	769.7	0.6906	1.50	0.005228	0.000408	0.000267	0.6551	12.81
15	22	769.4	0.6904	3.50	0.006935	0.000553	0.000408	0.7385	12.54
15	23	769.4	0.6901	5.50	0.008667	0.000740	0.000571	0.7710	11.71
15	24	769.0	0.6899	6.50	0.009683	0.000868	0.000674	0.7762	11.16
15	25	769.0	0.6899	7.50	0.010562	0.000980	0.000768	0.7832	10.78
15	26	769.0	0.6898	8.50	0.011526	0.001117	0.000875	0.7833	10.32
15	27	768.7	0.6896	9.50	0.012538	0.001274	0.000993	0.7792	9.84
15	28	768.4	0.6894	10.50	0.013507	0.001444	0.001110	0.7687	9.35
15	29	768.4	0.6893	11.50	0.014393	0.001628	0.001221	0.7500	8.84
15	30	768.0	0.6890	12.50	0.015101	0.001812	0.001312	0.7242	8.33
15	31	767.7	0.6887	13.50	0.015746	0.002022	0.001397	0.6910	7.79
15	32	769.7	0.6904	-7.20	-0.000283	0.000261	0.000003	0.0129	-1.08
15	33	769.7	0.6904	-7.00	-0.000373	0.000236	0.000005	0.0216	-1.58
15	34	769.7	0.6905	-5.00	0.001303	0.000195	0.000033	0.1706	6.68
15	35	769.7	0.6905	-3.00	0.002273	0.000218	0.000077	0.3515	10.43

RUN	Point	Vtip (fps)	M tip	Coll.	CT	CP	Ideal CP	FM	CT/CP
15	36	769.7	0.6904	-1.00	0.003392	0.000281	0.000140	0.4971	12.07
15	37	769.4	0.6904	1.00	0.004735	0.000374	0.000230	0.6160	12.66
15	38	769.4	0.6902	3.00	0.006404	0.000515	0.000362	0.7036	12.43
15	39	769.4	0.6899	5.00	0.008373	0.000710	0.000542	0.7630	11.79
15	40	769.4	0.6898	6.00	0.009291	0.000815	0.000633	0.7770	11.40
15	41	769.0	0.6896	7.00	0.010370	0.000949	0.000747	0.7868	10.93
15	42	768.7	0.6896	8.00	0.011203	0.001066	0.000838	0.7866	10.51
15	43	768.7	0.6893	9.00	0.012309	0.001227	0.000966	0.7870	10.03
15	44	768.4	0.6892	10.00	0.013177	0.001382	0.001070	0.7739	9.53
15	45	771.0	0.6912	11.00	0.014106	0.001565	0.001185	0.7570	9.01
15	46	772.3	0.6923	-7.30	-0.000220	0.000271	0.000002	0.0085	-0.81
15	47	772.3	0.6925	-5.50	0.000935	0.000191	0.000020	0.1058	4.90
15	48	770.3	0.6909	-3.40	0.002131	0.000213	0.000070	0.3266	10.00
15	49	770.3	0.6908	-1.50	0.003133	0.000268	0.000124	0.4627	11.69
15	50	770.3	0.6908	0.50	0.004507	0.000356	0.000214	0.6010	12.66
15	51	770.3	0.6907	2.50	0.006060	0.000482	0.000334	0.6921	12.57
15	52	770.0	0.6905	4.50	0.007821	0.000648	0.000489	0.7548	12.07
15	53	770.0	0.6904	5.50	0.008827	0.000768	0.000586	0.7636	11.49
15	54	769.7	0.6903	6.50	0.009772	0.000883	0.000683	0.7736	11.07
15	55	769.7	0.6902	7.50	0.010722	0.001003	0.000785	0.7827	10.69
15	56	769.4	0.6900	8.50	0.011628	0.001141	0.000887	0.7771	10.19
15	57	769.4	0.6900	9.50	0.012629	0.001289	0.001004	0.7785	9.80
15	58	769.0	0.6899	10.50	0.013406	0.001438	0.001098	0.7633	9.32
15	59	769.0	0.6899	11.50	0.014310	0.001627	0.001210	0.7440	8.80
15	60	768.7	0.6897	12.50	0.015052	0.001821	0.001306	0.7171	8.27
16	3	669.3	0.5997	-7.00	-0.000388	0.000253	0.000005	0.0214	-1.53
16	4	669.0	0.5993	5.00	0.007934	0.000643	0.000500	0.7772	12.34
16	5	668.6	0.5990	8.00	0.010633	0.000976	0.000775	0.7944	10.89
16	6	668.6	0.5988	10.00	0.012563	0.001257	0.000996	0.7921	9.99
16	7	668.3	0.5982	12.00	0.014320	0.001571	0.001212	0.7713	9.12
16	8	741.1	0.6632	5.00	0.007847	0.000646	0.000492	0.7609	12.15
16	9	740.8	0.6632	8.00	0.010786	0.000998	0.000792	0.7937	10.81
16	10	740.5	0.6627	10.00	0.012478	0.001262	0.000986	0.7810	9.89
16	11	740.2	0.6624	12.00	0.014453	0.001611	0.001229	0.7627	8.97
16	12	771.7	0.6906	5.00	0.008135	0.000677	0.000519	0.7664	12.02
16	13	771.3	0.6903	8.00	0.010794	0.000999	0.000793	0.7938	10.80
16	14	771.0	0.6899	10.00	0.012684	0.001292	0.001010	0.7818	9.82
16	15	770.7	0.6896	12.00	0.014283	0.001625	0.001207	0.7428	8.79
16	16	818.6	0.7322	5.00	0.008485	0.000698	0.000553	0.7918	12.16
16	17	817.9	0.7316	8.00	0.011038	0.001020	0.000820	0.8039	10.82
16	18	817.6	0.7311	10.00	0.012846	0.001321	0.001030	0.7794	9.72
16	19	816.9	0.7306	12.00	0.014962	0.001744	0.001294	0.7420	8.58
22	4	763.8	0.6917	-7.20	-0.000285	0.000234	0.000003	0.0145	-1.22
22	5	763.8	0.6915	-6.00	0.000667	0.000190	0.000012	0.0641	3.51
22	6	763.8	0.6915	-4.00	0.001875	0.000188	0.000057	0.3054	9.97
22	7	763.5	0.6914	-2.00	0.002951	0.000231	0.000113	0.4907	12.77
22	8	763.5	0.6914	0.00	0.004128	0.000309	0.000188	0.6069	13.36

RUN	Point	Vtip (fps)	M tip	Coll.	CT	CP	Ideal CP	FM	CT/CP
22	9	763.5	0.6911	2.00	0.005855	0.000439	0.000317	0.7216	13.34
22	10	763.1	0.6909	4.00	0.007572	0.000598	0.000466	0.7791	12.66
22	11	763.1	0.6907	6.00	0.009528	0.000807	0.000658	0.8149	11.81
22	12	762.8	0.6906	7.00	0.010466	0.000930	0.000757	0.8141	11.25
22	13	762.8	0.6905	8.00	0.011426	0.001069	0.000864	0.8079	10.69
22	14	762.8	0.6902	9.00	0.012277	0.001204	0.000962	0.7989	10.20
22	15	762.5	0.6900	10.00	0.013258	0.001365	0.001079	0.7908	9.71
22	16	762.1	0.6899	11.00	0.014005	0.001524	0.001172	0.7690	9.19
22	17	762.1	0.6896	12.00	0.014761	0.001709	0.001268	0.7420	8.64
22	18	761.8	0.6894	13.00	0.015544	0.001921	0.001370	0.7133	8.09
22	19	761.5	0.6891	14.00	0.016116	0.002119	0.001447	0.6827	7.61
23	3	765.1	0.6909	-7.30	-0.000297	0.000237	0.000004	0.0153	-1.25
23	4	765.1	0.6909	-6.00	0.000805	0.000188	0.000016	0.0859	4.28
23	5	764.8	0.6908	-4.00	0.001903	0.000192	0.000059	0.3057	9.91
23	6	764.8	0.6908	-2.00	0.003016	0.000241	0.000117	0.4860	12.51
23	7	764.8	0.6905	0.00	0.004262	0.000317	0.000197	0.6206	13.44
23	8	764.8	0.6903	2.00	0.005884	0.000445	0.000319	0.7172	13.22
23	9	764.4	0.6900	4.00	0.007670	0.000602	0.000475	0.7890	12.74
23	10	764.1	0.6899	6.00	0.009529	0.000817	0.000658	0.8051	11.66
23	11	764.1	0.6897	7.00	0.010578	0.000954	0.000769	0.8064	11.09
23	12	764.1	0.6896	8.00	0.011458	0.001078	0.000867	0.8045	10.63
23	13	763.8	0.6893	9.00	0.012604	0.001248	0.001001	0.8017	10.10
23	14	763.5	0.6891	10.00	0.013577	0.001418	0.001119	0.7889	9.57
23	15	763.5	0.6890	11.00	0.014569	0.001607	0.001243	0.7738	9.07
23	16	763.1	0.6887	12.00	0.015160	0.001775	0.001320	0.7436	8.54
23	17	763.1	0.6885	13.00	0.015565	0.001947	0.001373	0.7052	7.99
23	18	764.8	0.6900	-7.00	0.000154	0.000224	0.000001	0.0060	0.69
23	19	764.8	0.6900	-5.00	0.001523	0.000194	0.000042	0.2166	7.85
23	20	764.8	0.6899	-3.00	0.002563	0.000225	0.000092	0.4078	11.39
23	21	764.8	0.6898	-1.00	0.003683	0.000287	0.000158	0.5507	12.83
23	22	764.4	0.6897	1.00	0.005124	0.000389	0.000259	0.6667	13.17
23	23	764.4	0.6896	3.00	0.006733	0.000526	0.000391	0.7427	12.80
23	25	764.1	0.6894	5.00	0.008320	0.000694	0.000537	0.7732	11.99
23	26	764.1	0.6892	6.50	0.009861	0.000871	0.000692	0.7950	11.32
23	27	763.8	0.6890	7.50	0.010767	0.000997	0.000790	0.7924	10.80
23	28	763.8	0.6889	8.50	0.011731	0.001140	0.000898	0.7881	10.29
23	29	763.8	0.6887	9.50	0.012702	0.001294	0.001012	0.7823	9.82
23	30	763.5	0.6885	10.50	0.013805	0.001479	0.001147	0.7755	9.33
23	31	763.5	0.6883	11.50	0.014503	0.001649	0.001235	0.7489	8.80
23	32	764.8	0.6893	-6.50	0.000586	0.000215	0.000010	0.0467	2.73
23	33	764.8	0.6893	-4.50	0.001692	0.000191	0.000049	0.2577	8.86
23	34	764.8	0.6891	-2.50	0.002811	0.000233	0.000105	0.4523	12.06
23	35	764.1	0.6891	-0.50	0.003938	0.000304	0.000175	0.5748	12.95
23	36	764.1	0.6890	1.50	0.005521	0.000423	0.000290	0.6858	13.05
23	37	764.4	0.6888	3.50	0.007330	0.000585	0.000444	0.7586	12.53
23	38	764.1	0.6886	5.50	0.009116	0.000766	0.000615	0.8035	11.90
23	39	764.1	0.6885	6.50	0.009998	0.000884	0.000707	0.7997	11.31
23	40	763.8	0.6883	7.50	0.011173	0.001041	0.000835	0.8022	10.73

RUN	Point	Vtip (fps)	M tip	Coll.	CT	CP	Ideal CP	FM	CT/CP
23	41	763.8	0.6882	8.50	0.012010	0.001167	0.000931	0.7975	10.29
23	42	763.8	0.6880	9.50	0.012752	0.001300	0.001018	0.7833	9.81
23	43	763.5	0.6878	10.50	0.013965	0.001505	0.001167	0.7754	9.28
23	44	763.1	0.6875	11.50	0.014860	0.001697	0.001281	0.7548	8.76
23	45	763.1	0.6873	12.50	0.015343	0.001866	0.001344	0.7202	8.22
24	3	816.9	0.7325	5.00	0.008407	0.000702	0.000545	0.7764	11.98
24	4	816.6	0.7318	8.00	0.011405	0.001082	0.000861	0.7960	10.54
24	5	816.3	0.7319	10.00	0.013505	0.001414	0.001110	0.7848	9.55
24	6	815.6	0.7313	12.00	0.015210	0.001814	0.001326	0.7312	8.38
24	10	669.3	0.5997	5.00	0.007803	0.000653	0.000487	0.7464	11.95
24	11	669.0	0.5995	8.00	0.010732	0.001005	0.000786	0.7822	10.68
24	13	692.9	0.6207	5.00	0.008021	0.000669	0.000508	0.7593	11.99
24	14	725.1	0.6497	5.00	0.008014	0.000677	0.000507	0.7493	11.84
24	15	724.7	0.6497	8.00	0.010631	0.001007	0.000775	0.7697	10.56
24	16	724.4	0.6492	10.00	0.012578	0.001296	0.000997	0.7697	9.71
24	17	724.1	0.6492	11.50	0.014242	0.001573	0.001202	0.7640	9.05
24	18	770.7	0.6906	10.00	0.012764	0.001318	0.001020	0.7737	9.68
24	19	770.7	0.6906	11.00	0.013549	0.001468	0.001115	0.7597	9.23
24	20	770.3	0.6905	12.00	0.014385	0.001662	0.001220	0.7340	8.66
25	10	767.7	0.6906	-7.10	-0.000402	0.000248	0.000006	0.0230	-1.62
25	11	767.7	0.6906	-5.10	0.000970	0.000184	0.000021	0.1161	5.27
25	12	767.4	0.6903	-3.00	0.002068	0.000199	0.000066	0.3342	10.39
25	13	767.4	0.6902	-1.00	0.003140	0.000255	0.000124	0.4879	12.31
25	14	767.4	0.6901	1.00	0.004486	0.000347	0.000212	0.6123	12.93
25	15	767.1	0.6900	3.00	0.005913	0.000459	0.000322	0.7005	12.88
25	16	767.1	0.6898	5.00	0.007960	0.000656	0.000502	0.7655	12.13
25	17	767.1	0.6897	6.00	0.008731	0.000766	0.000577	0.7531	11.40
25	18	767.1	0.6897	6.00	0.008820	0.000771	0.000586	0.7597	11.44
25	19	766.7	0.6896	7.00	0.009986	0.000888	0.000706	0.7946	11.25
25	20	766.7	0.6895	8.00	0.010530	0.000982	0.000764	0.7781	10.72
25	21	766.4	0.6893	9.00	0.011772	0.001163	0.000903	0.7766	10.12
25	22	766.4	0.6892	10.00	0.012455	0.001262	0.000983	0.7788	9.87
25	23	768.4	0.6901	11.00	0.013628	0.001446	0.001125	0.7780	9.42
25	24	758.2	0.6900	12.00	0.014217	0.001610	0.001199	0.7445	8.83
26	6	767.7	0.6885	-7.00	-0.000352	0.000266	0.000005	0.0176	-1.32
26	7	767.7	0.6886	-5.00	0.000996	0.000193	0.000022	0.1152	5.16
26	8	767.7	0.6885	-3.00	0.001881	0.000203	0.000058	0.2842	9.27
26	9	767.7	0.6884	-1.00	0.002962	0.000252	0.000114	0.4523	11.75
26	10	767.4	0.6883	1.00	0.004453	0.000340	0.000210	0.6180	13.10
26	11	767.4	0.6882	3.00	0.006162	0.000469	0.000342	0.7296	13.14
26	12	767.1	0.6881	5.00	0.007800	0.000638	0.000487	0.7635	12.23
26	13	767.1	0.6880	6.00	0.008819	0.000746	0.000586	0.7850	11.82
26	14	767.1	0.6878	7.00	0.009912	0.000866	0.000698	0.8058	11.45
26	15	766.7	0.6877	8.00	0.010684	0.000999	0.000781	0.7817	10.69
26	16	766.7	0.6876	9.00	0.011516	0.001112	0.000874	0.7858	10.36

Table A–3. XV-15 Metal-Blade Proprotor Test Results at WADC

RUN	Point	V tip (fps)	M tip	Coll.	CT	CP	Ideal CP	FM	CT/CP
Check Out	4	523.6	0.4650	-2.0	0.002622	0.000220	0.000095	0.4316	11.92
Check Out	5	595.6	0.5289	-2.0	0.002644	0.000219	0.000096	0.4400	12.10
Check Out	6	595.6	0.5289	-2.0	0.003531	0.000265	0.000148	0.5590	13.30
Check Out	7	595.6	0.5289	0.0	0.005120	0.000306	0.000259	0.8478	16.76
Check Out	8	596.9	0.5301	2.0	0.006812	0.000490	0.000398	0.8119	13.91
Check Out	9	596.9	0.5301	4.0	0.008526	0.000629	0.000557	0.8848	13.55
Check Out	10	595.6	0.5289	6.0	0.010493	0.000890	0.000760	0.8542	11.79
Check Out	11	595.6	0.5289	8.0	0.012019	0.001135	0.000932	0.8209	10.59
1	1	596.9	0.5301	-3.7	0.002520	0.000215	0.000089	0.4162	11.73
1	2	596.9	0.5301	-2.0	0.003539	0.000268	0.000149	0.5554	13.20
1	3	598.2	0.5312	0.0	0.005020	0.000359	0.000252	0.7010	13.99
1	4	595.6	0.5289	2.0	0.006890	0.000502	0.000404	0.8059	13.73
1	5	599.5	0.5324	4.0	0.008604	0.000671	0.000564	0.8407	12.82
1	6	600.8	0.5336	6.0	0.010432	0.000869	0.000753	0.8671	12.01
1	7	598.2	0.5312	8.0	0.011924	0.001131	0.000921	0.8138	10.54
1	8	596.9	0.5301	9.0	0.012921	0.001285	0.001039	0.8083	10.06
1	9	595.6	0.5289	10.0	0.013464	0.001412	0.001105	0.7825	9.54
1	10	595.6	0.5289	11.0	0.014560	0.001592	0.001242	0.7802	9.14
1	11	599.5	0.5324	12.0	0.014923	0.001736	0.001289	0.7425	8.60
1	12	600.8	0.5336	13.0	0.015397	0.001929	0.001351	0.7003	7.98
1	13	598.2	0.5312	14.0	0.015642	0.002201	0.001383	0.6285	7.11
2	1	700.3	0.6219	-3.7	0.002608	0.000214	0.000094	0.4400	12.19
2	2	699.0	0.6207	-2.0	0.003608	0.000262	0.000153	0.5847	13.77
2	3	700.3	0.6219	0.0	0.005253	0.000365	0.000269	0.7376	14.39
2	4	697.7	0.6196	2.0	0.006747	0.000504	0.000392	0.7782	13.40
2	5	700.3	0.6219	4.0	0.008494	0.000664	0.000554	0.8338	12.79
2	6	699.0	0.6207	6.0	0.010897	0.000942	0.000804	0.8536	11.56
2	7	701.6	0.6231	8.0	0.012537	0.001205	0.000993	0.8240	10.41
2	8	701.6	0.6231	9.0	0.013240	0.001295	0.001077	0.8321	10.23
2	9	701.6	0.6231	10.0	0.014012	0.001497	0.001173	0.7838	9.36
2	10	702.9	0.6242	11.0	0.014694	0.001674	0.001259	0.7524	8.78
2	11	699.0	0.6207	12.0	0.015178	0.001936	0.001322	0.6832	7.84
2	12	702.9	0.6242	13.0	0.015673	0.002076	0.001387	0.6685	7.55
3	1	739.6	0.6624	-3.7	0.002680	0.000219	0.000098	0.4480	12.24
3	2	739.6	0.6624	-2.0	0.003615	0.000273	0.000154	0.5639	13.26
3	3	742.2	0.6648	0.0	0.005280	0.000377	0.000271	0.7199	14.01
3	4	742.2	0.6648	2.0	0.007026	0.000519	0.000416	0.8030	13.55
3	5	739.6	0.6624	4.0	0.008960	0.000703	0.000600	0.8525	12.74
3	6	742.2	0.6648	6.0	0.010707	0.000948	0.000783	0.8260	11.29
3	7	743.5	0.6660	8.0	0.012856	0.001213	0.001031	0.8499	10.60
3	8	739.6	0.6624	9.0	0.013579	0.001388	0.001119	0.8059	9.78
3	9	740.9	0.6636	10.0	0.014040	0.001514	0.001176	0.7768	9.27
3	10	740.9	0.6636	11.0	0.014809	0.001686	0.001274	0.7560	8.79
3	11	740.9	0.6636	12.0	0.015394	0.001948	0.001351	0.6935	7.90
3	12	740.9	0.6636	12.0	0.015087	0.001868	0.001310	0.7016	8.08

RUN	Point	V tip (fps)	M tip	Coll.	CT	CP	Ideal CP	FM	CT/CP
3	13	739.6	0.6624	12.5	0.015757	0.002004	0.001399	0.6978	7.86
4	14	738.3	0.6556	7.0	0.011936	0.001122	0.000922	0.8220	10.64
5	2	590.4	0.5243	-3.7	0.002549	0.000222	0.000091	0.4097	11.48
5	3	734.3	0.6521	-3.7	0.002645	0.000228	0.000096	0.4211	11.58
5	4	740.9	0.6579	-2.0	0.003672	0.000270	0.000157	0.5829	13.60
5	5	738.3	0.6556	0.0	0.005328	0.000390	0.000275	0.7053	13.67
5	6	739.6	0.6568	2.0	0.007089	0.000532	0.000422	0.7928	13.32
5	7	739.6	0.6568	4.0	0.009073	0.000730	0.000611	0.8368	12.42
5	9	739.6	0.6568	8.0	0.012743	0.001250	0.001017	0.8139	10.20
6	1	599.5	0.5351	-3.7	0.002574	0.000223	0.000092	0.4141	11.54
6	2	598.2	0.5340	0.0	0.005051	0.000363	0.000254	0.6990	13.91
6	3	596.9	0.5328	4.0	0.008591	0.000691	0.000563	0.8146	12.43
6	4	598.2	0.5340	8.0	0.012360	0.001184	0.000972	0.8205	10.44
6	5	599.5	0.5351	10.0	0.013919	0.001472	0.001161	0.7891	9.46
6	6	599.5	0.5351	12.0	0.015230	0.001800	0.001329	0.7386	8.46
6	7	739.6	0.6602	-4.0	0.002614	0.000221	0.000095	0.4270	11.81
6	8	744.8	0.6648	-2.0	0.003649	0.000274	0.000156	0.5695	13.33
6	9	740.9	0.6591	1.0	0.006034	0.000443	0.000331	0.7488	13.63
6	10	742.2	0.6602	3.0	0.007857	0.000612	0.000492	0.8047	12.84
6	11	743.5	0.6614	5.0	0.009760	0.000847	0.000682	0.8048	11.52
6	12	739.6	0.6579	7.0	0.011521	0.001117	0.000874	0.7828	10.31
6	13	739.6	0.6579	8.0	0.012497	0.001228	0.000988	0.8047	10.18
6	14	738.3	0.6567	9.0	0.013412	0.001405	0.001098	0.7816	9.54
6	15	738.3	0.6567	10.0	0.014267	0.001575	0.001205	0.7651	9.06
6	16	739.6	0.6579	11.0	0.015006	0.001742	0.001300	0.7460	8.61
6	17	740.9	0.6591	12.0	0.015430	0.001909	0.001355	0.7099	8.08
7	1	784.1	0.6951	-3.7	0.002638	0.000220	0.000096	0.4356	11.99
7	2	784.1	0.6951	-3.0	0.003040	0.000244	0.000119	0.4851	12.44
7	3	784.1	0.6951	-2.0	0.003553	0.000281	0.000150	0.5339	12.67
7	4	784.1	0.6951	-1.0	0.004414	0.000330	0.000207	0.6278	13.36
7	5	782.8	0.6939	0.0	0.005223	0.000388	0.000267	0.6879	13.46
7	6	785.4	0.6963	1.0	0.005977	0.000448	0.000327	0.7289	13.33
7	7	784.1	0.6951	2.0	0.007024	0.000537	0.000416	0.7758	13.09
7	8	784.1	0.6951	3.0	0.008274	0.000637	0.000532	0.8351	12.98
7	9	785.4	0.6963	4.0	0.008859	0.000742	0.000590	0.7946	11.94
7	10	786.7	0.6974	5.0	0.009887	0.000859	0.000695	0.8090	11.51
7	11	784.1	0.6951	6.0	0.010883	0.000997	0.000803	0.8052	10.92
7	12	784.1	0.6951	7.0	0.011800	0.001126	0.000906	0.8049	10.48
7	13	782.8	0.6939	8.0	0.012842	0.001290	0.001029	0.7978	9.96
7	15	782.8	0.6939	9.0	0.013622	0.001438	0.001124	0.7817	9.47
7	16	785.4	0.6963	10.0	0.014389	0.001582	0.001221	0.7713	9.09
7	17	786.7	0.6974	11.0	0.015237	0.001806	0.001330	0.7365	8.44

Appendix B

XV-15 Full-Scale Advance Technology Blade Proprotor (NASA OARF Test)

This appendix contains:

1. Proprotor configuration (table B-1 and figs. B-1 to B-9).
2. Performance data of C_P versus C_T and C_T versus 3/4 radius collective for the NASA OARF test (figs. B-10 through B-13, and tables B-2 through B-5).

1. Proprotor Configuration

The ATB proprotor was well described in references 8, 9, and 10. An overview of the baseline configuration along with the several modified configurations that were tested are shown in figure B-4.

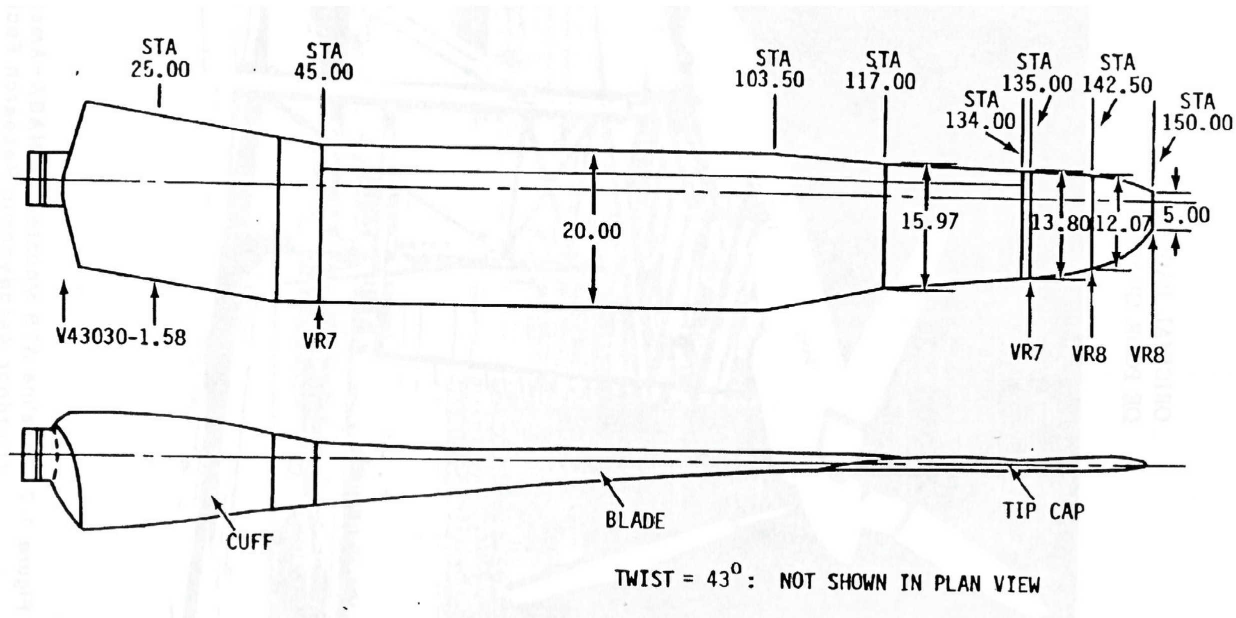

Figure B-1. ATB baseline composite-bladed proprotor.

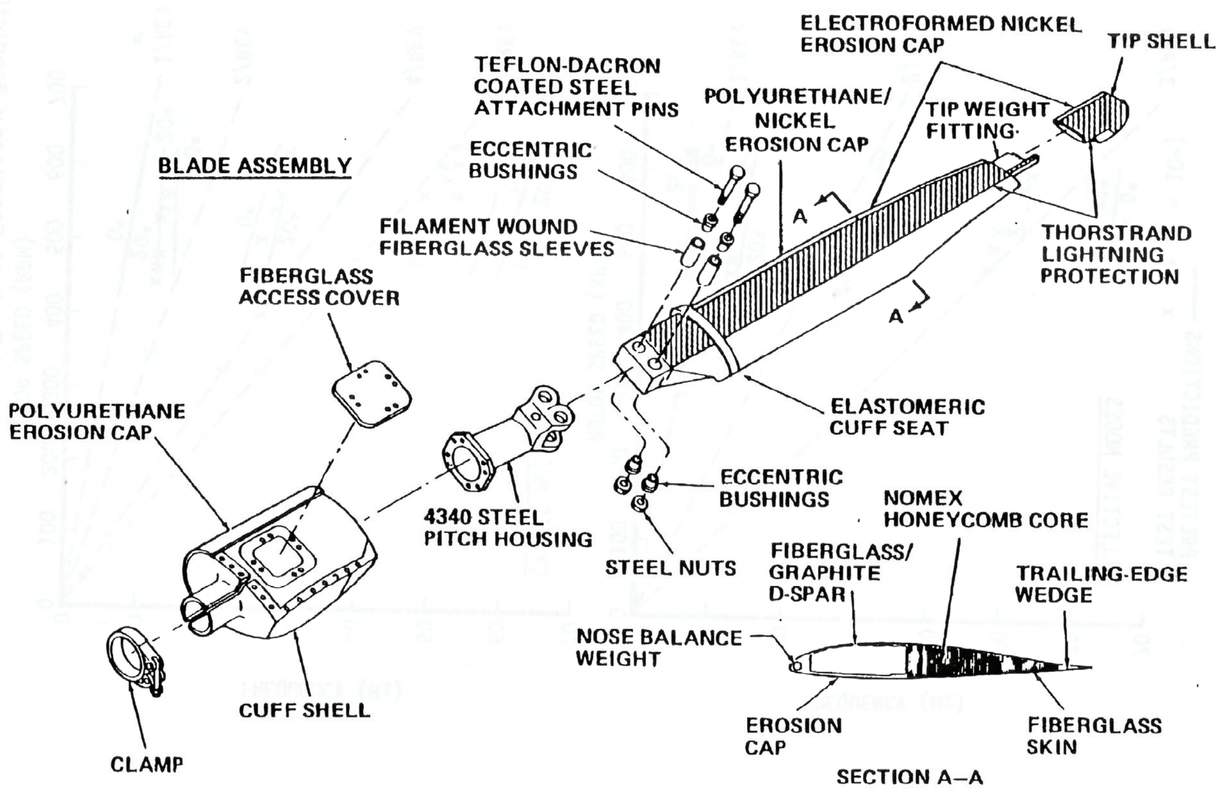

Figure B-2. ATB baseline composite-bladed proprotor in detail.

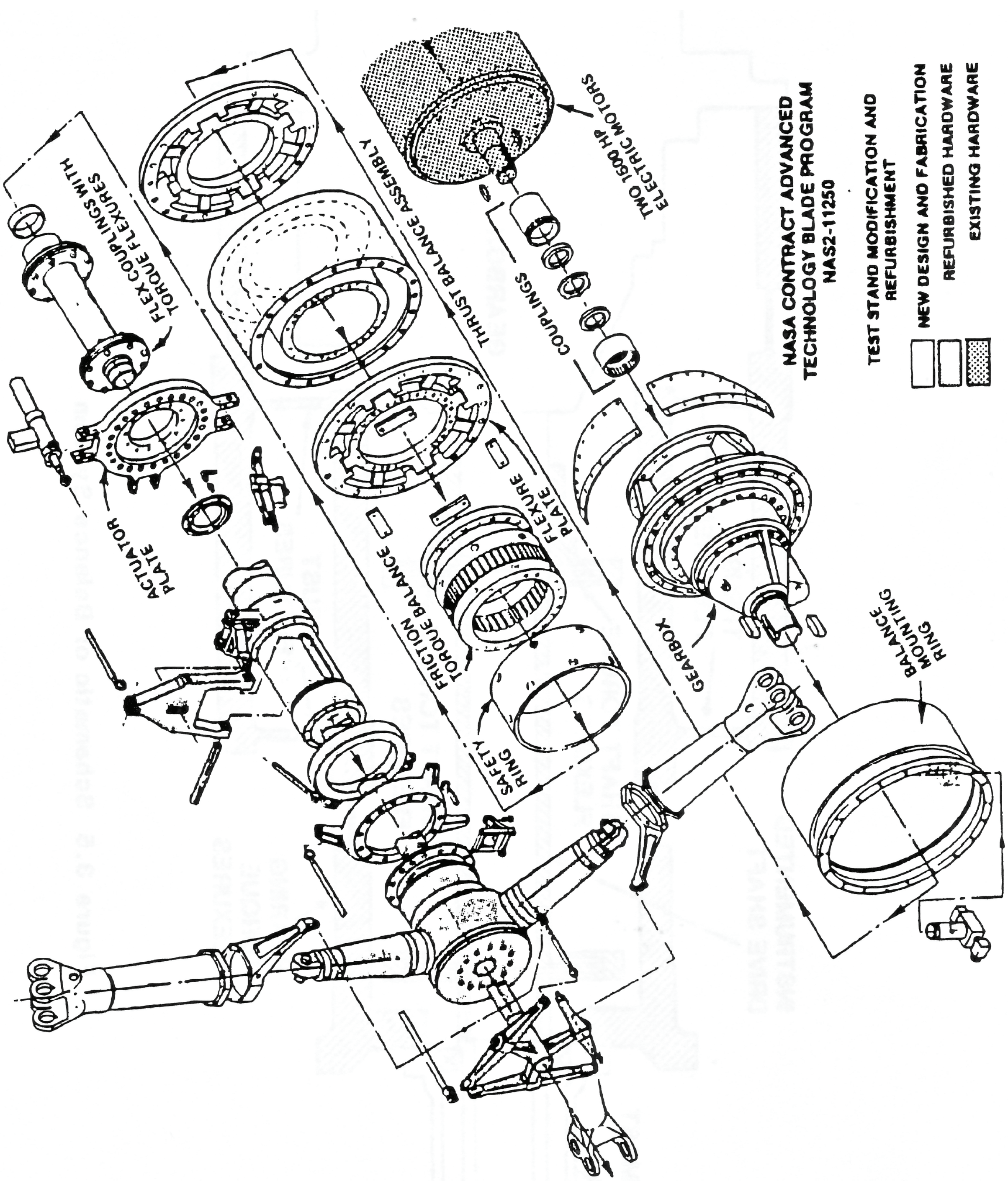

Figure B-3. OARF basic test stand for the ATB experiments.

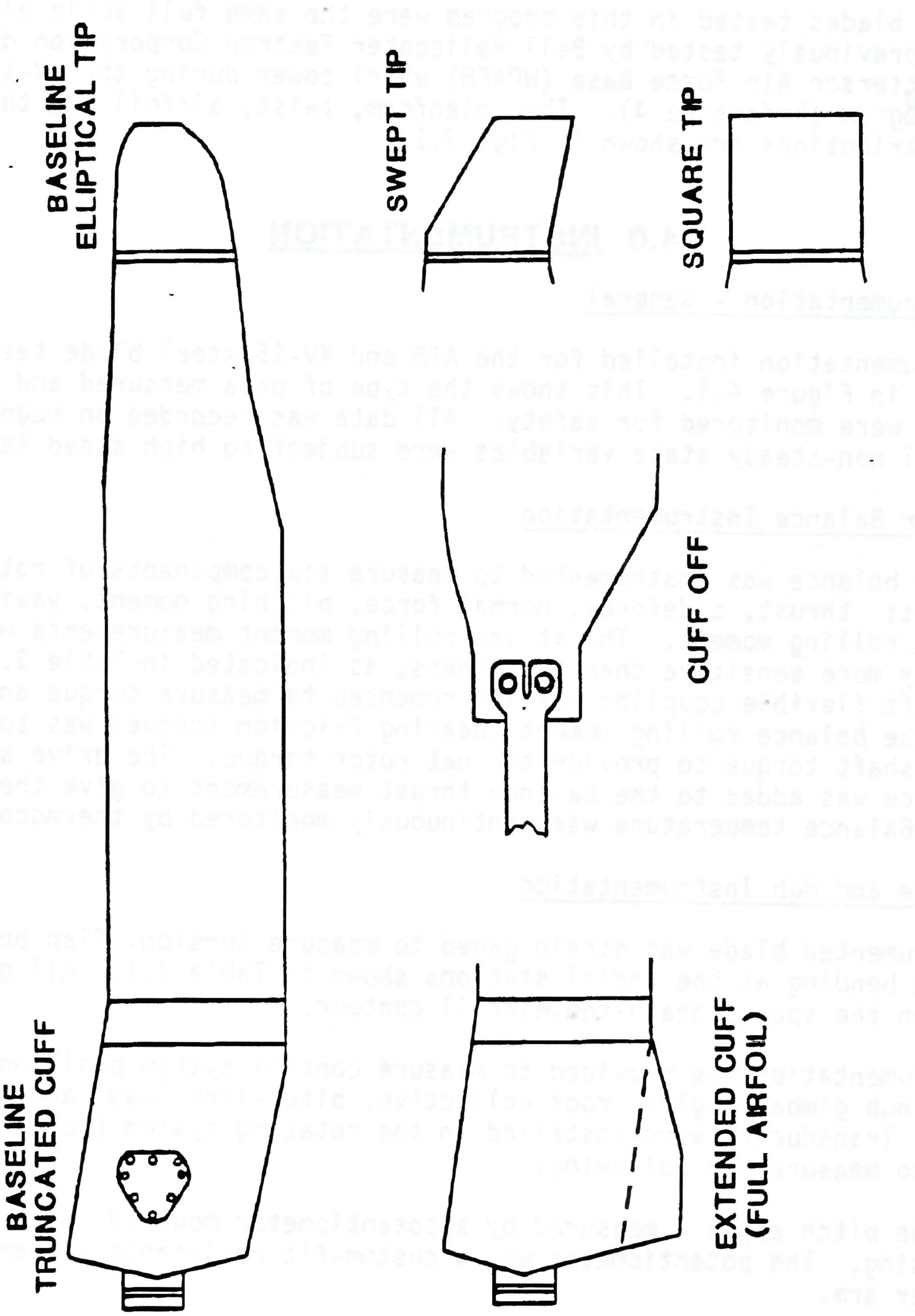

Figure B-4. ATB baseline composite-bladed proprotor and several modifications.

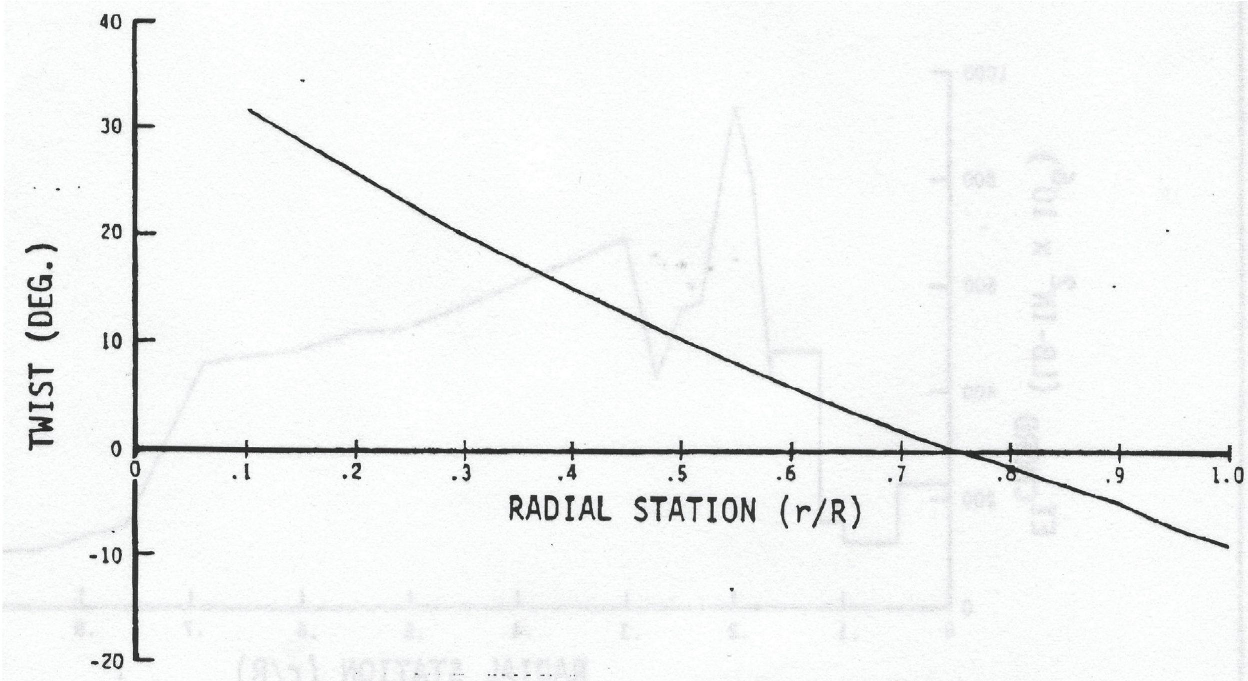

Figure B-5. ATB baseline composite-bladed proprotor—twist vs. radial station.

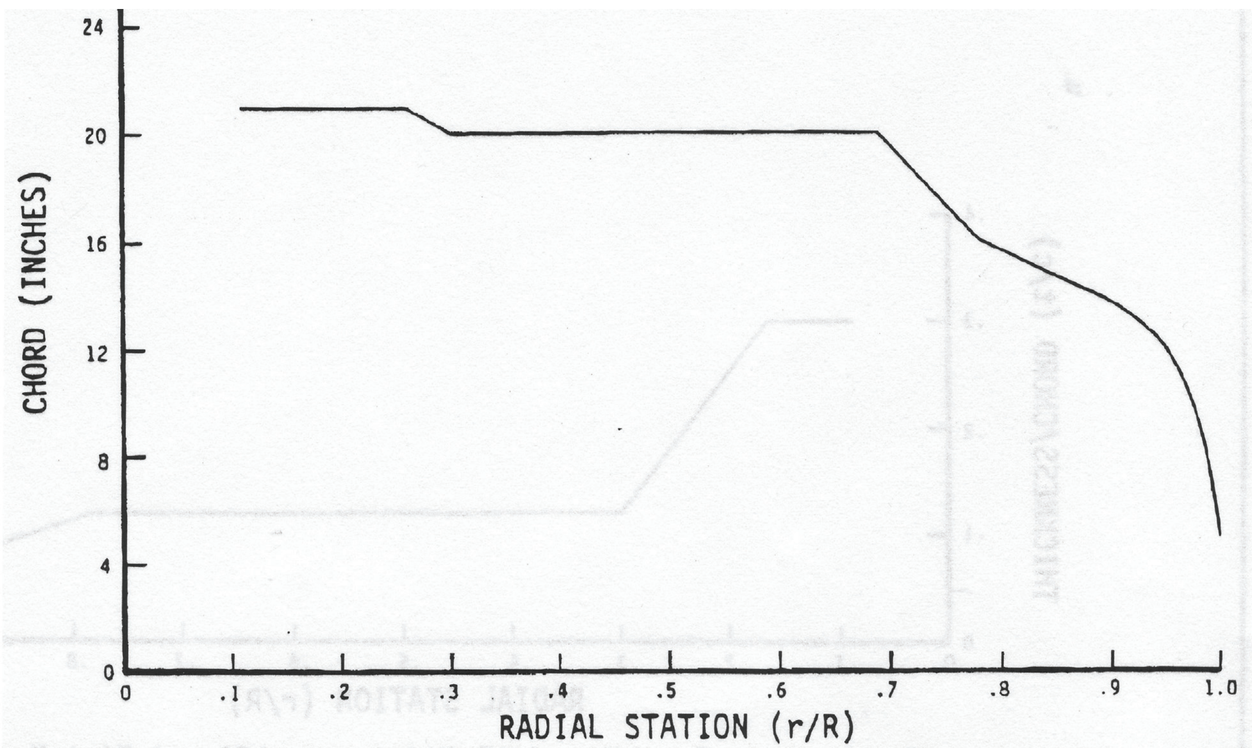

Figure B-6. ATB baseline composite-bladed proprotor—chord vs. radial station.

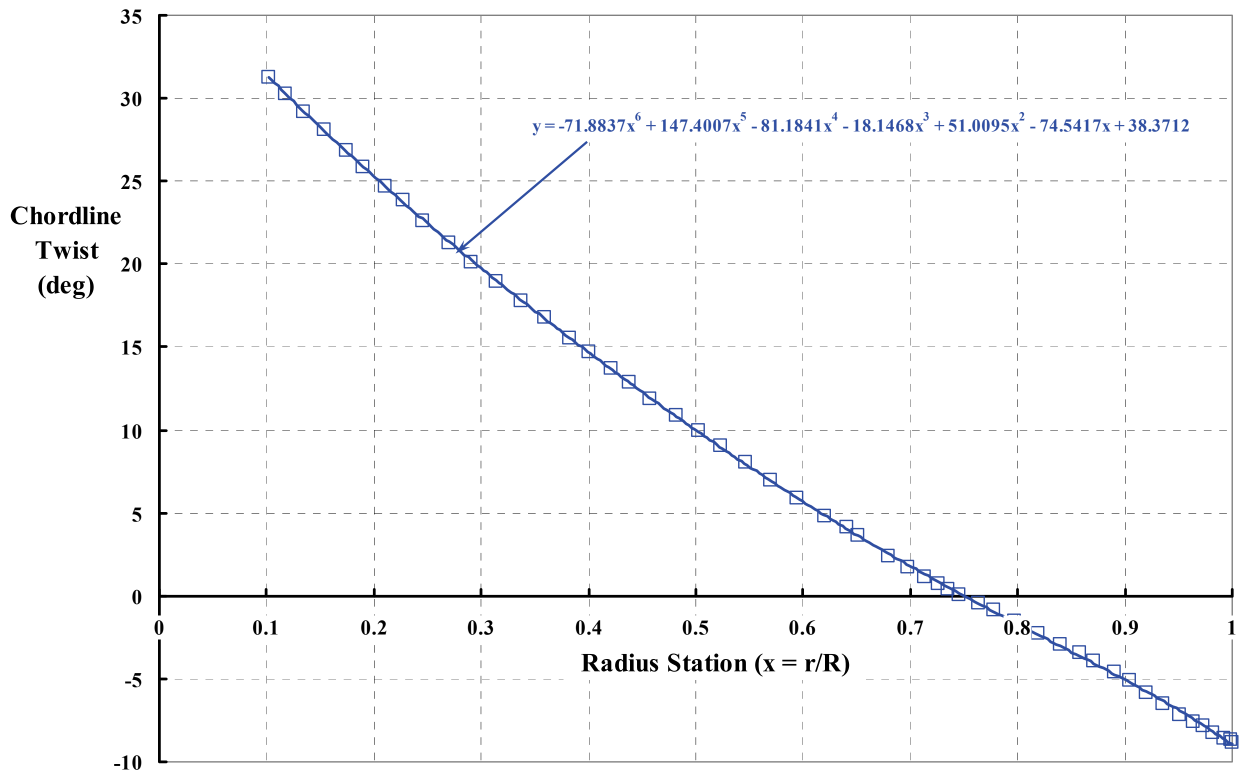

Figure B-7. ATB baseline composite-bladed proprotor—twist vs. radius station.

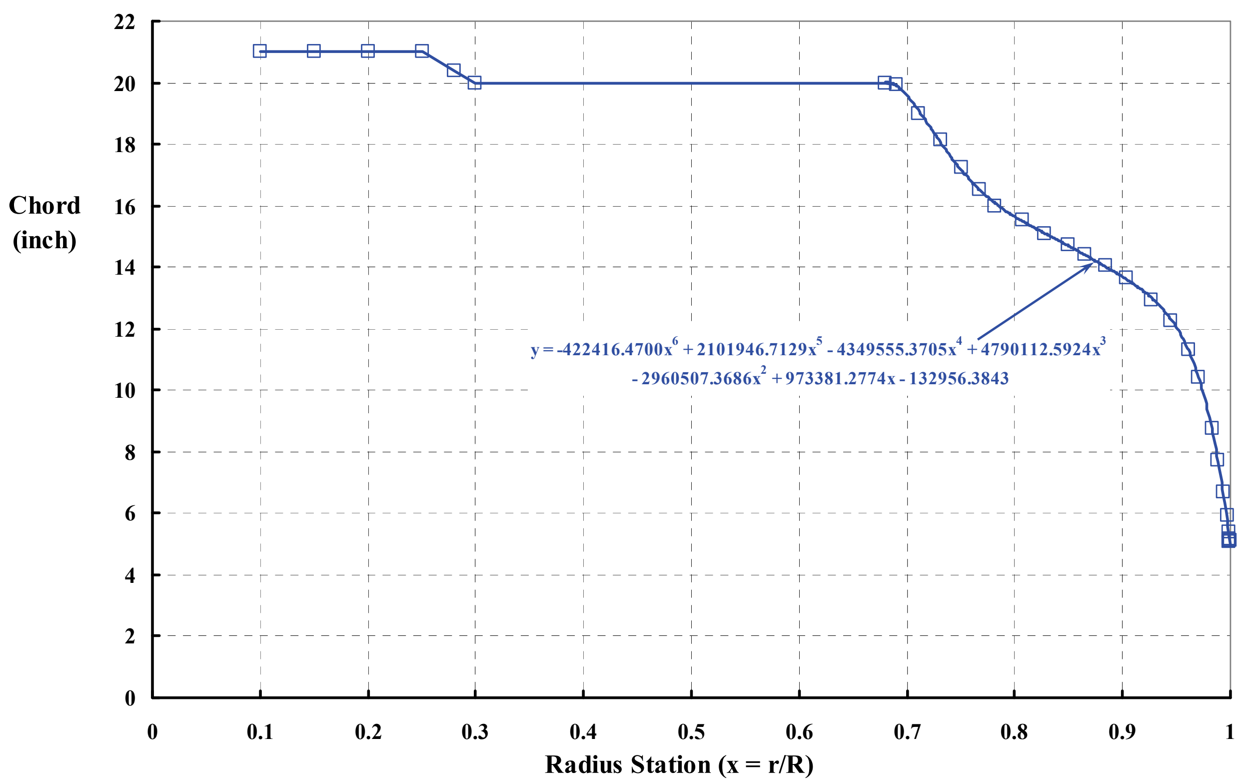

Figure B-8. ATB baseline composite-bladed proprotor—chord vs. radius station.

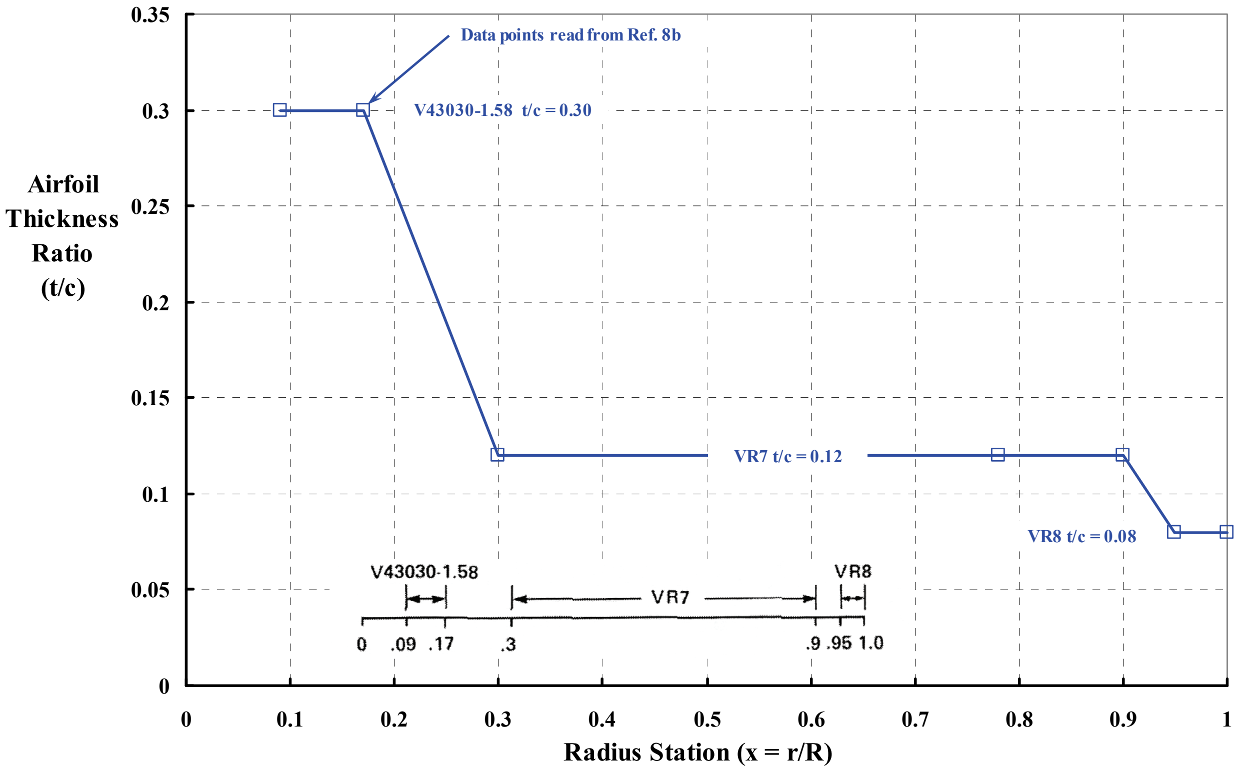

Figure B-9. ATB baseline composite-bladed proprotor—airfoil thickness ratio vs. radius station.

2. Performance Data

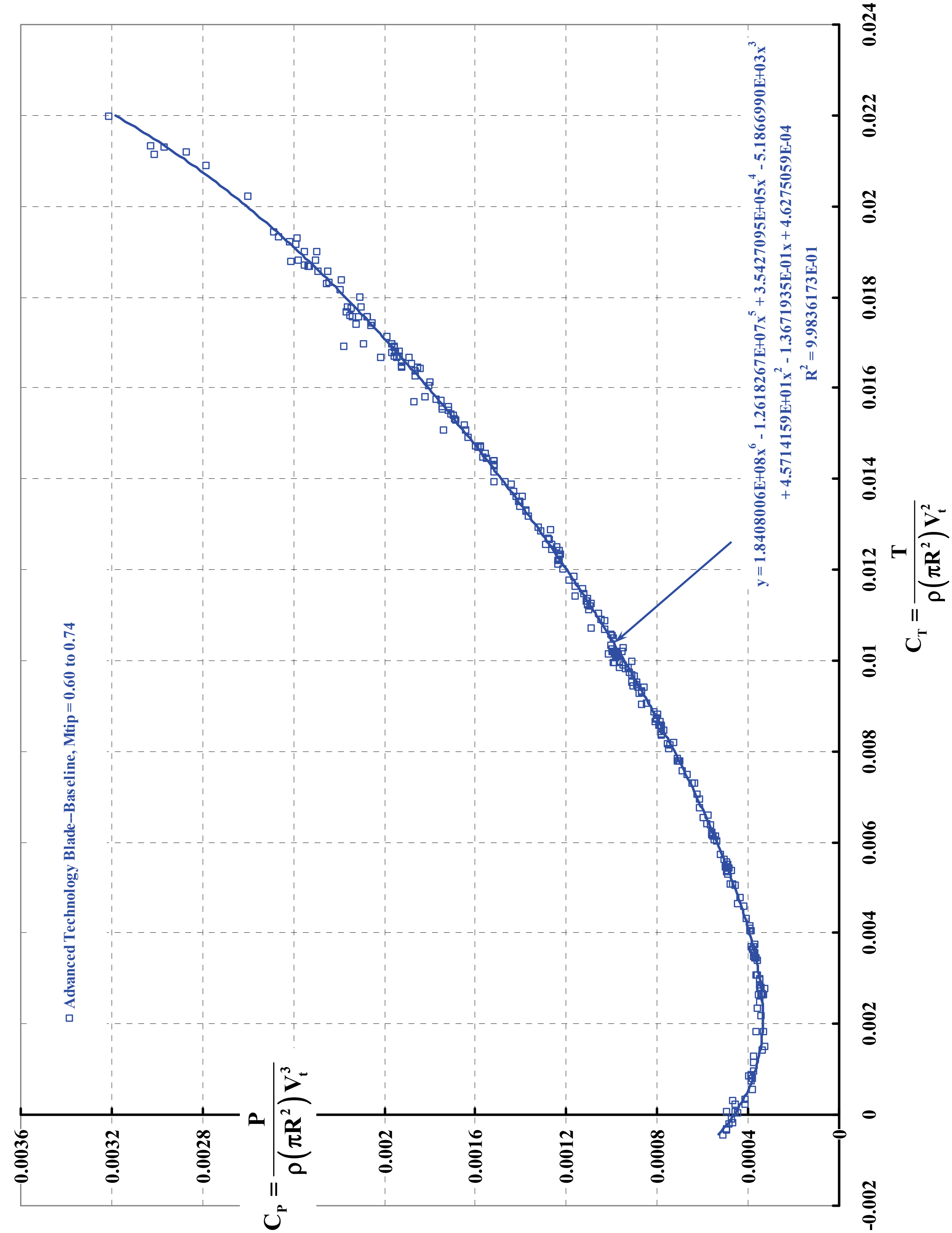

Figure B-10. ATB baseline test results at OARF—power vs. thrust coefficient.

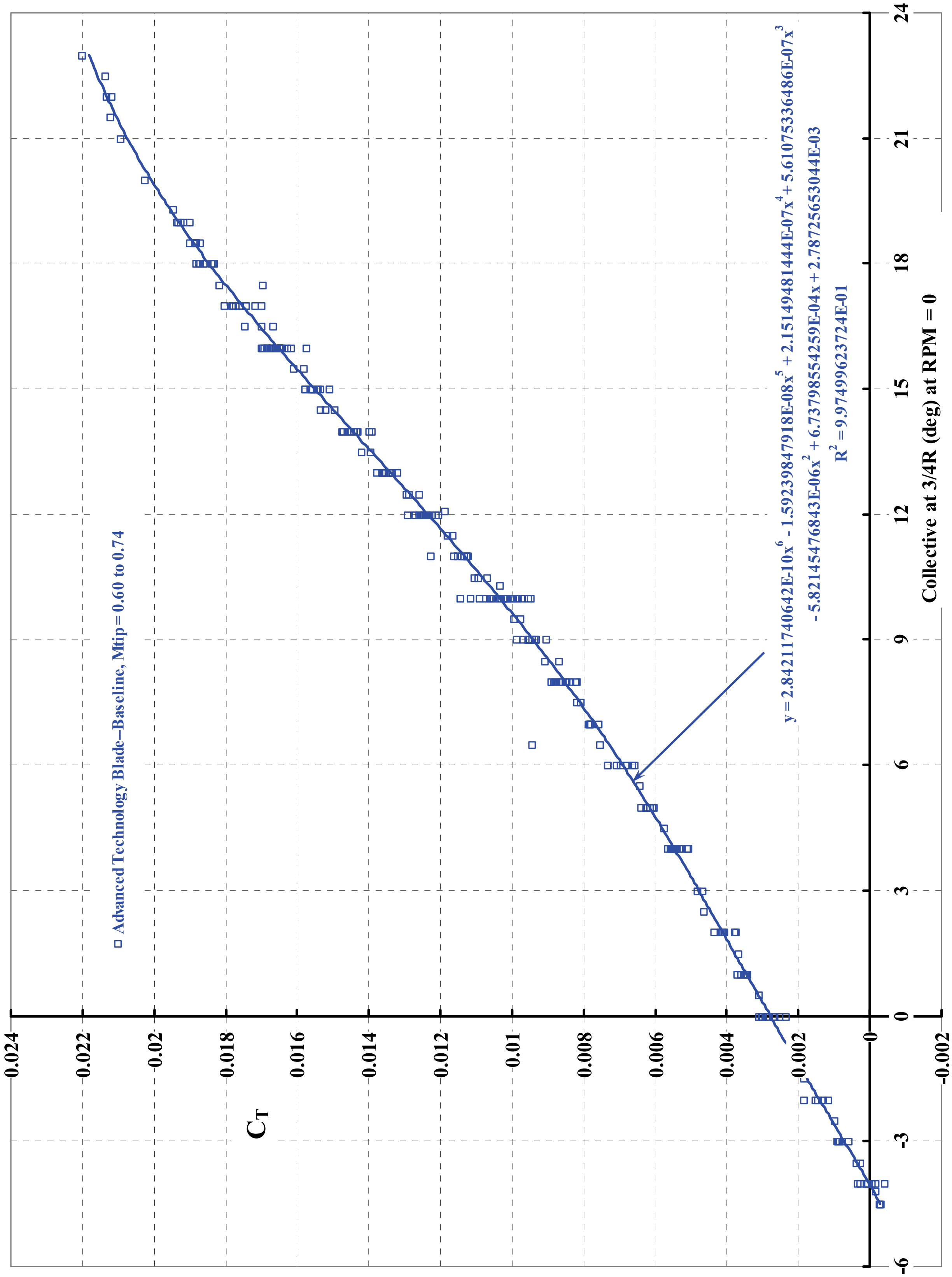

Figure B-11. ATB baseline test results at OARF—thrust coefficient vs. collective pitch.

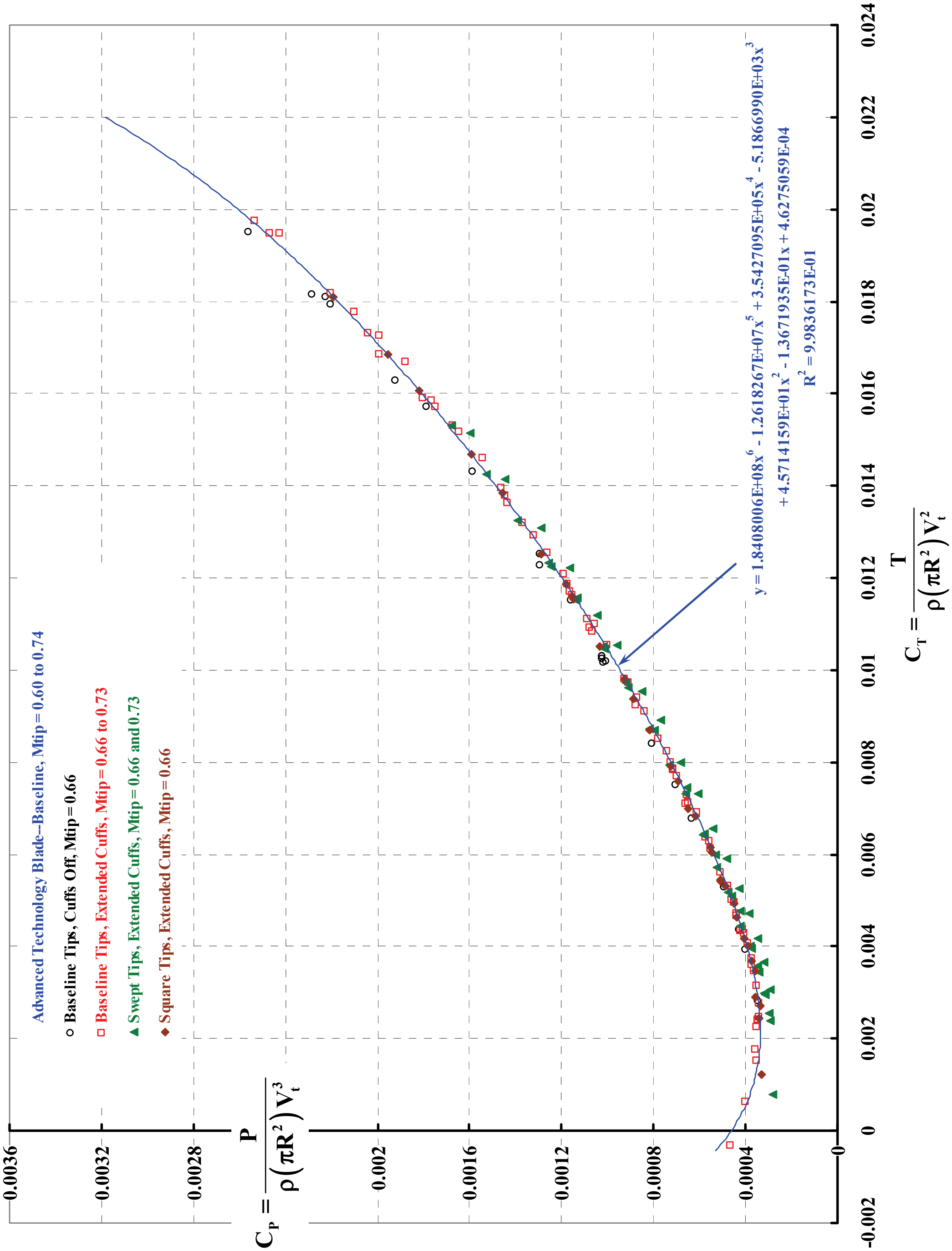

Figure B-12. ATB (other configurations) test results at OARF—power vs. thrust coefficient.

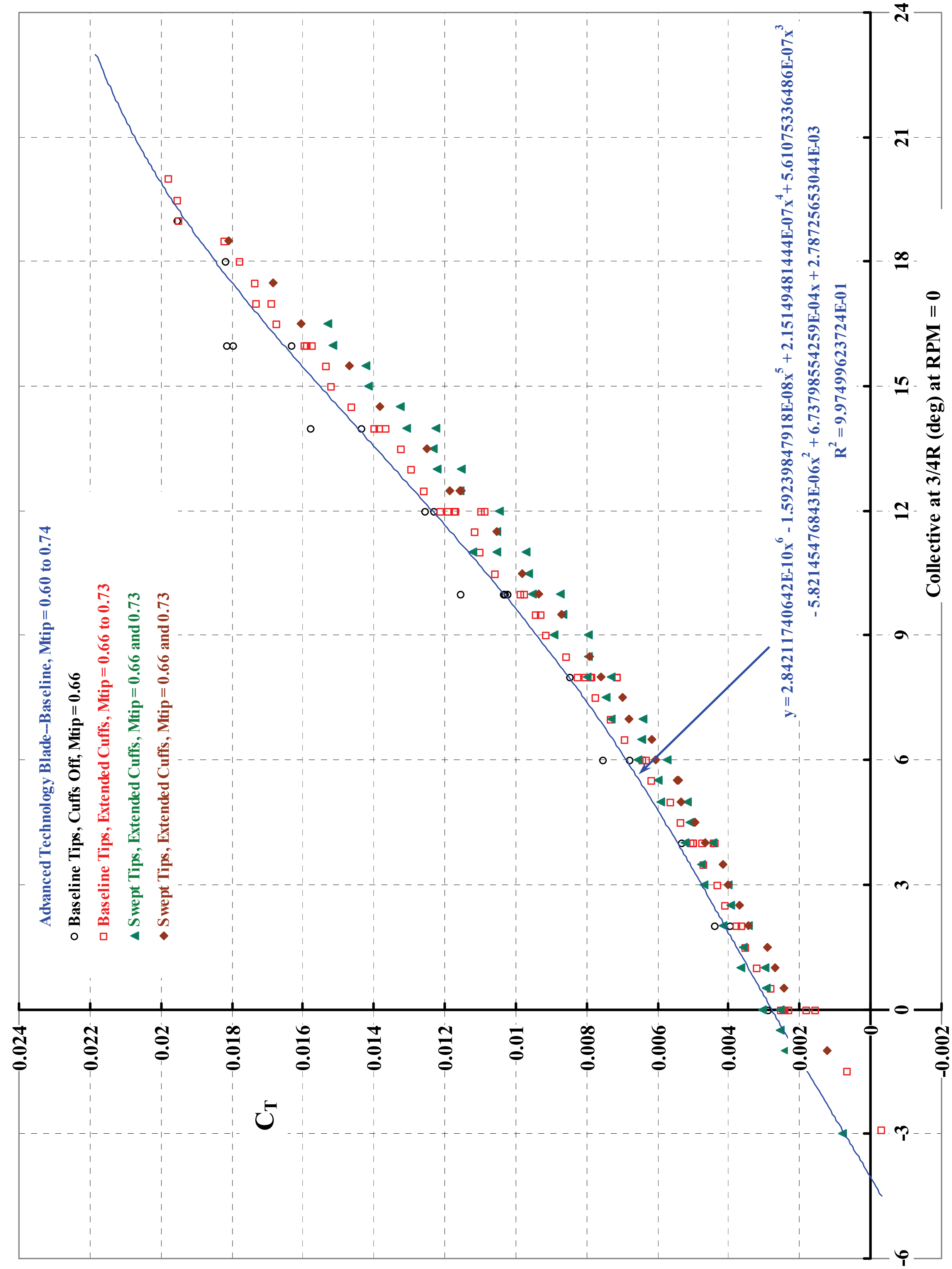

Figure B-13. ATB (other configurations) test results at OARF—thrust coefficient vs. collective pitch.

Table B–1. ATB Baseline Configuration Test Results at OARF

RUN	Point	V tip (fps)	M tip	Coll.	CT	CP	Ideal CP	FM	CT/CP
31	3	771.3	0.6768	10.3	0.010306	0.000950	0.000740	0.7787	10.85
31	4	771.8	0.6773	-2.0	0.001305	0.000375	0.000033	0.0889	3.48
31	5	771.8	0.6773	0.0	0.002496	0.000349	0.000088	0.2527	7.15
31	6	771.8	0.6773	2.0	0.003778	0.000370	0.000164	0.4438	10.21
31	7	771.7	0.6772	4.0	0.005068	0.000453	0.000255	0.5632	11.19
31	8	771.5	0.5771	6.0	0.006615	0.000576	0.000380	0.6605	11.48
31	9	771.4	0.6769	8.0	0.008203	0.000726	0.000525	0.7236	11.30
31	10	771.1	0.6767	10.0	0.010010	0.000907	0.000708	0.7808	11.04
31	11	770.9	0.6766	12.1	0.011867	0.001165	0.000914	0.7846	10.19
31	12	741.7	0.6764	14.0	0.013887	0.001441	0.001157	0.8030	9.64
31	13	770.1	0.676	16.0	0.016146	0.001796	0.001451	0.8077	8.99
32	5	747.2	0.6638	7.0	0.007575	0.000688	0.000466	0.6776	11.01
32	6	746.9	0.6636	9.0	0.009324	0.000868	0.000637	0.7334	10.74
32	7	746.7	0.6634	11.0	0.011208	0.001091	0.000839	0.7690	10.27
32	8	746.4	0.6629	13.0	0.013313	0.001376	0.001086	0.7894	9.68
32	9	746.0	0.6625	15.0	0.015450	0.001704	0.001358	0.7969	9.07
32	10	745.5	0.6617	17.0	0.017582	0.002074	0.001648	0.7948	8.48
32	11	745.0	0.6612	19.0	0.019348	0.002465	0.001903	0.7720	7.85
32	12	746.8	0.6628	7.5	0.008167	0.000743	0.000522	0.7024	10.99
32	13	746.7	0.6627	9.5	0.009759	0.000922	0.000682	0.7394	10.58
32	14	746.5	0.6625	11.5	0.011644	0.001156	0.000888	0.7686	10.07
32	15	746.1	0.6622	13.5	0.013939	0.001467	0.001164	0.7932	9.50
32	16	745.7	0.6618	15.5	0.016070	0.001805	0.001440	0.7981	8.90
32	17	745.2	0.6614	17.5	0.018173	0.002190	0.001732	0.7910	8.30
33	3	748.0	0.6628	8.0	0.008488	0.000770	0.000553	0.7181	11.02
33	4	747.7	0.6624	10.0	0.010197	0.000972	0.000728	0.7491	10.49
33	5	747.4	0.6624	12.0	0.012325	0.001227	0.000968	0.7885	10.04
33	6	747.2	0.6621	14.0	0.014332	0.001517	0.001213	0.7998	9.45
33	7	746.8	0.6613	16.0	0.016546	0.001876	0.001505	0.8022	8.82
33	8	746.1	0.6609	18.0	0.018820	0.002303	0.001826	0.7927	8.17
33	9	747.8	0.6623	8.5	0.008678	0.000804	0.000572	0.7110	10.79
33	10	747.6	0.6621	10.5	0.010690	0.001030	0.000782	0.7588	10.38
33	11	747.3	0.6619	12.5	0.012582	0.001286	0.000998	0.7760	9.78
33	12	746.9	0.6616	14.5	0.014931	0.001627	0.001290	0.7929	9.18
33	13	746.5	0.6612	16.5	0.016996	0.001965	0.001567	0.7973	8.65
33	14	746.1	0.6609	18.5	0.018704	0.002331	0.001809	0.7760	8.02
36	3	745.5	0.6633	-4.2	-0.000176	0.000480	#NUM!	#NUM!	-0.37
36	4	745.5	0.6635	-2.0	0.001442	0.000338	0.000039	0.1146	4.27
36	5	745.5	0.6636	0.0	0.002794	0.000346	0.000104	0.3018	8.08
36	6	745.5	0.6636	2.0	0.004130	0.000392	0.000188	0.4788	10.54
36	7	745.3	0.6634	4.0	0.005437	0.000486	0.000283	0.5833	11.19
36	8	745.2	0.6633	6.0	0.006784	0.000614	0.000395	0.6435	11.05
36	9	745.1	0.6629	8.0	0.008389	0.000780	0.000543	0.6966	10.76
36	10	745.0	0.6628	10.0	0.010158	0.000970	0.000724	0.7463	10.47

RUN	Point	V tip (fps)	M tip	Coll.	CT	CP	Ideal CP	FM	CT/CP
36	11	744.7	0.6625	11.0	0.012243	0.001230	0.000958	0.7788	9.95
36	12	744.3	0.6622	14.0	0.014469	0.001546	0.001231	0.7960	9.36
36	13	743.9	0.6618	16.0	0.016281	0.001864	0.001469	0.7881	8.73
36	14	743.5	0.6613	18.0	0.018313	0.002252	0.001752	0.7781	8.13
36	15	745.5	0.6631	-3.0	0.000821	0.000379	0.000017	0.0439	2.17
36	16	745.6	0.6629	-1.0	0.002194	0.000340	0.000073	0.2137	6.45
36	17	745.5	0.6628	1.0	0.003578	0.000369	0.000151	0.4101	9.70
36	18	745.5	0.6623	3.0	0.004656	0.000443	0.000225	0.5071	10.51
36	19	745.3	0.6622	5.0	0.006210	0.000558	0.000346	0.6201	11.13
36	20	745.2	0.6619	7.0	0.007811	0.000710	0.000488	0.6875	11.00
36	21	745.0	0.6617	9.0	0.009300	0.000875	0.000634	0.7248	10.63
36	22	744.8	0.6615	11.0	0.011332	0.001110	0.000853	0.7685	10.21
36	23	744.4	0.661	13.0	0.013616	0.001390	0.001123	0.8082	9.80
36	24	744.0	0.6607	15.0	0.015410	0.001697	0.001353	0.7971	9.08
36	25	743.6	0.6605	17.0	0.017790	0.002099	0.001678	0.7993	8.48
36	26	718.4	0.6381	19.0	0.019004	0.002298	0.001852	0.8061	8.27
37	3	779.9	0.6921	-4.0	-0.000432	0.000511	#NUM!	#NUM!	-0.85
37	4	780.0	0.6922	-2.0	0.001166	0.000371	0.000028	0.0759	3.14
37	5	780.0	0.6921	0.0	0.002348	0.000355	0.000080	0.2266	6.61
37	6	779.9	0.6921	2.0	0.003717	0.000385	0.000160	0.4162	9.65
37	7	779.9	0.6919	4.0	0.005106	0.000475	0.000258	0.5431	10.75
37	8	779.8	0.6917	6.0	0.006567	0.000593	0.000376	0.6346	11.07
37	9	784.9	0.6916	8.0	0.008181	0.000751	0.000523	0.6967	10.89
37	10	779.4	0.6914	10.0	0.009831	0.000939	0.000689	0.7340	10.47
37	11	779.0	0.6913	12.0	0.012037	0.001215	0.000934	0.7686	9.91
37	12	778.7	0.6908	14.0	0.014294	0.001517	0.001208	0.7966	9.42
37	13	778.3	0.6904	16.0	0.016402	0.001864	0.001485	0.7969	8.80
37	14	777.7	0.6899	18.0	0.018592	0.002292	0.001793	0.7821	8.11
37	15	748.7	0.6637	15.0	0.015319	0.001684	0.001341	0.7961	9.10
37	16	748.2	0.6632	17.0	0.017401	0.002057	0.001623	0.7891	8.46
37	17	748.0	0.6628	18.0	0.018336	0.002243	0.001756	0.7827	8.17
37	18	747.8	0.6627	18.5	0.019004	0.002352	0.001852	0.7876	8.08
37	19	747.8	0.6629	19.0	0.019242	0.002412	0.001887	0.7825	7.98
37	20	747.7	0.6629	19.3	0.019458	0.002486	0.001919	0.7720	7.83
39	4	423.1	0.3782	10.0	0.010216	0.000996	0.000730	0.7331	10.26
39	5	423.1	0.378	10.0	0.010269	0.000995	0.000736	0.7395	10.32
40	4	773.6	0.6904	-4.5	-0.000283	0.000494	#NUM!	#NUM!	-0.57
40	5	773.7	0.6905	-2.0	0.001838	0.000365	0.000056	0.1527	5.04
40	6	773.7	0.6905	0.0	0.003091	0.000357	0.000122	0.3404	8.66
40	7	773.6	0.6905	2.0	0.004327	0.000408	0.000201	0.4933	10.61
40	8	773.6	0.6903	4.0	0.005630	0.000505	0.000299	0.5915	11.15
40	9	773.4	0.6901	6.0	0.007328	0.000646	0.000444	0.6866	11.34
40	10	773.2	0.6899	8.0	0.008901	0.000810	0.000594	0.7331	10.99
40	11	773.0	0.6897	10.0	0.010902	0.001029	0.000805	0.7822	10.59
40	12	772.8	0.6895	12.0	0.012889	0.001266	0.001035	0.8173	10.18

RUN	Point	V tip (fps)	M tip	Coll.	CT	CP	Ideal CP	FM	CT/CP
41	3	776.5	0.6915	-4.0	-0.000161	0.000463	#NUM!	#NUM!	-0.35
41	4	776.6	0.6916	0.0	0.002819	0.000342	0.000106	0.3095	8.24
41	5	776.5	0.6917	4.0	0.005306	0.000485	0.000273	0.5635	10.94
41	6	776.1	0.6914	8.0	0.008562	0.000781	0.000560	0.7173	10.96
41	7	775.7	0.6907	12.0	0.012215	0.001235	0.000955	0.7730	9.89
41	8	775.3	0.6906	14.0	0.014586	0.001555	0.001246	0.8010	9.38
41	9	774.9	0.6902	16.0	0.016835	0.001933	0.001545	0.7990	8.71
41	10	774.3	0.6897	18.0	0.018690	0.002330	0.001807	0.7754	8.02
41	11	776.5	0.6918	-3.5	0.000254	0.000412	0.000003	0.0069	0.62
41	12	776.6	0.6912	0.5	0.003092	0.000361	0.000122	0.3368	8.57
41	13	776.4	0.6911	4.5	0.005733	0.000518	0.000307	0.5926	11.07
41	14	776.1	0.6906	8.5	0.009073	0.000847	0.000611	0.7215	10.71
41	15	775.8	0.6906	10.5	0.010917	0.001047	0.000807	0.7704	10.43
41	16	775.6	0.6903	12.5	0.012943	0.001320	0.001041	0.7888	9.81
41	17	775.2	0.6897	14.5	0.015186	0.001648	0.001323	0.8030	9.21
41	18	774.7	0.6893	16.5	0.017459	0.002054	0.001631	0.7942	8.50
41	19	774.1	0.6886	18.5	0.018809	0.002409	0.001824	0.7572	7.81
41	20	776.5	0.6907	-3.0	0.000881	0.000394	0.000018	0.0469	2.24
41	21	776.6	0.6908	1.0	0.003458	0.000369	0.000144	0.3897	9.37
41	22	776.4	0.6906	5.0	0.006071	0.000549	0.000334	0.6093	11.06
41	23	776.0	0.6906	9.0	0.009857	0.000926	0.000692	0.7473	10.64
41	24	775.7	0.69	11.0	0.011390	0.001105	0.000860	0.7779	10.31
41	25	775.4	0.6894	13.0	0.013529	0.001401	0.001113	0.7942	9.66
41	26	774.9	0.6891	15.0	0.015612	0.001716	0.001379	0.8038	9.10
41	27	774.4	0.6888	17.0	0.017576	0.002075	0.001648	0.7940	8.47
41	28	774.0	0.6686	18.5	0.018837	0.002374	0.001828	0.7701	7.93
41	29	393.2	0.3495	10.0	0.010161	0.001013	0.000724	0.7150	10.03
41	30	419.4	0.3729	10.0	0.009964	0.000990	0.000703	0.7104	10.06
41	31	445.8	0.3962	10.0	0.009965	0.000984	0.000703	0.7148	10.13
41	32	471.4	0.4189	10.0	0.010175	0.000984	0.000726	0.7376	10.34
41	33	498.1	0.4426	10.0	0.010225	0.000988	0.000731	0.7400	10.35
41	34	524.3	0.466	10.0	0.010149	0.000977	0.000723	0.7400	10.39
41	35	550.7	0.4892	10.0	0.009855	0.000965	0.000692	0.7169	10.21
41	36	576.7	0.5121	10.0	0.010142	0.000980	0.000722	0.7370	10.35
41	37	603.2	0.5359	10.0	0.010094	0.000970	0.000717	0.7393	10.41
41	38	628.7	0.5583	10.0	0.010222	0.000980	0.000731	0.7457	10.43
41	39	655.4	0.5819	10.0	0.010344	0.001002	0.000744	0.7424	10.32
41	40	684.6	0.6076	10.0	0.010132	0.000970	0.000721	0.7435	10.45
41	41	707.8	0.6281	10.0	0.009964	0.000963	0.000703	0.7303	10.35
41	42	734.0	0.6514	10.0	0.010087	0.000980	0.000716	0.7310	10.29
41	43	760.3	0.6747	10.0	0.010220	0.000953	0.000731	0.7666	10.72
42	3	760.3	0.6736	10.0	0.009527	0.000908	0.000658	0.7242	10.49
42	4	785.5	0.6963	10.0	0.009447	0.000903	0.000649	0.7190	10.46
42	5	818.3	0.7259	10.0	0.009702	0.000911	0.000676	0.7418	10.65
43	3	393.2	0.3532	10.0	0.010723	0.001086	0.000785	0.7230	9.87
43	4	419.5	0.3768	10.0	0.011430	0.001161	0.000864	0.7443	9.84
43	5	449.9	0.404	10.0	0.011126	0.001099	0.000830	0.7551	10.12

RUN	Point	V tip (fps)	M tip	Coll.	CT	CP	Ideal CP	FM	CT/CP
44	3	818.3	0.7329	-4.5	-0.000309	0.000491	#NUM!	#NUM!	-0.63
44	4	818.5	0.7331	-2.0	0.001510	0.000324	0.000041	0.1281	4.66
44	5	818.5	0.7331	0.0	0.002793	0.000327	0.000104	0.3192	8.54
44	6	818.4	0.7328	2.0	0.004065	0.000388	0.000183	0.4723	10.48
44	7	818.3	0.7327	4.0	0.005406	0.000473	0.000281	0.5942	11.43
44	8	818.1	0.7324	6.0	0.007320	0.000636	0.000443	0.6963	11.51
44	9	818.0	0.7322	8.0	0.008596	0.000781	0.000564	0.7216	11.01
44	10	817.7	0.7318	10.0	0.010605	0.000999	0.000772	0.7730	10.62
44	11	817.5	0.7315	12.0	0.012126	0.001232	0.000944	0.7664	9.84
44	12	817.1	0.7312	14.0	0.013960	0.001517	0.001166	0.7688	9.20
44	13	816.6	0.7306	16.0	0.015722	0.001869	0.001394	0.7458	8.41
44	14	816.2	0.73	17.5	0.016944	0.002174	0.001560	0.7174	7.79
44	15	818.4	0.7316	-3.5	0.000363	0.000411	0.000005	0.0119	0.88
44	16	818.5	0.7313	-1.5	0.001844	0.000328	0.000056	0.1707	5.62
44	17	818.5	0.7313	2.5	0.004618	0.000417	0.000222	0.5321	11.07
44	18	818.1	0.7308	6.5	0.007516	0.000666	0.000461	0.6918	11.29
44	19	817.9	0.7302	8.5	0.009429	0.000856	0.000647	0.7563	11.02
44	20	817.7	0.73	10.5	0.011051	0.001055	0.000821	0.7786	10.47
44	21	817.3	0.7297	12.5	0.012861	0.001310	0.001031	0.7873	9.82
44	22	816.8	0.7291	14.5	0.015343	0.001688	0.001344	0.7961	9.09
44	23	816.3	0.7284	16.5	0.016675	0.002013	0.001523	0.7564	8.28
44	24	818.5	0.7303	-3.0	0.000580	0.000377	0.000010	0.0262	1.54
44	25	818.5	0.7301	1.0	0.003470	0.000364	0.000145	0.3971	9.53
44	26	818.3	0.7299	5.0	0.006038	0.000536	0.000332	0.6190	11.26
44	27	818.0	0.7297	7.0	0.007791	0.000701	0.000486	0.6937	11.11
44	28	817.9	0.7293	9.0	0.009044	0.000865	0.000608	0.7031	10.46
44	29	817.6	0.7286	11.0	0.011257	0.001105	0.000845	0.7643	10.19
44	30	817.2	0.7284	13.0	0.013408	0.001403	0.001098	0.7825	9.56
44	31	816.7	0.728	15.0	0.015097	0.001736	0.001312	0.7556	8.70
44	32	816.0	0.7279	17.0	0.016976	0.002087	0.001564	0.7494	8.13
44	33	818.4	0.7298	-2.5	0.000970	0.000374	0.000021	0.0571	2.59
44	34	818.4	0.7297	1.5	0.003651	0.000378	0.000156	0.4127	9.66
44	35	818.1	0.7298	5.5	0.006433	0.000580	0.000365	0.6290	11.09
44	36	818.0	0.7292	7.5	0.008081	0.000747	0.000514	0.6876	10.82
44	37	817.7	0.7289	9.5	0.009920	0.000950	0.000699	0.7354	10.44
44	38	817.3	0.7283	11.5	0.011773	0.001185	0.000903	0.7622	9.94
44	39	816.9	0.7279	13.5	0.014178	0.001514	0.001194	0.7885	9.36
44	40	816.4	0.7278	15.5	0.015815	0.001819	0.001406	0.7731	8.69
44	41	773.0	0.688	-4.0	-0.000064	0.000473	#NUM!	#NUM!	-0.14
44	42	773.1	0.6884	4.0	0.005085	0.000468	0.000256	0.5479	10.87
44	43	772.7	0.688	8.0	0.008454	0.000780	0.000550	0.7047	10.84
44	44	772.2	0.6875	12.0	0.012357	0.001226	0.000971	0.7923	10.08
44	45	771.8	0.6872	14.0	0.014502	0.001562	0.001235	0.7906	9.28
44	46	771.1	0.6866	16.0	0.016704	0.001932	0.001527	0.7901	8.65
44	47	771.1	0.6866	16.0	0.016678	0.001892	0.001523	0.8050	8.82
44	48	787.0	0.7011	-4.0	0.000091	0.000495	0.000001	0.0012	0.18
44	49	787.1	0.7012	0.0	0.002649	0.000354	0.000096	0.2723	7.48
44	50	787.0	0.7008	4.0	0.005376	0.000494	0.000279	0.5642	10.88
44	51	786.6	0.7006	8.0	0.008378	0.000779	0.000542	0.6961	10.75

RUN	Point	V tip (fps)	M tip	Coll.	CT	CP	Ideal CP	FM	CT/CP
45	3	787.4	0.7047	-4.0	0.000254	0.000454	0.000003	0.0063	0.56
45	4	787.5	0.705	0.0	0.002999	0.000347	0.000116	0.3347	8.64
45	5	787.2	0.7048	4.0	0.005530	0.000487	0.000291	0.5971	11.36
45	6	787.0	0.7046	8.0	0.008763	0.000801	0.000580	0.7242	10.94
45	7	786.4	0.7042	12.0	0.012580	0.001259	0.000998	0.7925	9.99
45	8	786.1	0.7038	14.0	0.014718	0.001576	0.001263	0.8011	9.34
45	9	785.5	0.7033	16.0	0.016935	0.001956	0.001558	0.7967	8.66
45	10	785.5	0.7033	16.0	0.016977	0.001964	0.001564	0.7964	8.64
45	11	785.0	0.7028	18.0	0.018722	0.002352	0.001811	0.7702	7.96
45	12	804.4	0.7198	-4.0	0.000316	0.000466	0.000004	0.0085	0.68
45	13	804.5	0.7199	0.0	0.002862	0.000347	0.000108	0.3120	8.25
45	14	804.2	0.7198	4.0	0.005484	0.000496	0.000287	0.5790	11.06
45	15	804.0	0.7194	8.0	0.008734	0.000801	0.000577	0.7206	10.90
45	16	803.5	0.7188	12.0	0.012680	0.001270	0.001010	0.7950	9.98
45	17	803.1	0.7184	14.0	0.014730	0.001573	0.001264	0.8036	9.36
45	18	802.8	0.7181	15.0	0.015753	0.001747	0.001398	0.8003	9.02
45	19	802.4	0.7179	16.0	0.016820	0.001951	0.001542	0.7906	8.62
45	20	802.2	0.7176	17.0	0.017802	0.002161	0.001680	0.7772	8.24
45	21	804.4	0.7195	-3.0	0.000902	0.000385	0.000019	0.0498	2.34
45	22	804.4	0.7193	1.0	0.003577	0.000374	0.000151	0.4045	9.56
45	23	804.2	0.7191	5.0	0.006187	0.000555	0.000344	0.6200	11.15
45	24	803.9	0.7187	9.0	0.009435	0.000884	0.000648	0.7331	10.67
45	25	803.1	0.7181	13.0	0.013630	0.001418	0.001125	0.7935	9.61
45	26	802.7	0.7174	15.0	0.015594	0.001742	0.001377	0.7904	8.95
45	27	802.4	0.7172	16.0	0.016895	0.001955	0.001553	0.7943	8.64
45	28	802.2	0.7169	17.0	0.017580	0.002109	0.001648	0.7815	8.34
45	29	802.0	0.7168	17.0	0.017774	0.002142	0.001676	0.7822	8.30
45	30	814.7	0.7287	-4.0	0.000083	0.000456	0.000001	0.0012	0.18
45	31	814.9	0.729	0.0	0.002993	0.000349	0.000116	0.3318	8.58
45	32	814.7	0.7289	4.0	0.005401	0.000493	0.000281	0.5693	10.96
45	33	814.3	0.7286	8.0	0.008595	0.000790	0.000563	0.7132	10.88
45	34	813.7	0.7281	12.0	0.012719	0.001277	0.001014	0.7943	9.96
45	35	813.3	0.7276	14.0	0.014704	0.001584	0.001261	0.7959	9.28
45	36	812.8	0.7271	16.0	0.016488	0.001922	0.001497	0.7789	8.58
45	37	812.8	0.7271	16.0	0.016684	0.001946	0.001524	0.7831	8.57
45	38	812.4	0.7269	17.0	0.017596	0.002147	0.001650	0.7687	8.20
45	39	814.9	0.7289	-3.0	0.000861	0.000384	0.000018	0.0465	2.24
45	40	814.9	0.7289	1.0	0.003704	0.000374	0.000159	0.4262	9.90
45	41	814.6	0.7286	5.0	0.006385	0.000565	0.000361	0.6385	11.30
45	42	814.2	0.7283	9.0	0.009667	0.000898	0.000672	0.7484	10.77
45	43	813.4	0.7276	13.0	0.013742	0.001430	0.001139	0.7966	9.61
45	44	812.9	0.727	15.0	0.015774	0.001771	0.001401	0.7910	8.91
45	45	812.6	0.7268	16.0	0.016788	0.001965	0.001538	0.7827	8.54
45	46	812.2	0.7265	17.0	0.017691	0.002167	0.001664	0.7678	8.16
45	47	819.4	0.7322	-4.0	0.000055	0.000442	0.000000	0.0007	0.12
45	48	819.4	0.7322	0.0	0.002865	0.000346	0.000108	0.3134	8.28
45	49	819.3	0.7321	4.0	0.005478	0.000492	0.000287	0.5827	11.13
45	50	818.9	0.7315	8.0	0.008599	0.000787	0.000564	0.7164	10.93
45	51	818.3	0.7309	12.0	0.012473	0.001260	0.000985	0.7818	9.90

RUN	Point	V tip (fps)	M tip	Coll.	CT	CP	Ideal CP	FM	CT/CP
45	52	817.9	0.7309	14.0	0.014736	0.001596	0.001265	0.7925	9.23
45	53	817.2	0.7304	16.0	0.016459	0.001920	0.001493	0.7777	8.57
45	54	817.2	0.7304	16.0	0.016581	0.001920	0.001510	0.7863	8.64
45	55	819.4	0.7326	-3.0	0.000751	0.000382	0.000015	0.0381	1.97
45	56	819.4	0.7326	1.0	0.003495	0.000371	0.000146	0.3938	9.42
45	57	819.2	0.7323	5.0	0.006146	0.000551	0.000341	0.6183	11.15
45	58	818.8	0.7319	9.0	0.009532	0.000889	0.000658	0.7402	10.72
45	59	818.0	0.7316	13.0	0.013511	0.001410	0.001110	0.7876	9.58
45	60	817.5	0.7312	15.0	0.015553	0.001745	0.001372	0.7860	8.91
45	61	817.1	0.7305	16.0	0.016708	0.001954	0.001527	0.7815	8.55
45	62	816.7	0.7301	17.0	0.017407	0.002124	0.001624	0.7646	8.20
45	63	816.6	0.7301	17.0	0.017585	0.002139	0.001649	0.7709	8.22
50	3	735.1	0.6624	0.0	0.002672	0.000336	0.000098	0.2907	7.95
50	4	735.0	0.6623	2.0	0.004072	0.000384	0.000184	0.4785	10.60
50	5	735.0	0.6622	4.0	0.005440	0.000480	0.000284	0.5911	11.33
50	6	734.7	0.6613	6.0	0.006954	0.000611	0.000410	0.6711	11.38
50	7	734.6	0.661	8.0	0.008664	0.000783	0.000570	0.7283	11.07
50	8	734.3	0.6605	10.0	0.010502	0.000992	0.000761	0.7672	10.59
50	9	734.2	0.6604	12.0	0.012423	0.001230	0.000979	0.7960	10.10
50	10	734.0	0.6598	14.0	0.014414	0.001516	0.001224	0.8072	9.51
50	11	733.7	0.6595	16.0	0.016471	0.001851	0.001495	0.8075	8.90
50	12	733.2	0.6588	18.0	0.018589	0.002246	0.001792	0.7979	8.28
50	13	655.2	0.5886	0.0	0.002664	0.000328	0.000097	0.2964	8.12
50	14	655.2	0.5878	2.0	0.004166	0.000388	0.000190	0.4900	10.74
50	15	655.2	0.5876	4.0	0.005571	0.000492	0.000294	0.5976	11.32
50	16	655.0	0.5873	6.0	0.007065	0.000620	0.000420	0.6773	11.40
50	17	654.9	0.5871	8.0	0.008822	0.000798	0.000586	0.7342	11.06
50	18	654.8	0.5868	10.0	0.010556	0.000996	0.000767	0.7700	10.60
50	19	654.6	0.5867	12.0	0.012504	0.001241	0.000989	0.7967	10.08
50	20	654.4	0.5862	14.0	0.014414	0.001516	0.001224	0.8072	9.51
50	21	654.6	0.5865	16.0	0.016440	0.001842	0.001491	0.8092	8.93
50	22	654.6	0.5862	18.0	0.018385	0.002189	0.001763	0.8053	8.40
50	23	654.5	0.5862	20.0	0.020239	0.002596	0.002036	0.7843	7.80
50	24	654.6	0.586	22.0	0.021162	0.003011	0.002177	0.7230	7.03
50	25	656.7	0.5879	1.0	0.003405	0.000358	0.000140	0.3924	9.51
50	26	656.7	0.5677	3.0	0.004798	0.000435	0.000235	0.5402	11.03
50	27	656.6	0.5876	5.0	0.006143	0.000544	0.000340	0.6258	11.29
50	28	656.5	0.5875	7.0	0.007848	0.000707	0.000492	0.6954	11.10
50	29	656.3	0.5872	9.0	0.009483	0.000887	0.000653	0.7362	10.69
50	30	656.2	0.587	11.0	0.011261	0.001090	0.000845	0.7752	10.33
50	31	655.9	0.5869	13.0	0.013189	0.001365	0.001071	0.7846	9.66
50	32	655.7	0.5868	15.0	0.015089	0.001639	0.001311	0.7996	9.21
50	33	655.4	0.5862	17.0	0.017142	0.001987	0.001587	0.7987	8.63
50	34	655.0	0.5862	19.0	0.019326	0.002383	0.001900	0.7972	8.11
50	35	654.6	0.5857	21.0	0.020921	0.002784	0.002140	0.7686	7.51
50	36	654.6	0.5857	21.5	0.021215	0.002871	0.002185	0.7611	7.39
50	37	654.5	0.5855	22.0	0.021326	0.002965	0.002202	0.7427	7.19
50	38	654.5	0.5855	22.5	0.021358	0.003025	0.002207	0.7296	7.06

RUN	Point	V tip (fps)	M tip	Coll.	CT	CP	Ideal CP	FM	CT/CP
50	39	654.2	0.5853	23.0	0.022002	0.003209	0.002308	0.7191	6.86
50	40	741.3	0.6631	0.0	0.002649	0.000342	0.000096	0.2819	7.75
50	41	741.0	0.6625	5.0	0.006239	0.000556	0.000348	0.6267	11.22
50	42	740.9	0.6619	7.0	0.007808	0.000705	0.000488	0.6920	11.08
50	43	740.8	0.6617	9.0	0.009346	0.000866	0.000639	0.7377	10.79
50	44	740.4	0.6612	11.0	0.011592	0.001125	0.000883	0.7845	10.30
50	45	740.5	0.6613	11.0	0.011496	0.001123	0.000872	0.7761	10.24
50	46	740.2	0.6607	13.0	0.013338	0.001377	0.001089	0.7910	9.69
50	47	739.8	0.6604	15.0	0.015536	0.001714	0.001369	0.7989	9.06
50	48	739.3	0.6599	17.0	0.018021	0.002107	0.001711	0.8119	8.55
50	49	738.9	0.6595	19.0	0.019170	0.002389	0.001877	0.7856	8.02

Table B–2. ATB Baseline Tips, Cuffs-Off Test Results at OARF

RUN	Point	V tip (fps)	M tip	Coll.	CT	CP	Ideal CP	FM	CT/CP
53	5	742.3	0.6622	0.0	0.002855	0.000348	0.000108	0.3100	8.20
53	6	742.2	0.6621	2.0	0.003959	0.000403	0.000176	0.4371	9.82
53	7	742.2	0.6621	4.0	0.005308	0.000492	0.000273	0.5558	10.79
53	8	741.9	0.662	6.0	0.006789	0.000636	0.000396	0.6219	10.67
53	9	741.8	0.6616	8.0	0.008440	0.000805	0.000548	0.6811	10.48
53	10	741.5	0.6615	10.0	0.010324	0.001022	0.000742	0.7258	10.10
53	11	741.5	0.6615	10.0	0.010323	0.001022	0.000742	0.7257	10.10
53	12	741.5	0.6613	10.0	0.010275	0.001024	0.000736	0.7192	10.03
53	13	741.5	0.6614	10.0	0.010218	0.001005	0.000730	0.7267	10.17
53	14	741.5	0.6614	10.0	0.010195	0.001016	0.000728	0.7164	10.03
53	15	741.3	0.661	12.0	0.012295	0.001293	0.000964	0.7456	9.51
53	16	741.3	0.6607	12.0	0.012532	0.001293	0.000992	0.7672	9.69
53	17	741.0	0.6603	14.0	0.014340	0.001585	0.001214	0.7661	9.05
53	18	740.5	0.6603	16.0	0.016312	0.001922	0.001473	0.7665	8.49
53	19	740.1	0.6597	18.0	0.018180	0.002287	0.001733	0.7579	7.95
53	20	739.7	0.6597	19.0	0.019524	0.002558	0.001929	0.7541	7.63
54	3	741.8	0.6657	2.0	0.004380	0.000427	0.000205	0.4800	10.26
54	4	741.5	0.6655	6.0	0.007539	0.000704	0.000463	0.6575	10.71
54	5	741.3	0.6651	10.0	0.011538	0.001158	0.000876	0.7568	9.96
54	6	740.5	0.6643	14.0	0.015753	0.001787	0.001398	0.7824	8.82
54	7	740.1	0.6639	16.0	0.017953	0.002204	0.001701	0.7718	8.15
54	8	740.0	0.6639	16.0	0.018122	0.002223	0.001725	0.7760	8.15

Table B–3. ATB Baseline Tips, Cuffs Extended Test Results at OARF

RUN	Point	V tip (fps)	M tip	Coll.	CT	CP	Ideal CP	FM	CT/CP
55	5	739.1	0.6624	0.0	0.002495	0.000342	0.000088	0.2577	7.30
55	6	739.1	0.6624	2.0	0.003768	0.000376	0.000164	0.4350	10.02
55	7	738.9	0.6622	4.0	0.005047	0.000459	0.000254	0.5524	11.00
55	8	738.8	0.6621	6.0	0.006409	0.000574	0.000363	0.6321	11.17
55	9	738.7	0.662	8.0	0.008016	0.000727	0.000507	0.6981	11.03
55	10	738.4	0.6618	10.0	0.009846	0.000928	0.000691	0.7444	10.61
55	11	738.3	0.6616	12.0	0.011726	0.001165	0.000898	0.7707	10.07
55	12	737.9	0.6613	14.0	0.013986	0.001459	0.001170	0.8016	9.59
55	13	737.6	0.6611	16.0	0.015734	0.001749	0.001396	0.7979	9.00
55	14	737.2	0.6607	18.0	0.017786	0.002099	0.001677	0.7991	8.47
55	15	738.9	0.6622	0.5	0.002806	0.000339	0.000105	0.3100	8.28
55	16	738.9	0.6622	2.5	0.004088	0.000388	0.000185	0.4763	10.54
55	17	738.8	0.6621	4.5	0.005335	0.000479	0.000276	0.5752	11.14
55	18	738.7	0.662	6.5	0.006925	0.000614	0.000407	0.6637	11.28
55	19	738.5	0.6618	8.5	0.008547	0.000779	0.000559	0.7172	10.97
55	20	738.3	0.6615	10.5	0.010580	0.001004	0.000770	0.7664	10.54
55	21	737.9	0.6613	12.5	0.012562	0.001262	0.000996	0.7889	9.95
55	22	737.6	0.661	14.5	0.014627	0.001544	0.001251	0.8102	9.47
55	23	737.2	0.6607	16.5	0.016725	0.001880	0.001529	0.8135	8.90
55	24	736.8	0.6603	18.5	0.018198	0.002203	0.001736	0.7880	8.26
55	25	736.4	0.6601	20.0	0.019772	0.002532	0.001966	0.7764	7.81
55	26	738.8	0.6622	1.0	0.003182	0.000354	0.000127	0.3585	8.99
55	27	738.7	0.6621	3.0	0.004313	0.000408	0.000200	0.4909	10.57
55	28	738.7	0.662	5.0	0.005640	0.000509	0.000300	0.5884	11.08
55	29	738.4	0.6618	7.0	0.007326	0.000654	0.000443	0.6780	11.20
55	30	738.3	0.6616	9.0	0.009122	0.000839	0.000616	0.7343	10.87
55	31	738.0	0.6613	11.0	0.011016	0.001058	0.000818	0.7727	10.41
55	32	737.8	0.6611	13.0	0.012948	0.001321	0.001042	0.7887	9.80
55	33	737.4	0.6607	15.0	0.015200	0.001647	0.001325	0.8046	9.23
55	34	737.0	0.6602	17.0	0.017289	0.001994	0.001607	0.8061	8.67
55	35	736.4	0.6598	19.0	0.019504	0.002426	0.001926	0.7939	8.04
55	36	738.7	0.6617	1.5	0.003501	0.000364	0.000146	0.4024	9.62
55	37	738.7	0.6617	3.5	0.004689	0.000440	0.000227	0.5160	10.66
55	38	738.4	0.6615	5.5	0.006157	0.000550	0.000342	0.6211	11.19
55	39	738.3	0.6614	7.5	0.007735	0.000698	0.000481	0.6892	11.08
55	40	738.1	0.6614	9.5	0.009273	0.000875	0.000631	0.7216	10.60
55	41	738.1	0.6614	9.5	0.009422	0.000874	0.000647	0.7399	10.78
55	42	738.0	0.6612	11.5	0.011146	0.001086	0.000832	0.7662	10.26
55	43	737.6	0.661	13.5	0.013231	0.001370	0.001076	0.7855	9.66
55	44	737.4	0.6606	15.5	0.015339	0.001673	0.001343	0.8029	9.17
55	45	736.8	0.6602	17.5	0.017338	0.002041	0.001614	0.7909	8.49
55	46	736.3	0.6598	19.5	0.019511	0.002470	0.001927	0.7802	7.90
55	50	819.7	0.7336	0.0	0.002433	0.000349	0.000085	0.2431	6.97
55	51	819.6	0.7333	2.0	0.003620	0.000372	0.000154	0.4140	9.73
55	52	819.4	0.7332	4.0	0.004750	0.000441	0.000231	0.5249	10.77
55	53	819.3	0.7331	6.0	0.006316	0.000558	0.000355	0.6361	11.32
55	54	819.2	0.733	8.0	0.007884	0.000714	0.000495	0.6933	11.04

RUN	Point	V tip (fps)	M tip	Coll.	CT	CP	Ideal CP	FM	CT/CP
55	55	818.8	0.7327	10.0	0.009746	0.000910	0.000680	0.7476	10.71
55	56	818.5	0.7324	12.0	0.011663	0.001152	0.000891	0.7731	10.12
55	57	818.1	0.732	14.0	0.013644	0.001433	0.001127	0.7864	9.52
56	3	746.8	0.6654	0.0	0.002422	0.000348	0.000084	0.2422	6.96
56	4	746.8	0.6654	4.0	0.004983	0.000452	0.000249	0.5503	11.02
56	5	746.4	0.665	8.0	0.008255	0.000741	0.000530	0.7157	11.14
56	6	746.0	0.6645	12.0	0.012111	0.001193	0.000942	0.7900	10.15
56	7	745.3	0.6639	16.0	0.015885	0.001763	0.001416	0.8030	9.01
56	8	819.4	0.7298	0.0	0.002292	0.000352	0.000078	0.2204	6.51
56	9	819.4	0.7295	4.0	0.004981	0.000451	0.000249	0.5512	11.04
56	10	819.0	0.7291	8.0	0.007865	0.000715	0.000493	0.6898	11.00
56	11	818.5	0.7286	12.0	0.011887	0.001174	0.000916	0.7806	10.13
56	12	818.1	0.7283	14.0	0.013812	0.001447	0.001148	0.7932	9.55
56	13	817.5	0.7276	16.0	0.015932	0.001801	0.001422	0.7895	8.85
56	14	817.2	0.7274	17.0	0.016890	0.001990	0.001552	0.7800	8.49
58	5	743.9	0.6624	-2.9	-0.000305	0.000467	#NUM!	#NUM!	-0.65
58	6	775.3	0.6898	-1.5	0.000667	0.000398	0.000012	0.0306	1.68
58	7	775.3	0.6898	0.0	0.001798	0.000359	0.000054	0.1502	5.01
58	8	775.2	0.6897	4.0	0.004394	0.000414	0.000206	0.4975	10.61
58	9	774.9	0.6894	8.0	0.007144	0.000649	0.000427	0.6579	11.01
58	10	774.5	0.6891	12.0	0.010853	0.001068	0.000799	0.7486	10.16
58	11	818.8	0.7285	0.0	0.001537	0.000354	0.000043	0.1204	4.34
58	12	818.8	0.7284	4.0	0.004373	0.000424	0.000204	0.4823	10.31
58	13	818.5	0.7282	8.0	0.007125	0.000662	0.000425	0.6424	10.76
58	14	817.9	0.7277	12.0	0.010949	0.001075	0.000810	0.7536	10.19

Table B–4. ATB Swept Tips, Extended Cuffs Test Results at OARF

RUN	Point	V tip (fps)	M tip	Coll.	CT	CP	Ideal CP	FM	CT/CP
59	5	739.7	0.6632	0.0	0.003056	0.000290	0.000119	0.4119	10.54
59	6	739.7	0.6632	2.0	0.004171	0.000349	0.000190	0.5458	11.95
59	7	739.6	0.6631	4.0	0.005252	0.000430	0.000269	0.6259	12.21
59	8	739.5	0.663	6.0	0.006569	0.000543	0.000376	0.6933	12.10
59	9	739.3	0.6628	8.0	0.007987	0.000682	0.000505	0.7401	11.71
59	10	739.1	0.6626	10.0	0.009536	0.000850	0.000658	0.7747	11.22
59	11	738.9	0.6625	11.0	0.011200	0.001043	0.000838	0.8036	10.74
59	12	739.5	0.663	14.0	0.013078	0.001290	0.001058	0.8198	10.14
59	13	739.2	0.6627	16.0	0.015145	0.001596	0.001318	0.8258	9.49
59	14	740.0	0.6635	1.0	0.003649	0.000317	0.000156	0.4917	11.51
59	15	740.0	0.6634	3.0	0.004713	0.000387	0.000229	0.5912	12.18
59	16	739.8	0.6633	5.0	0.005916	0.000483	0.000322	0.6662	12.25
59	17	739.7	0.6632	7.0	0.007328	0.000608	0.000444	0.7296	12.05
59	18	739.6	0.6631	9.0	0.008912	0.000769	0.000595	0.7736	11.59
59	19	739.5	0.663	11.0	0.010530	0.000956	0.000764	0.7992	11.01
59	20	739.3	0.6628	13.0	0.012231	0.001165	0.000956	0.8210	10.50
59	21	738.9	0.6625	15.0	0.014154	0.001448	0.001191	0.8223	9.77
60	3	741.5	0.6621	-3.0	0.000786	0.000282	0.000016	0.0553	2.79
60	4	741.5	0.6621	-1.0	0.002393	0.000290	0.000083	0.2854	8.25
60	5	741.4	0.662	0.5	0.002945	0.000314	0.000113	0.3599	9.38
60	6	741.4	0.662	2.5	0.003955	0.000374	0.000176	0.4703	10.57
60	7	741.3	0.6619	4.5	0.005090	0.000458	0.000257	0.5607	11.11
60	8	741.2	0.6618	6.5	0.006455	0.000581	0.000367	0.6312	11.11
60	9	741.0	0.6616	8.5	0.007953	0.000730	0.000502	0.6870	10.89
60	10	740.9	0.6615	10.5	0.009628	0.000909	0.000668	0.7349	10.59
60	11	740.6	0.6613	12.5	0.011562	0.001130	0.000879	0.7780	10.23
60	12	740.4	0.6611	14.5	0.013253	0.001393	0.001079	0.7745	9.51
60	13	740.0	0.6608	16.5	0.015302	0.001679	0.001338	0.7972	9.11
60	14	741.3	0.6616	-0.5	0.002549	0.000298	0.000091	0.3054	8.55
60	15	741.3	0.6615	1.5	0.003577	0.000348	0.000151	0.4347	10.28
60	16	741.2	0.6615	3.5	0.004763	0.000421	0.000232	0.5521	11.31
60	17	741.2	0.6614	5.5	0.005980	0.000532	0.000327	0.6146	11.24
60	18	741.0	0.6609	7.5	0.007449	0.000657	0.000455	0.6919	11.34
60	19	740.9	0.6608	9.5	0.008685	0.000795	0.000572	0.7199	10.92
60	20	740.6	0.6606	11.5	0.010522	0.001020	0.000763	0.7482	10.32
60	21	740.4	0.6604	13.5	0.012325	0.001254	0.000968	0.7716	9.83
60	22	740.1	0.6602	15.5	0.014239	0.001526	0.001201	0.7873	9.33
61	3	818.8	0.7302	0.0	0.002563	0.000299	0.000092	0.3069	8.57
61	4	818.6	0.7302	2.0	0.003456	0.000340	0.000144	0.4225	10.16
61	5	818.5	0.7296	4.0	0.004447	0.000422	0.000210	0.4969	10.54
61	6	818.4	0.7295	6.0	0.005722	0.000523	0.000306	0.5852	10.94
61	7	818.3	0.7294	8.0	0.007307	0.000659	0.000442	0.6702	11.09
61	8	818.0	0.7292	10.0	0.008729	0.000818	0.000577	0.7050	10.67
61	9	817.7	0.7289	12.0	0.010456	0.001015	0.000756	0.7448	10.30
61	10	817.5	0.7286	14.0	0.012242	0.001243	0.000958	0.7705	9.85
61	11	818.5	0.7296	1.0	0.002983	0.000319	0.000115	0.3611	9.35
61	12	818.4	0.7295	3.0	0.004004	0.000381	0.000179	0.4702	10.51
61	13	818.4	0.7295	5.0	0.005174	0.000475	0.000263	0.5540	10.89

RUN	Point	V tip (fps)	M tip	Coll.	CT	CP	Ideal CP	FM	CT/CP
61	14	818.1	0.7293	7.0	0.006412	0.000583	0.000363	0.6227	11.00
61	15	818.0	0.7292	9.0	0.007952	0.000732	0.000501	0.6850	10.86
61	16	817.7	0.729	11.0	0.009717	0.000920	0.000677	0.7362	10.56
61	17	817.5	0.7287	13.0	0.011520	0.001139	0.000874	0.7676	10.11

Table B–5. ATB Square Tips, Extended Cuffs Test Results at OARF

RUN	Point	V tip (fps)	M tip	Coll.	CT	CP	Ideal CP	FM	CT/CP
62	7	741.0	0.6622	-1.0	0.001215	0.000328	0.000030	0.0913	3.70
62	8	741.3	0.662	2.0	0.003460	0.000360	0.000144	0.3998	9.61
62	9	741.2	0.6618	4.0	0.004648	0.000436	0.000224	0.5139	10.66
62	10	741.0	0.6615	6.0	0.006041	0.000549	0.000332	0.6048	11.00
62	11	740.8	0.6613	8.0	0.007580	0.000694	0.000467	0.6724	10.92
62	12	740.5	0.661	10.0	0.009369	0.000887	0.000641	0.7229	10.56
62	13	740.8	0.6612	1.0	0.002703	0.000335	0.000099	0.2966	8.07
62	14	740.6	0.6608	3.0	0.004015	0.000391	0.000180	0.4601	10.27
62	15	740.2	0.6604	5.0	0.005326	0.000487	0.000275	0.5644	10.94
62	16	740.0	0.66	7.0	0.006819	0.000619	0.000398	0.6432	11.02
63	7	748.1	0.6628	0.5	0.002431	0.000340	0.000085	0.2493	7.15
63	8	748.1	0.6631	2.5	0.003695	0.000376	0.000159	0.4224	9.83
63	9	748.0	0.6626	4.5	0.004944	0.000449	0.000246	0.5475	11.01
63	10	747.8	0.6628	6.5	0.006148	0.000554	0.000341	0.6153	11.10
63	11	747.7	0.6626	8.5	0.007916	0.000723	0.000498	0.6888	10.95
63	12	747.6	0.6627	10.5	0.009807	0.000925	0.000687	0.7424	10.60
63	13	747.3	0.6621	12.5	0.011864	0.001178	0.000914	0.7757	10.07
63	14	747.3	0.6621	12.5	0.011546	0.001150	0.000877	0.7628	10.04
63	15	747.3	0.6621	12.5	0.011583	0.001151	0.000881	0.7658	10.06
63	16	747.0	0.6618	14.5	0.013846	0.001458	0.001152	0.7902	9.50
63	17	746.7	0.6617	16.5	0.016052	0.001820	0.001438	0.7901	8.82
63	18	746.3	0.6613	18.5	0.018104	0.002193	0.001722	0.7854	8.26
63	19	748.1	0.6624	1.5	0.002905	0.000356	0.000111	0.3110	8.16
63	20	748.0	0.6623	3.5	0.004163	0.000406	0.000190	0.4678	10.25
63	21	747.8	0.6625	5.5	0.005435	0.000510	0.000283	0.5555	10.66
63	22	747.8	0.6625	5.5	0.005418	0.000511	0.000282	0.5519	10.60
63	23	747.8	0.6622	7.5	0.006979	0.000650	0.000412	0.6343	10.74
63	24	747.6	0.662	9.5	0.008691	0.000817	0.000573	0.7012	10.64
63	25	747.3	0.6621	11.5	0.010526	0.001033	0.000764	0.7392	10.19
63	26	747.2	0.6619	13.5	0.012504	0.001287	0.000989	0.7682	9.72
63	27	746.8	0.6616	15.5	0.014684	0.001589	0.001258	0.7918	9.24
63	28	746.3	0.6612	17.5	0.016855	0.001956	0.001547	0.7911	8.62

Appendix C

0.658-Scale Proprotor for JVX Configuration of V-22 (NASA OARF Test)

This appendix contains:

1. Proprotor configuration (figs. C-1 to C-4).
2. Performance data of C_P versus C_T and C_T versus 3/4 radius collective for the NASA OARF test (figs. C-5 and C-6, and table C-1).

1. Proprotor Configuration

The 0.658-scaled JVX proprotor was described in references 12 and 14. With some editing, the following summary discussion is as follows:

The JVX rotor was an experimental precursor to the V-22 rotor, hence the name "Joint Vertical Experimental." Several tests of the JVX rotor were performed at NASA Ames Research Center, including hover testing at the NASA Outdoor Aerodynamic Research Facility (OARF) and high-speed, axial-flow tests in the 40- by 80-ft test section (the "40 x 80") of the National Full-Scale Aerodynamics Complex (NFAC). The hover data were originally reported in reference 12. The installation, check-out, and then hover testing were conducted from the end of April to the middle of June in 1984.

Sometimes referred to as a "2/3-scale V-22," and more rarely "M901 rotor," the JVX rotor in fact differed from the V-22 in several respects. The JVX rotor was 25 feet in diameter, which is 0.656-scale relative to the production V-22. The JVX rotor used an XV-15 hub with fixed, 2.5-degree precone, whereas the V-22 hub has a coning flexure with slightly different at-rest precone. An XV-15 spinner was used for the JVX rotor, instead of the proportionately much shorter V-22 spinner. Hover testing was done with the original JVX blade planform and airfoil distribution, which had linear taper and an XN-28 airfoil at the root. The JVX rotor was always tested when mounted to the Propeller Test Rig (PTR), which had a fairing over the rotor balance just behind the hub. The trailing edges at the blade roots were slightly clipped to clear the rotor balance fairing.

Figure C-1. The 0.658-scale JVX composite-bladed proprotor tested in hover at the NASA OARF.

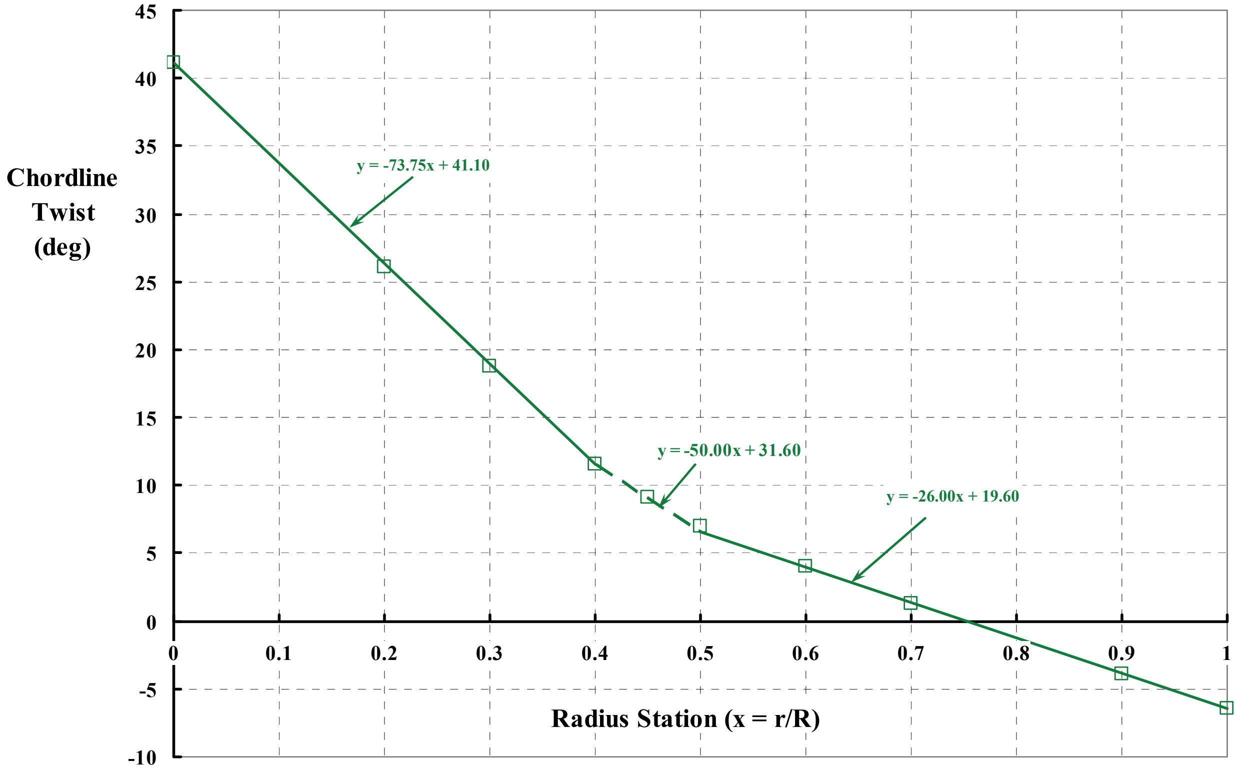

Figure C-2. The 0.658-scale JVX proprotor—twist vs. radius station.

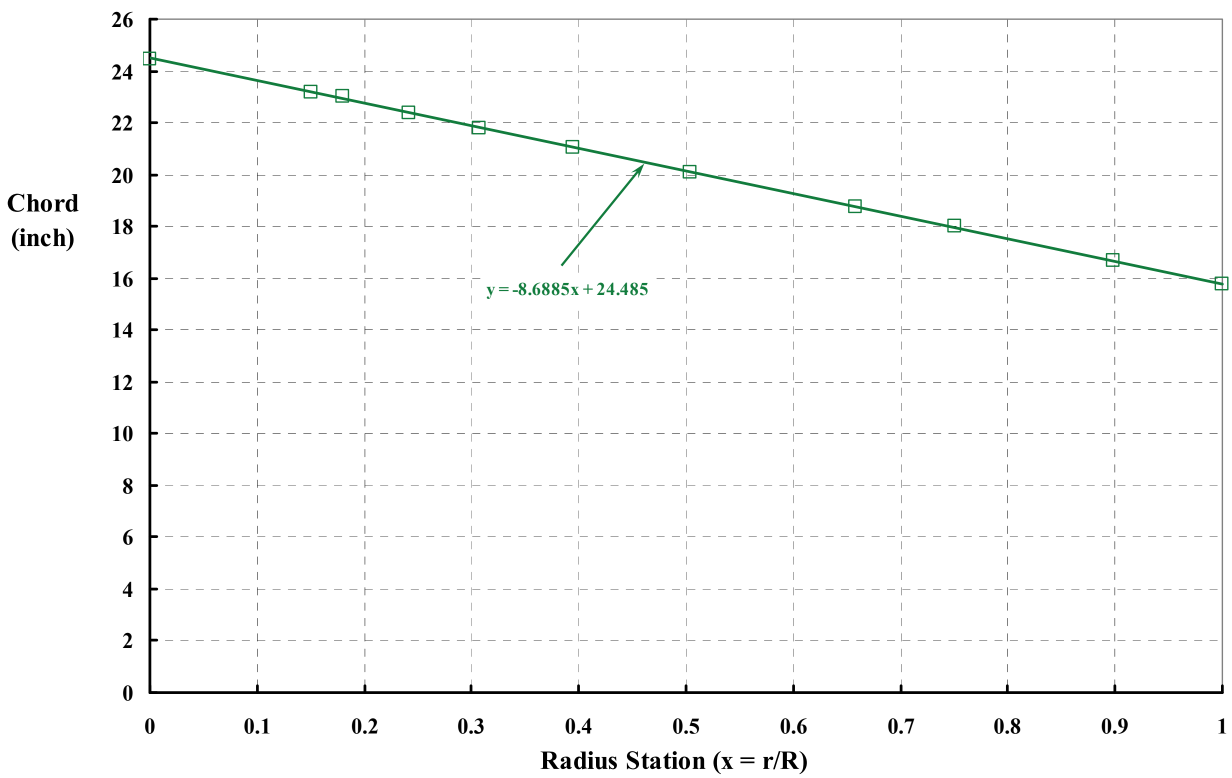

Figure C-3. The 0.658-scale JVX proprotor—chord vs. radius station.

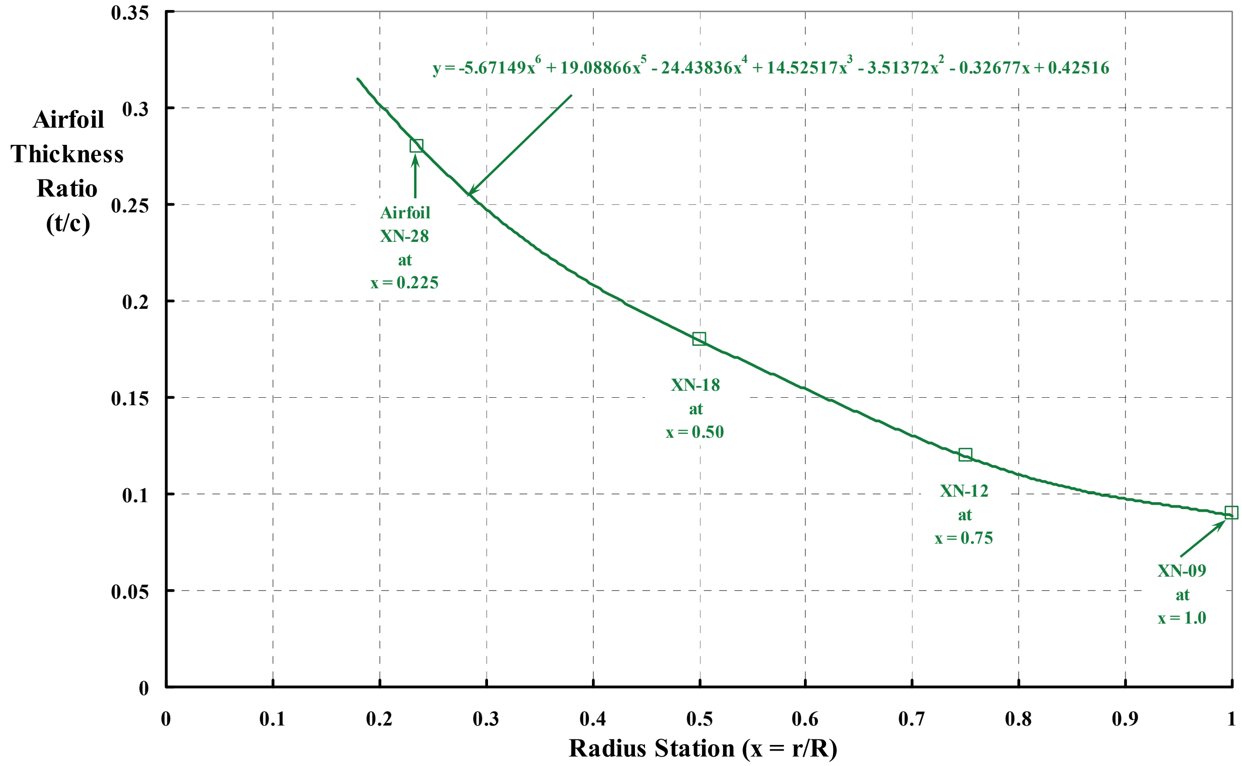

Figure C-4. The 0.658-scale JVX proprotor—airfoil thickness ratio vs. radius station.

2. Performance Data

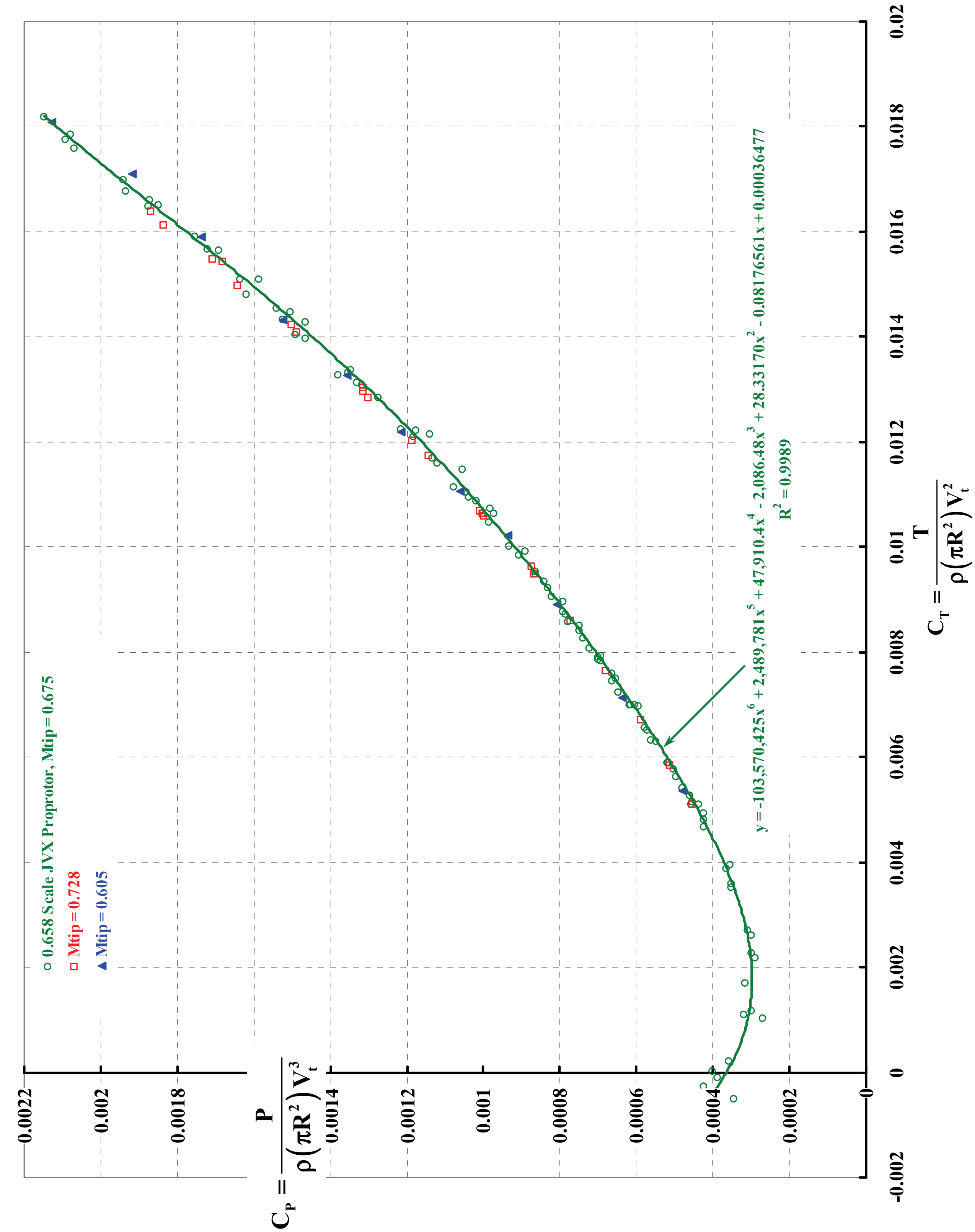

Figure C-5. The 0.658-scale JVX test results at OARF—power vs. thrust coefficient.

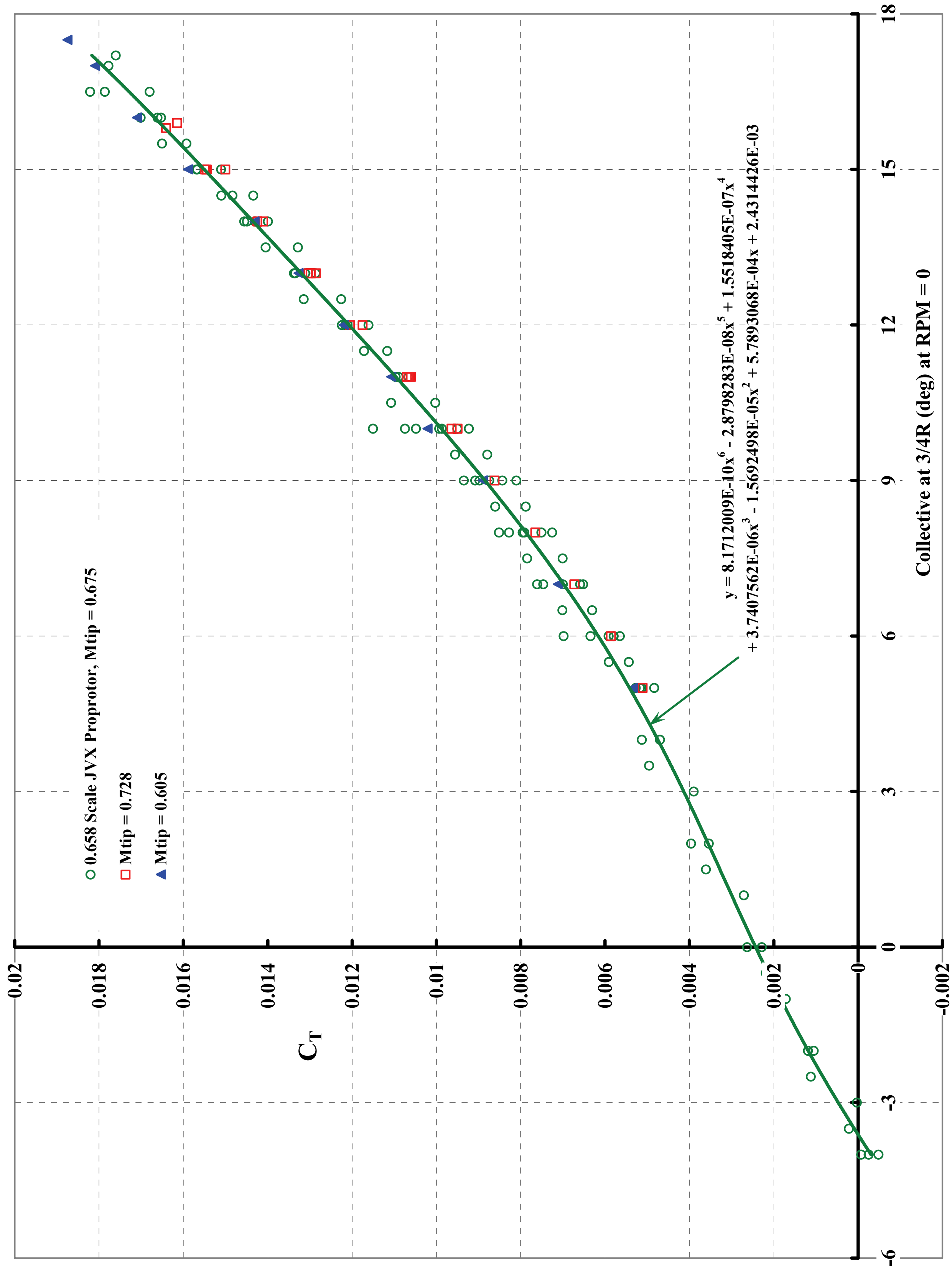

Figure C-6. The 0.658-scale JVX test results at OARF—thrust coefficient vs. collective pitch.

Table C–1. The 0.658-Scale JVX Test Results at OARF

RUN	Point	V tip (fps)	M tip	Coll.	CT	CP	Ideal CP	FM	CT/CP
1	7	750.2	0.6747	10.0	0.010744	0.000983	0.000787	0.8011	10.93
1	8	752.8	0.6768	-4.0	-0.000484	0.000345	0.000008	0.0218	-1.40
1	9	752.9	0.6768	-2.0	0.001053	0.000269	0.000024	0.0898	3.91
1	10	752.8	0.6768	0.0	0.002630	0.000300	0.000095	0.3179	8.77
1	11	752.8	0.6765	2.0	0.003959	0.000354	0.000176	0.4976	11.18
1	12	752.7	0.6765	4.0	0.005125	0.000438	0.000259	0.5923	11.70
1	13	752.5	0.6762	6.0	0.006981	0.000595	0.000412	0.6932	11.73
1	14	752.5	0.6761	7.0	0.007611	0.000663	0.000470	0.7082	11.48
1	15	752.4	0.6760	8.0	0.008513	0.000748	0.000555	0.7425	11.38
1	17	752.3	0.6759	9.0	0.009077	0.000821	0.000612	0.7448	11.06
2	4	759.5	0.6776	-3.5	0.000217	0.000359	0.000002	0.0063	0.60
2	5	759.4	0.6776	-4.0	-0.000071	0.000386	0.000000	0.0011	-0.18
2	6	759.4	0.6771	-2.5	0.001117	0.000317	0.000026	0.0833	3.52
2	7	759.5	0.6770	-0.5	0.002188	0.000290	0.000072	0.2496	7.54
2	8	759.4	0.6765	1.5	0.003605	0.000350	0.000153	0.4373	10.30
2	9	759.3	0.6765	3.5	0.004952	0.000423	0.000246	0.5825	11.71
2	10	759.2	0.6766	5.5	0.005908	0.000515	0.000321	0.6235	11.47
2	11	759.2	0.6761	6.5	0.007009	0.000613	0.000415	0.6769	11.43
2	12	759.1	0.6760	7.5	0.007846	0.000694	0.000491	0.7081	11.31
2	13	759.0	0.6755	8.5	0.008603	0.000778	0.000564	0.7252	11.06
2	14	758.9	0.6755	9.5	0.009554	0.000862	0.000660	0.7660	11.08
2	15	758.7	0.6753	10.5	0.011072	0.001045	0.000824	0.7883	10.60
2	16	758.6	0.6752	11.5	0.011712	0.001132	0.000896	0.7917	10.35
2	17	760.6	0.6766	12.5	0.013145	0.001329	0.001066	0.8019	9.89
2	19	760.4	0.6766	13.5	0.014046	0.001491	0.001177	0.7895	9.42
2	20	760.2	0.6769	14.5	0.014833	0.001620	0.001277	0.7885	9.16
2	21	759.8	0.6769	15.5	0.016506	0.001874	0.001500	0.8002	8.81
2	22	759.6	0.6760	16.5	0.018209	0.002146	0.001737	0.8096	8.49
2	23	761.4	0.6779	-4.0	-0.000252	0.000423	0.000003	0.0067	-0.60
2	24	761.6	0.6786	-2.0	0.001186	0.000300	0.000029	0.0963	3.95
2	25	761.6	0.6786	0.0	0.002281	0.000299	0.000077	0.2576	7.63
2	26	761.5	0.6780	2.0	0.003537	0.000351	0.000149	0.4238	10.08
2	27	761.4	0.6785	4.0	0.004698	0.000425	0.000228	0.5358	11.05
2	28	761.2	0.6779	6.0	0.006345	0.000561	0.000357	0.6370	11.31
2	29	761.1	0.6781	8.0	0.008278	0.000739	0.000533	0.7207	11.20
2	30	760.9	0.6782	9.0	0.009349	0.000842	0.000639	0.7591	11.10
2	31	760.8	0.6781	10.0	0.010483	0.000986	0.000759	0.7697	10.63
3	3	746.9	0.6760	5.0	0.005171	0.000452	0.000263	0.5817	11.44

RUN	Point	V tip (fps)	M tip	Coll.	CT	CP	Ideal CP	FM	CT/CP
3	4	746.8	0.6758	6.0	0.005793	0.000504	0.000312	0.6186	11.49
3	5	746.7	0.6757	7.0	0.006590	0.000578	0.000378	0.6545	11.40
3	6	746.6	0.6753	8.0	0.007253	0.000648	0.000437	0.6740	11.19
3	7	746.5	0.6749	9.0	0.008101	0.000721	0.000516	0.7151	11.24
3	8	746.4	0.6747	10.0	0.009228	0.000832	0.000627	0.7534	11.09
3	9	746.3	0.6745	11.0	0.010657	0.000972	0.000778	0.8003	10.96
3	10	746.1	0.6743	12.0	0.012160	0.001139	0.000948	0.8325	10.68
3	11	749.5	0.6772	13.0	0.012863	0.001275	0.001032	0.8091	10.09
3	12	749.3	0.6769	14.0	0.014296	0.001466	0.001209	0.8245	9.75
3	13	749.2	0.6767	14.5	0.015100	0.001586	0.001312	0.8273	9.52
4	3	754.4	0.6774	-3.0	0.000028	0.000400	0.000000	0.0003	0.07
4	4	754.4	0.6774	-1.0	0.001711	0.000316	0.000050	0.1584	5.41
4	5	754.4	0.6773	1.0	0.002710	0.000310	0.000100	0.3218	8.74
4	6	754.3	0.6772	3.0	0.003894	0.000365	0.000172	0.4707	10.67
4	7	754.2	0.6771	5.0	0.005274	0.000459	0.000271	0.5900	11.49
4	8	754.1	0.6770	7.0	0.007001	0.000603	0.000414	0.6869	11.61
4	9	754.0	0.6768	8.0	0.007950	0.000693	0.000501	0.7233	11.47
4	10	753.9	0.6765	9.0	0.008974	0.000790	0.000601	0.7609	11.36
4	11	753.8	0.6765	10.0	0.009931	0.000890	0.000700	0.7863	11.16
4	12	753.7	0.6763	11.0	0.010900	0.001018	0.000805	0.7905	10.71
4	13	753.5	0.6762	12.0	0.012238	0.001177	0.000957	0.8133	10.40
4	14	753.3	0.6758	13.0	0.013375	0.001346	0.001094	0.8126	9.94
4	15	753.1	0.6756	14.0	0.014488	0.001503	0.001233	0.8204	9.64
4	16	752.9	0.6755	15.0	0.015670	0.001690	0.001387	0.8207	9.27
4	17	752.7	0.6751	16.0	0.016527	0.001849	0.001502	0.8125	8.94
5	3	756.7	0.6766	5.0	0.004832	0.000424	0.000238	0.5602	11.40
5	4	756.5	0.6766	6.0	0.005648	0.000497	0.000300	0.6039	11.36
5	5	756.5	0.6765	7.0	0.006520	0.000570	0.000372	0.6531	11.44
5	6	756.4	0.6763	8.0	0.007507	0.000654	0.000460	0.7032	11.48
5	7	756.3	0.6762	9.0	0.008434	0.000750	0.000548	0.7303	11.25
5	8	756.2	0.6761	10.0	0.009502	0.000864	0.000655	0.7580	11.00
5	9	756.0	0.6760	11.0	0.010660	0.001002	0.000778	0.7767	10.64
5	10	755.9	0.6759	12.0	0.011608	0.001121	0.000884	0.7889	10.36
5	11	755.7	0.6758	13.0	0.013107	0.001316	0.001061	0.8063	9.96
5	12	755.5	0.6755	14.0	0.013994	0.001463	0.001171	0.8001	9.57
5	13	755.4	0.6756	15.0	0.015104	0.001635	0.001313	0.8028	9.24
5	14	755.1	0.6752	16.0	0.016609	0.001871	0.001514	0.8090	8.88
5	15	754.6	0.6749	17.0	0.017776	0.002093	0.001676	0.8007	8.49
5	16	756.6	0.6767	5.5	0.005437	0.000479	0.000283	0.5918	11.35
5	17	756.5	0.6766	6.5	0.006305	0.000550	0.000354	0.6437	11.46

RUN	Point	V tip (fps)	M tip	Coll.	CT	CP	Ideal CP	FM	CT/CP
5	18	756.4	0.6765	7.5	0.007005	0.000616	0.000415	0.6730	11.37
5	19	756.3	0.6764	8.5	0.007878	0.000701	0.000494	0.7053	11.24
5	20	756.2	0.6763	9.5	0.008792	0.000792	0.000583	0.7360	11.10
5	21	756.1	0.6762	10.5	0.010026	0.000931	0.000710	0.7625	10.77
5	22	755.9	0.6760	11.5	0.011161	0.001078	0.000834	0.7734	10.35
5	23	755.7	0.6757	12.5	0.012256	0.001215	0.000959	0.7896	10.09
5	24	755.6	0.6755	13.5	0.013282	0.001378	0.001082	0.7855	9.64
5	25	755.4	0.6753	14.5	0.014339	0.001525	0.001214	0.7961	9.40
5	26	755.1	0.6751	15.5	0.015925	0.001753	0.001421	0.8106	9.08
5	27	754.9	0.6748	16.5	0.016797	0.001934	0.001539	0.7959	8.69
5	28	754.7	0.6745	17.2	0.017602	0.002068	0.001651	0.7985	8.51
6	6	755.6	0.6761	5.0	0.005128	0.000455	0.000260	0.5707	11.27
6	7	755.5	0.6756	6.0	0.005916	0.000520	0.000322	0.6188	11.38
6	8	755.4	0.6753	7.0	0.007463	0.000664	0.000456	0.6866	11.24
6	9	755.4	0.6751	8.0	0.007915	0.000701	0.000498	0.7103	11.29
6	10	755.3	0.6749	9.0	0.008745	0.000785	0.000578	0.7366	11.14
6	11	755.2	0.6746	10.0	0.009871	0.000905	0.000693	0.7663	10.91
6	12	755.0	0.6745	11.0	0.010965	0.001037	0.000812	0.7829	10.57
6	13	754.9	0.6742	12.0	0.012104	0.001183	0.000942	0.7960	10.23
6	14	758.1	0.6738	13.0	0.013345	0.001352	0.001090	0.8063	9.87
6	15	757.9	0.6766	14.0	0.014553	0.001539	0.001241	0.8066	9.46
6	16	757.7	0.6764	15.0	0.015687	0.001720	0.001389	0.8077	9.12
6	17	757.7	0.6764	16.0	0.017009	0.001939	0.001569	0.8090	8.77
6	18	757.5	0.6762	16.5	0.017863	0.002080	0.001688	0.8116	8.59
7	3	818.2	0.7290	5.0	0.005109	0.000454	0.000258	0.5688	11.25
7	4	818.1	0.7289	6.0	0.005862	0.000513	0.000317	0.6186	11.43
7	5	818.0	0.7288	7.0	0.006727	0.000587	0.000390	0.6646	11.46
7	6	817.9	0.7285	8.0	0.007654	0.000679	0.000473	0.6973	11.27
7	7	817.8	0.7283	9.0	0.008620	0.000772	0.000566	0.7330	11.17
7	8	817.7	0.7280	10.0	0.009636	0.000873	0.000669	0.7662	11.04
7	9	817.5	0.7279	11.0	0.010652	0.001000	0.000777	0.7774	10.65
7	10	817.4	0.7276	12.0	0.012045	0.001184	0.000935	0.7895	10.17
7	11	817.2	0.7274	13.0	0.012978	0.001315	0.001045	0.7950	9.87
7	12	818.4	0.7286	14.0	0.014104	0.001487	0.001184	0.7965	9.48
7	13	818.0	0.7284	15.0	0.015483	0.001708	0.001362	0.7976	9.06
7	14	817.8	0.7279	15.8	0.016406	0.001868	0.001486	0.7954	8.78
7	15	819.1	0.7289	10.0	0.009498	0.000867	0.000655	0.7549	10.96
7	16	818.9	0.7287	11.0	0.010603	0.000997	0.000772	0.7743	10.63
7	17	818.8	0.7286	12.0	0.011749	0.001143	0.000901	0.7878	10.28
7	18	818.5	0.7285	13.0	0.012851	0.001301	0.001030	0.7918	9.88

RUN	Point	V tip (fps)	M tip	Coll.	CT	CP	Ideal CP	FM	CT/CP
7	19	818.3	0.7283	14.0	0.014244	0.001499	0.001202	0.8019	9.50
7	20	818.0	0.7281	15.0	0.015000	0.001642	0.001299	0.7911	9.14
7	21	817.8	0.7281	15.9	0.016145	0.001834	0.001451	0.7909	8.80
8	15	813.7	0.7248	11.0	0.010698	0.001007	0.000782	0.7770	10.62
8	16	813.3	0.7244	13.0	0.013039	0.001314	0.001053	0.8012	9.92
8	17	812.9	0.7242	15.0	0.015441	0.001680	0.001357	0.8076	9.19
8	3	674.1	0.6004	5.0	0.005346	0.000480	0.000276	0.5758	11.14
8	4	674.0	0.6003	7.0	0.007124	0.000637	0.000425	0.6675	11.18
8	5	673.9	0.6003	9.0	0.008899	0.000807	0.000594	0.7356	11.03
8	6	673.7	0.6002	10.0	0.010211	0.000936	0.000730	0.7795	10.91
8	7	673.6	0.6001	11.0	0.011072	0.001060	0.000824	0.7772	10.45
8	8	680.1	0.6062	12.0	0.012197	0.001214	0.000952	0.7846	10.05
8	9	679.9	0.6060	13.0	0.013271	0.001356	0.001081	0.7972	9.79
8	10	679.8	0.6058	14.0	0.014310	0.001523	0.001210	0.7948	9.40
8	11	679.6	0.6056	15.0	0.015892	0.001738	0.001417	0.8151	9.14
8	12	679.4	0.6054	16.0	0.017097	0.001919	0.001581	0.8237	8.91
8	13	679.2	0.6052	17.0	0.018092	0.002127	0.001721	0.8090	8.51
8	14	679.1	0.6053	17.5	0.018751	0.002254	0.001816	0.8055	8.32

Appendix D

Initial Full-Scale Propeller for XC-142A (WADC Test)

This appendix contains:

1. General discussion (figs. D-1 and D-2).
2. Propeller configuration (figs. D-3 to D-7).
3. Performance data of C_P versus C_T and C_T versus 3/4 radius collective from the WADC test (figs. D-8 through D-11, and table D-1).

1. General Discussion

Overview

During early Phase I testing, the original XC-142A propeller (2FE16A3-4A), shown in figures D-1 and D-2, was found to be approximately 10% below the power coefficient $C_P = 0.00349$ (proprotor notation) predicted at the design takeoff point. The prediction method used for the 2FE16A3-4A was based on forward flight performance theory that was then standard in the industry, since propeller static thrust was not of primary interest at that time. The following general discussion was taken primarily from reference 15 (plus references 16 through 19), but with some editing to summarize facts directly applicable to the test results for the initial (2FE) and final (2FF) full-scale propellers ultimately tested on the XC-142A.

The basic purpose of the testing was to obtain data necessary to improve the propeller static performance of the XC-142A V/STOL cargo transport. The XC-142A is a prototype tilt-wing vertical takeoff cargo aircraft with four wing-mounted turboprop power plants, which provide thrust for both vertical and forward propulsion. A static thrust of approximately 10,000 pounds per propeller was required for the design takeoff gross weight of 37,470 pounds (plus control power) at sea level standard (S. L. S.) day conditions. This thrust corresponds to a propeller disc loading of approximately 50 pounds per square foot with 15.625-foot-diameter propellers. Initial flight testing of the XC-142A indicated a need for additional propeller static thrust to provide the desired vertical takeoff capability for the aircraft. A program was initiated by the XC-142A System Program Office to increase the static thrust performance of the propeller system. A major portion of this performance improvement program consisted of static propeller whirl testing conducted at the propeller electric whirl test facility at Wright-Patterson Air Force Base (WPAFB), Ohio. The objectives of this performance improvement program were to:

a. Determine the efficiency of the existing propeller design.
b. Determine the adequacy of the contractor's performance prediction method.
c. Provide empirical performance data so the design could be improved.
d. Determine the efficiency of a redesigned propeller for the XC-142A.

The XC-142A aircraft's operational requirements that dictated the specific propeller design were:

a. V_{max}—37,474 pounds gross weight (G. W.) on a standard day at sea level, at military rated shaft power* (not less than) 355 kts (409 mph).
b. Vertical thrust-to-weight ratio—37,474 pounds G. W. on a standard day at sea level, out of ground effect, takeoff rated shaft power,* not less than 1.15 pounds of thrust per pound of gross weight.

* Rated takeoff propeller speed of 1,232 RPM (1,008 ft/sec tip speed, Mtip = 0.903 at standard day conditions).

Figure D-1. Initial full-scale propeller (2FE16A3-4A) mounted on the XC-142A.

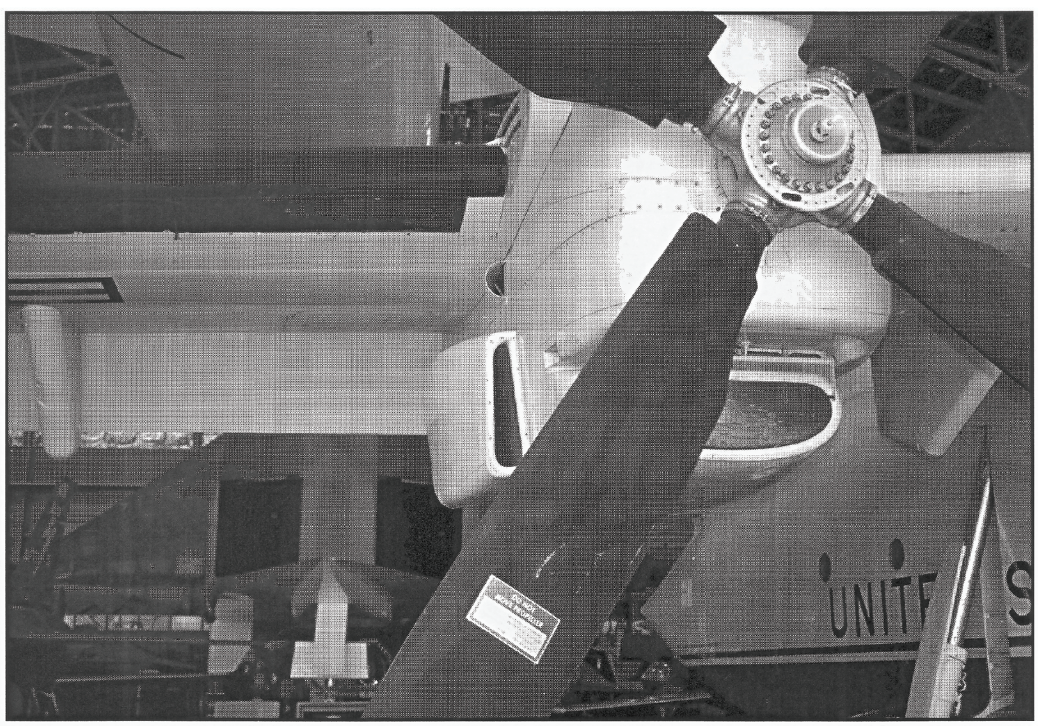
Figure D-2. The 2FE16A3-4A mounted on the XC-142A—no spinner was mounted during flight testing.

The conventional propeller is an efficient device for converting power to thrust. Propellers have demonstrated high Figures of Merit at the static or hover condition, and well-designed propellers, in the past, have demonstrated efficiencies above 90% at cruise speeds in the range of 200 to 400 kts. Thus, the propeller is a very suitable device for providing lift in the hover mode or thrust at cruise speeds in this speed range. Unfortunately, a compromise must be made between hover efficiency and cruise efficiency in the design of the optimum propeller for V/STOL applications.

In general, the hover performance of V/STOL aircraft has been below expectation, due in part to the lack of an accurate propeller performance prediction theory at zero airspeed. Developing a theory for calculating static performance requires good experimental data to check the accuracy of the theory. Very little experimental test data is available for propellers intended for high static thrust. Data that are available have been obtained on various commercial and government test devices, and results obtained from different devices make direct comparison difficult. Data in this report was obtained under controlled conditions from the same test facilities. Although limited in the range of parameters covered, the test program was designed to obtain data primarily for V/STOL applications and to obtain data that would be as accurate as possible under existing conditions. A special computer program was used during these tests for reducing the data. Details of this computer program can be found in technical report ASD-TR-68-19, *Computer Program for Reducing Static Propeller Test Data*.

Facilities

The tests described in this report consist basically of static whirl tests of various propeller configurations, and the measuring and recording of pertinent performance data. The original purpose of the propeller electric whirl rigs at WPAFB was to verify structural integrity and obtain a reasonable measurement of performance. Very accurate performance measurements for V/STOL applications were not considered in the design of these rigs, so they were not optimized in configuration and instrumentation for this purpose. Rig #4, installed in the mid-1950s at an approximate cost of $8 million, is the only equipment of this type and power range in the free world. It is the most accurate of the four whirl rigs at WPAFB.

The effect of rig blockage or the effect of the flat rig face on the indicated performance has often been questioned. For a smaller diameter propeller operating in proximity to the rig face, the effect is essentially that of operating in ground effect. This produces an increase in indicated thrust over that which would be produced in a free stream condition. Therefore, all tests were conducted on the 30,000-hp Electric Whirl Rig #4 and used a 12-foot gearbox extension. This places the plane of the propeller approximately 12 feet ahead of the flat face of the rig. Exact dimensions, plus a general view of the test rig, are provided in reference 15 (appendix II, fig. 60) Propeller Mount Configuration, Rig #4.

The following paragraphs give a brief description of the torque, thrust, and RPM measuring systems used for these tests.

The torque shaft is located between the propeller mount and the drive motor. A constant voltage source (66.6 volts) was routed through the torque-shaft-mounted slip rings to the differential transformer or transducer in the torque shaft. The transducer produces an electrical output signal that is proportional in amplitude to the applied torque. The transducer output signal was applied to a torque signal preamplifier and then to a ring demodulator. The signal from the ring demodulator then went to a digital voltmeter where the read-out voltage units were proportional to the torque applied. The torque system was calibrated statically by applying a series of known torques to the torque shaft by use of a static mount and hydraulic load cells. (These load cells and their read-out equipment were calibrated by the National Bureau of Standards.) The torque shaft output voltage, which was a function of the known torque, was then adjusted to a suitable 20 x 1 or 40 x 1 multiple between read-out voltage and applied torque. Torque shaft static calibrating plots are presented in reference 15 (fig. 84).

The thrust measuring system incorporated on Rig #4 is of the “MILL” type. Propeller thrust is transmitted to the speed-increaser gearbox, which is mounted on vertical flexure supports thus allowing the gearbox to move freely in an axial direction. The entire unit is maintained in its axial position by hydraulic thrust measuring and jacking cells. The hydraulic jacking cells are used to force the gearbox axially back to its null position when it becomes displaced due to propeller thrust. The amount of jacking necessary to return the gearbox to its null position is measured and indicated on a linear displacement gage system thus providing readout of thrust produced by the propeller.

The thrust measuring system consists of A. H. Emery Company hydraulic cells, a Differential Tate-Emery Indicator that measures thrust load, and a General Electric Linear Displacement Gage system for indicating null position of the gearbox. A device can also be attached for applying a known thrust while running that is used for calibrating the readout equipment.

Accurate shaft RPM was provided by a magnetic pickup that receives impulses from a 60-tooth gear. These impulses are then presented on a digital display meter as propeller RPM.

Test Procedure and Data Reduction

The test procedure was to set the collective pitch and vary tip speed from about 825 to slightly over 1,100 feet per second. Basic measurements were thrust, horsepower, RPM, and atmospheric pressure and temperature. This “raw data” was then reduced and analyzed with software as reported in reference 17. The data reduction by computer was summarized in reference 17 as follows:

A computer program using a curve-fit technique was developed to reduce performance data obtained from static tests of aircraft propellers. The entire program is written in Fortran IV language for use on the IBM 7094 computer located at Wright-Patterson AFB, Ohio.

The program accepts static whirl rig test data (i.e., raw RPM, horsepower, and thrust data) obtained at a fixed blade angle and reduces it into pertinent propeller relationships. The program first reduces the test data into various coefficients and computes the propeller tip Mach number. A curve fit technique then fits running curves through the *test thrust and horsepower data points at the test tip Mach numbers*. Intermediate horsepower and thrust values are determined from the fitted curves at selected Mach number increments, and all coefficients are recomputed. This results in a presentation of the reduced data in two forms: first coefficients computed from the actual test data and then coefficients obtained at specific constant Mach number increments from the fitted curves. The data is presented in tabular printout form. This is a general program and is written so that the order of the curve fit, the Mach number increment, the number of test data points, and the Mach number range can be varied.

The entire program deck and all nonstandard subroutines are included. Detail instructions are provided that should allow the program to be used by technicians or students who are familiar with Fortran IV language.

2. Propeller Configuration

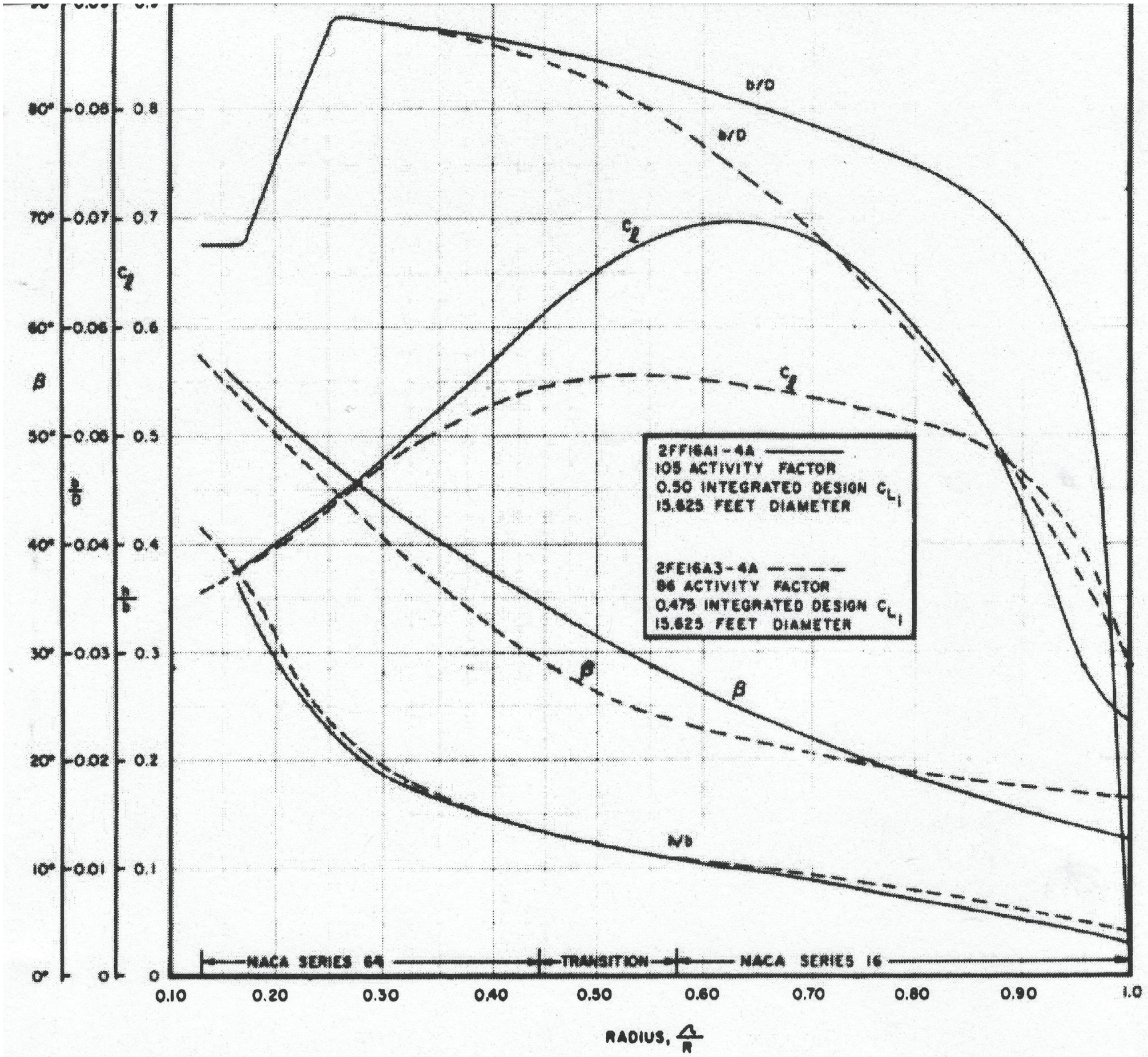

Figure D-3. Initial full-scale propeller (2FE16A3-4A) for the XC-142A. Follow the dashed lines. (This figure uses propeller nomenclature as shown in the table below.)

Parameter	Proprotor	Propeller
Diameter	D	D
Radius	R	R
Blade chord	c	b
Blade number	b	N or B
Airfoil thickness	t	h
Blade width ratio	Rarely used	b/D
Airfoil thickness ratio	t/c	h/b
Blade pitch angle	θ	β_0
Blade radial station	r or x = r/R	r or x = r/R

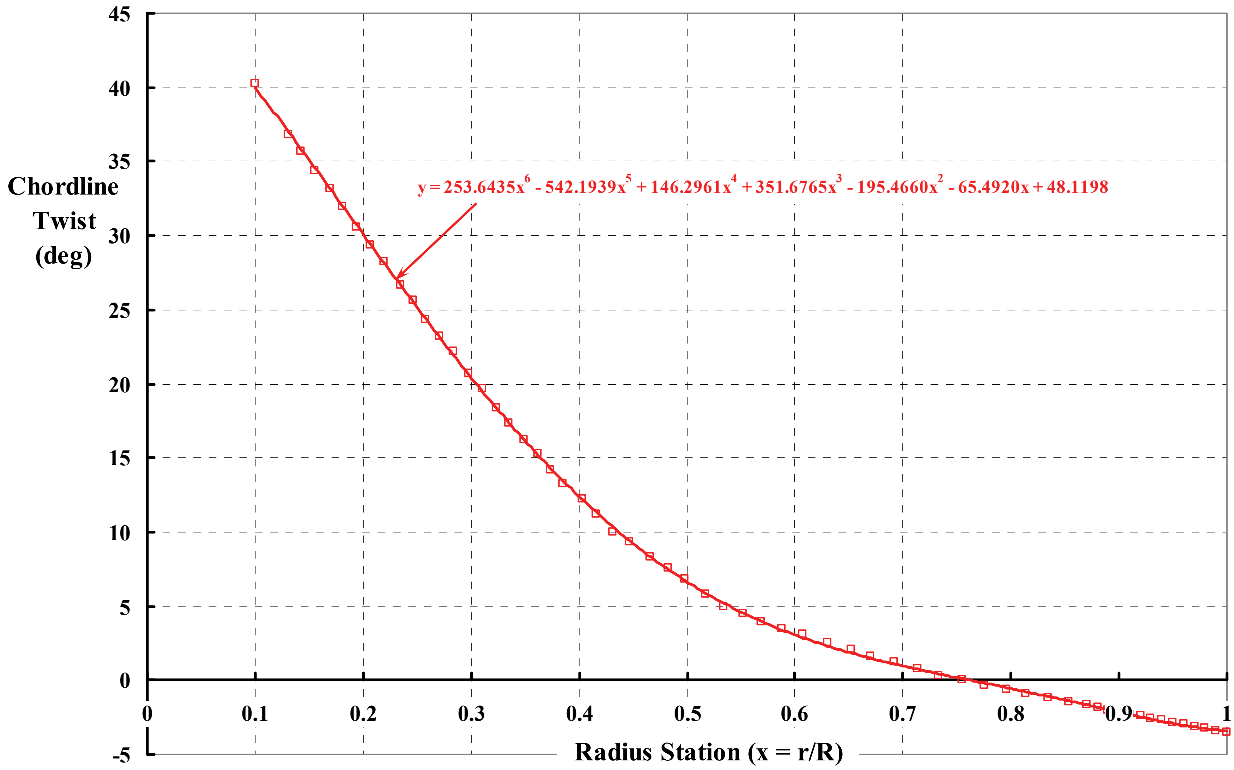

Figure D-4. Initial full-scale propeller (2FE16A3-4A) for the XC-142A—twist vs. radius station.

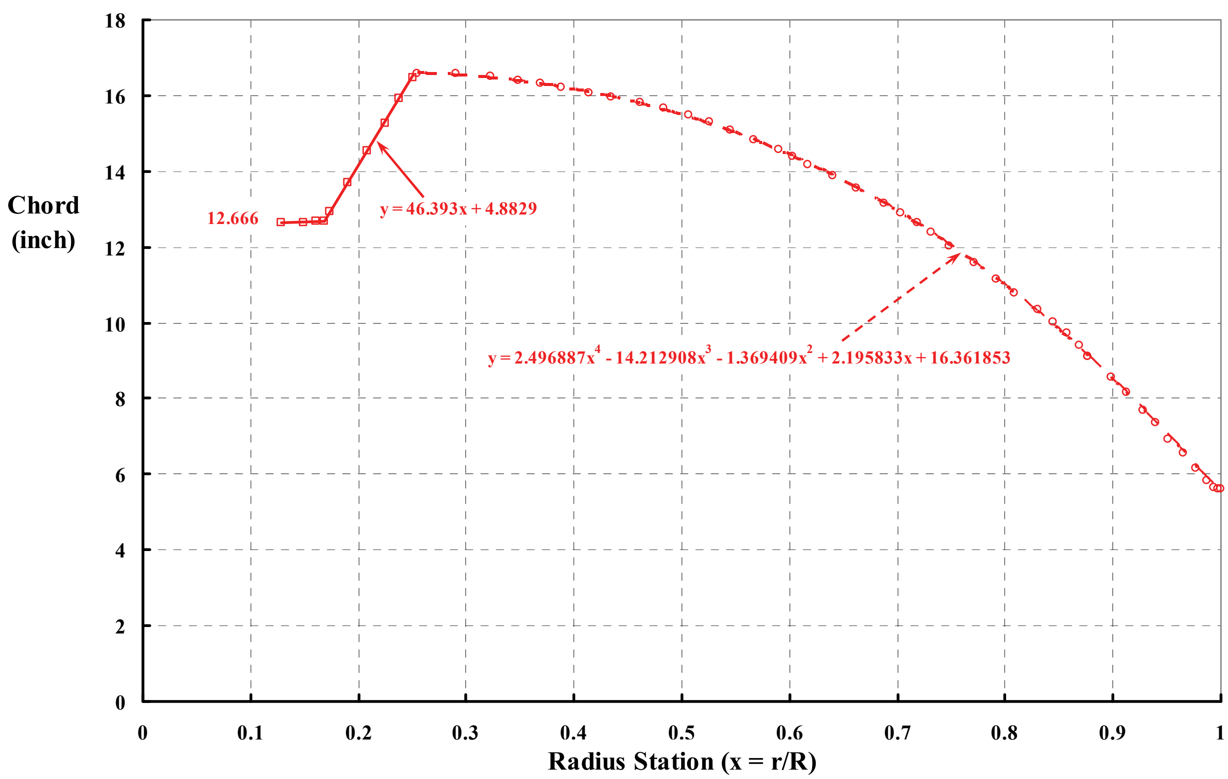

Figure D-5. Initial full-scale propeller (2FE16A3-4A) for the XC-142A—chord vs. radius station.

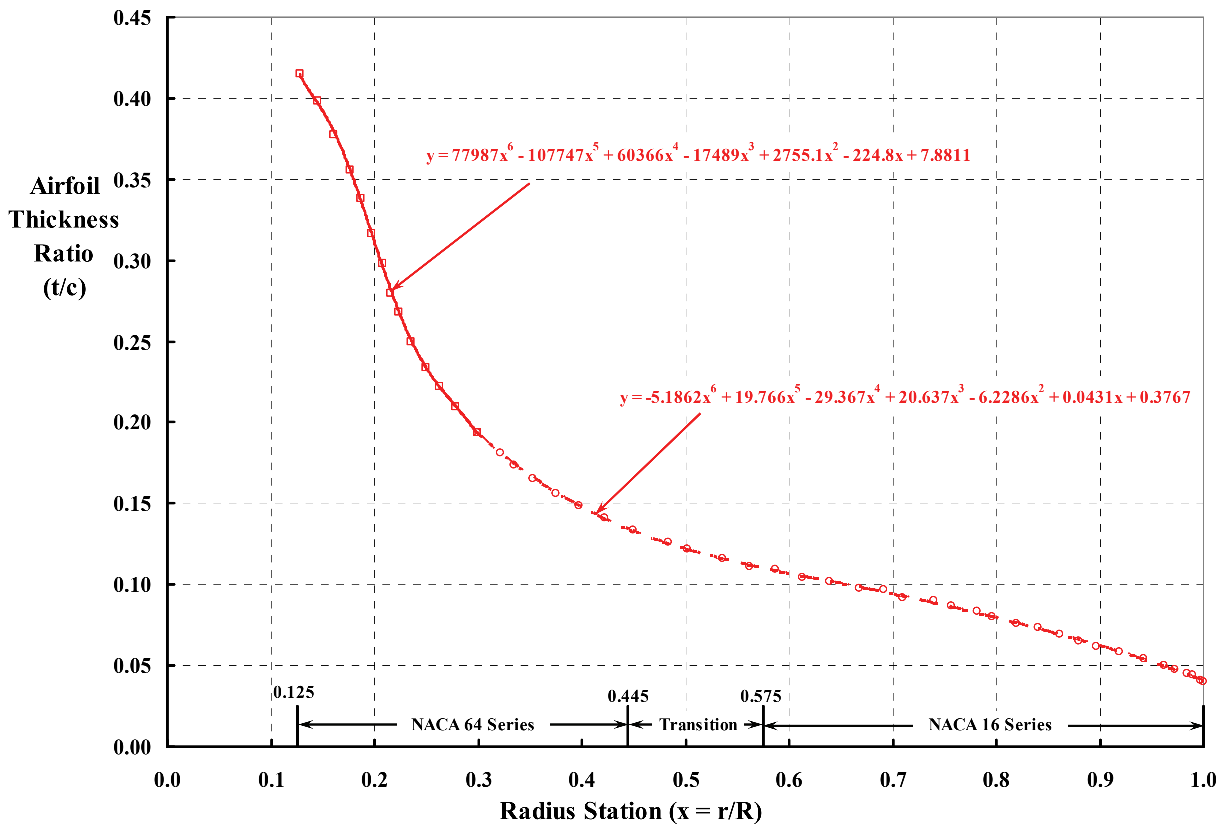

Figure D-6. Initial full-scale propeller (2FE16A3-4A) for the XC-142A—airfoil thickness ratio vs. radius station.

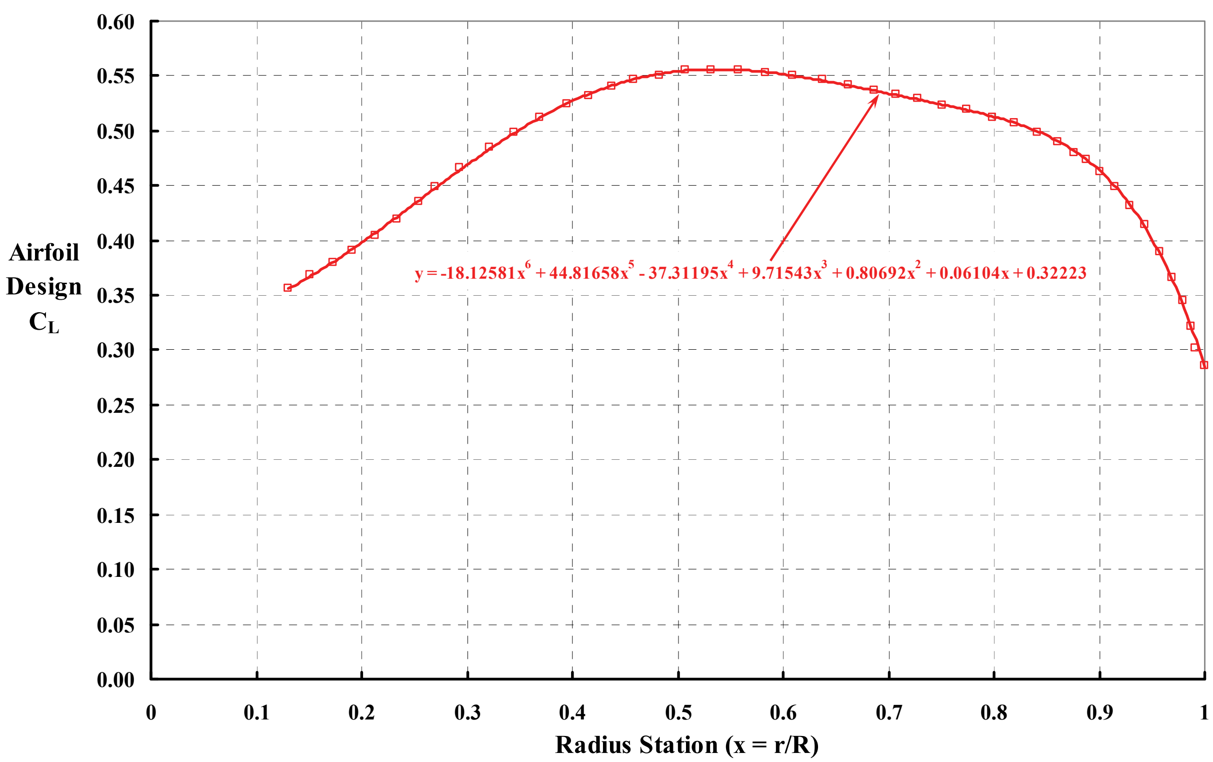

Figure D-7. Initial full-scale propeller (2FE16A3-4A) for the XC-142A—airfoil design C_L vs. radius station.

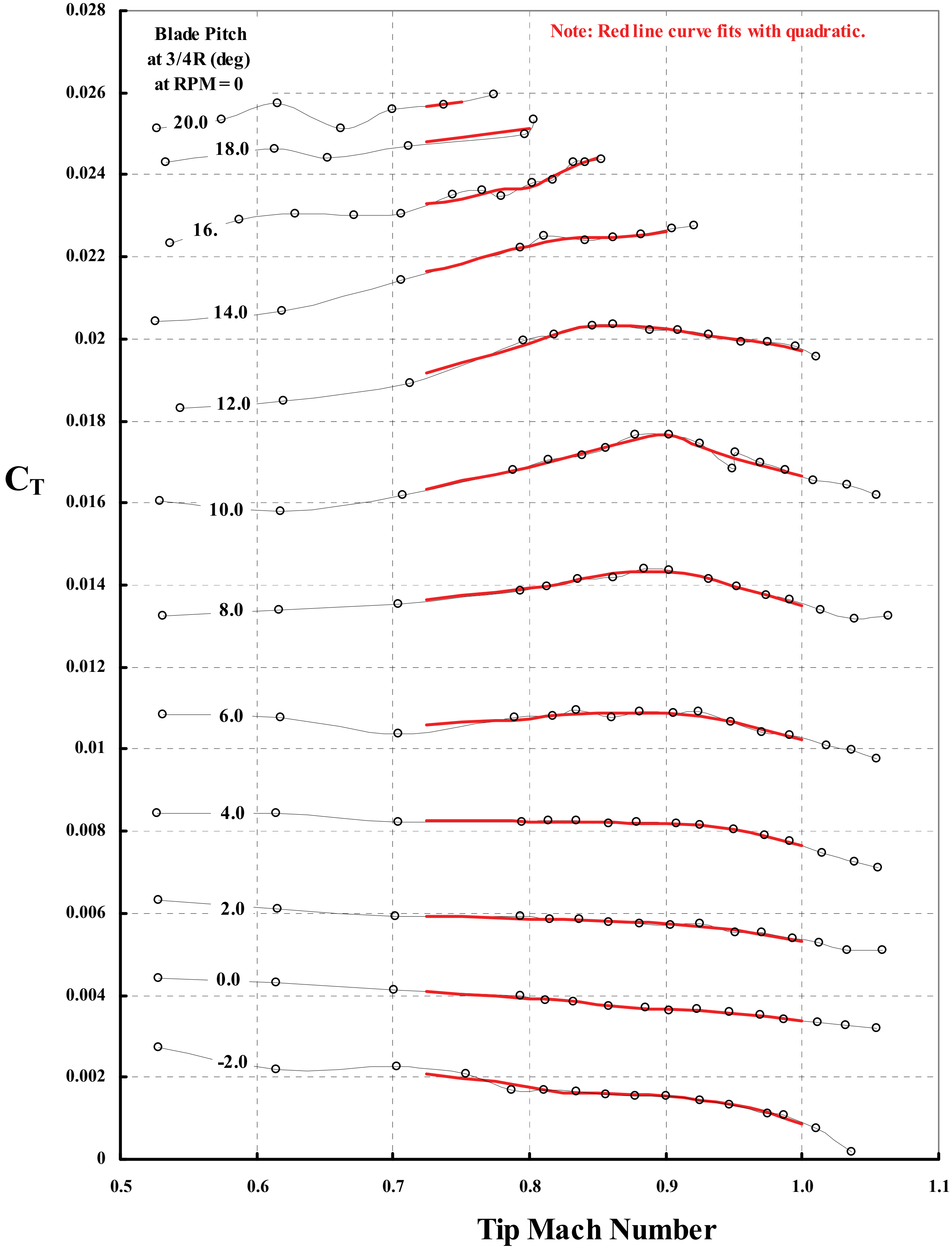

Figure D-8. Initial full-scale propeller (2FE16A3-4A) test results at WADC—thrust coefficient vs. tip Mach number.

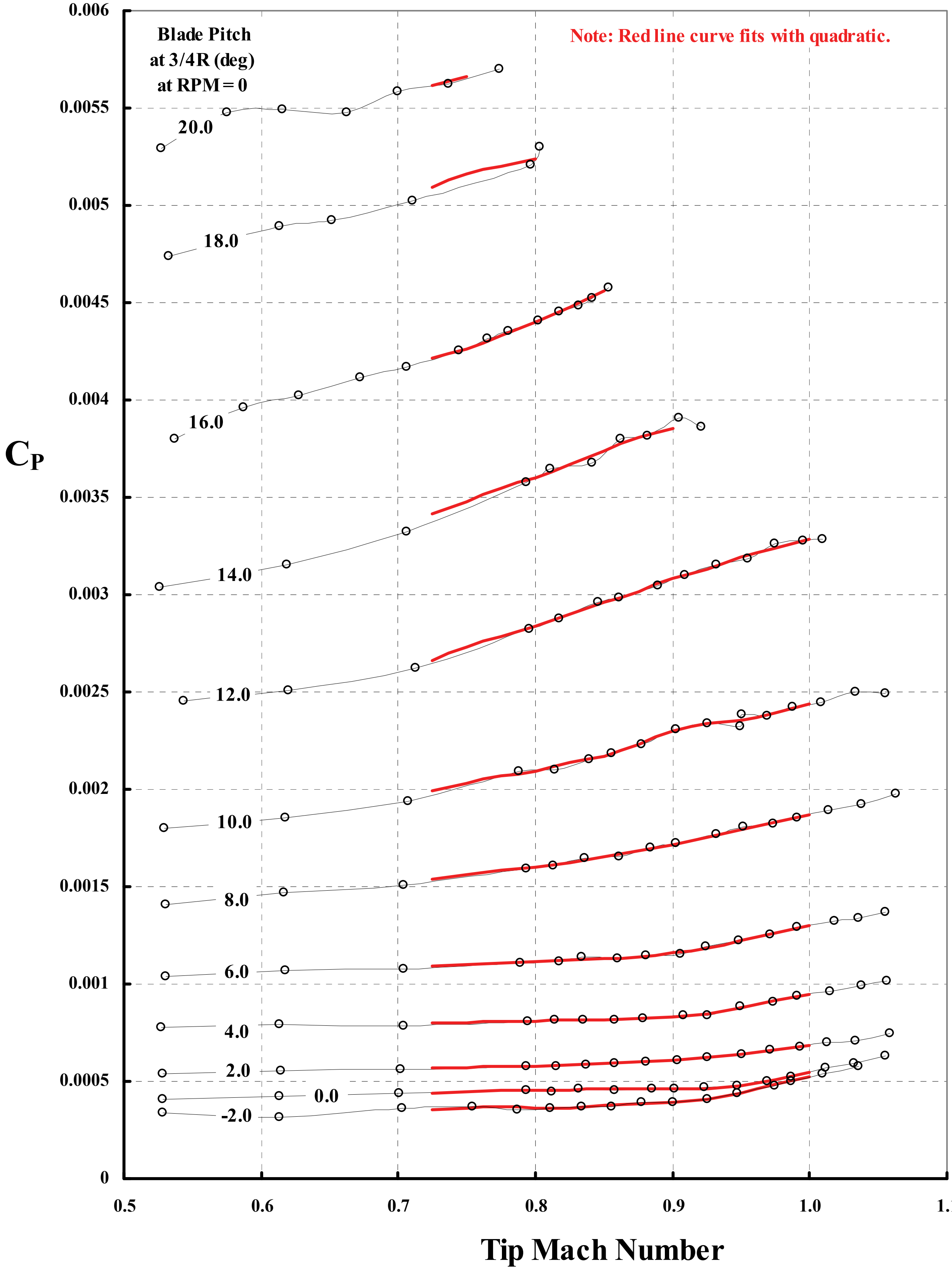

Figure D-9. Initial full-scale propeller (2FE16A3-4A) test results at WADC—power coefficient vs. tip Mach number.

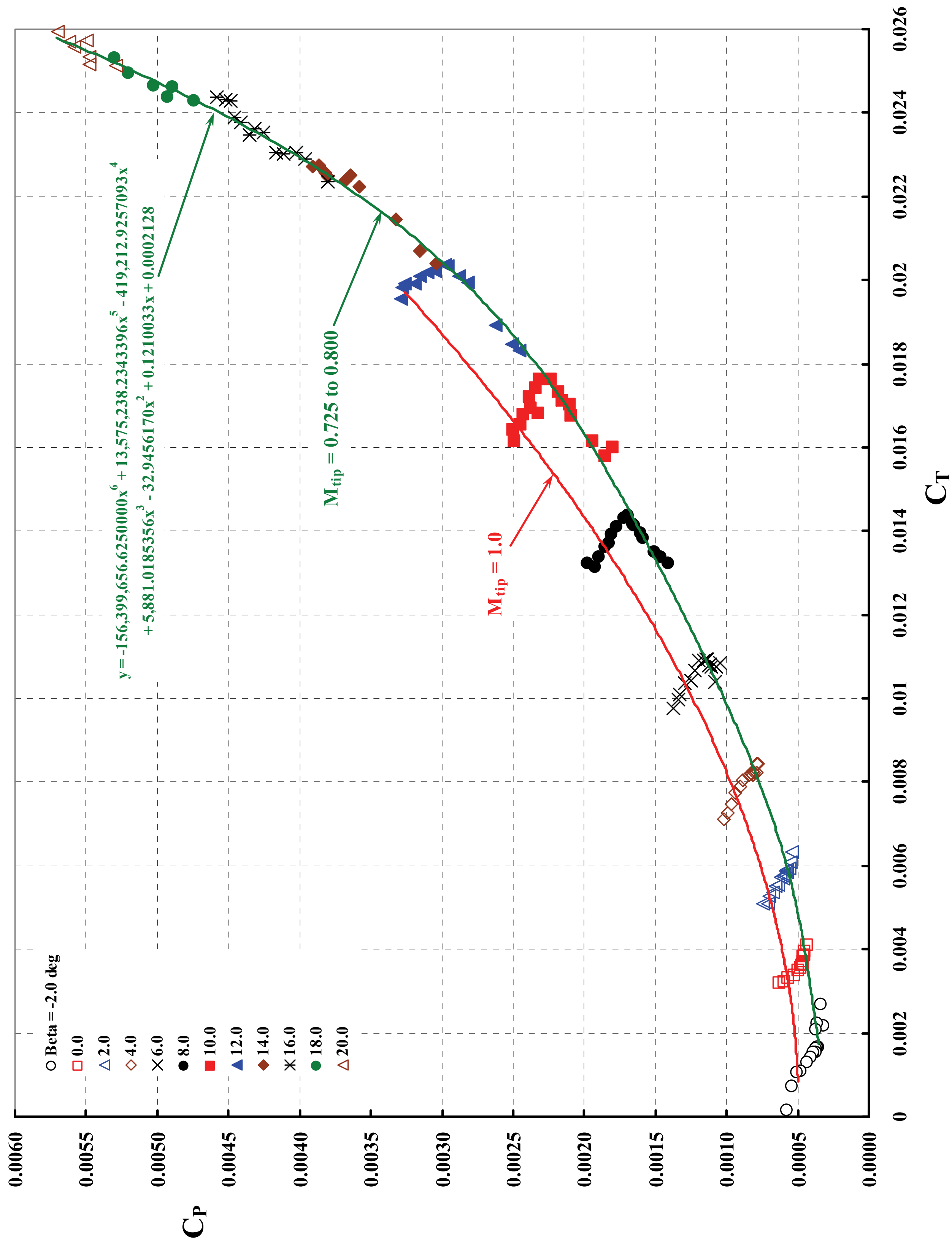

Figure D-10. Initial full-scale propeller (2FE16A3-4A) test results at WADC—power vs. thrust coefficient.

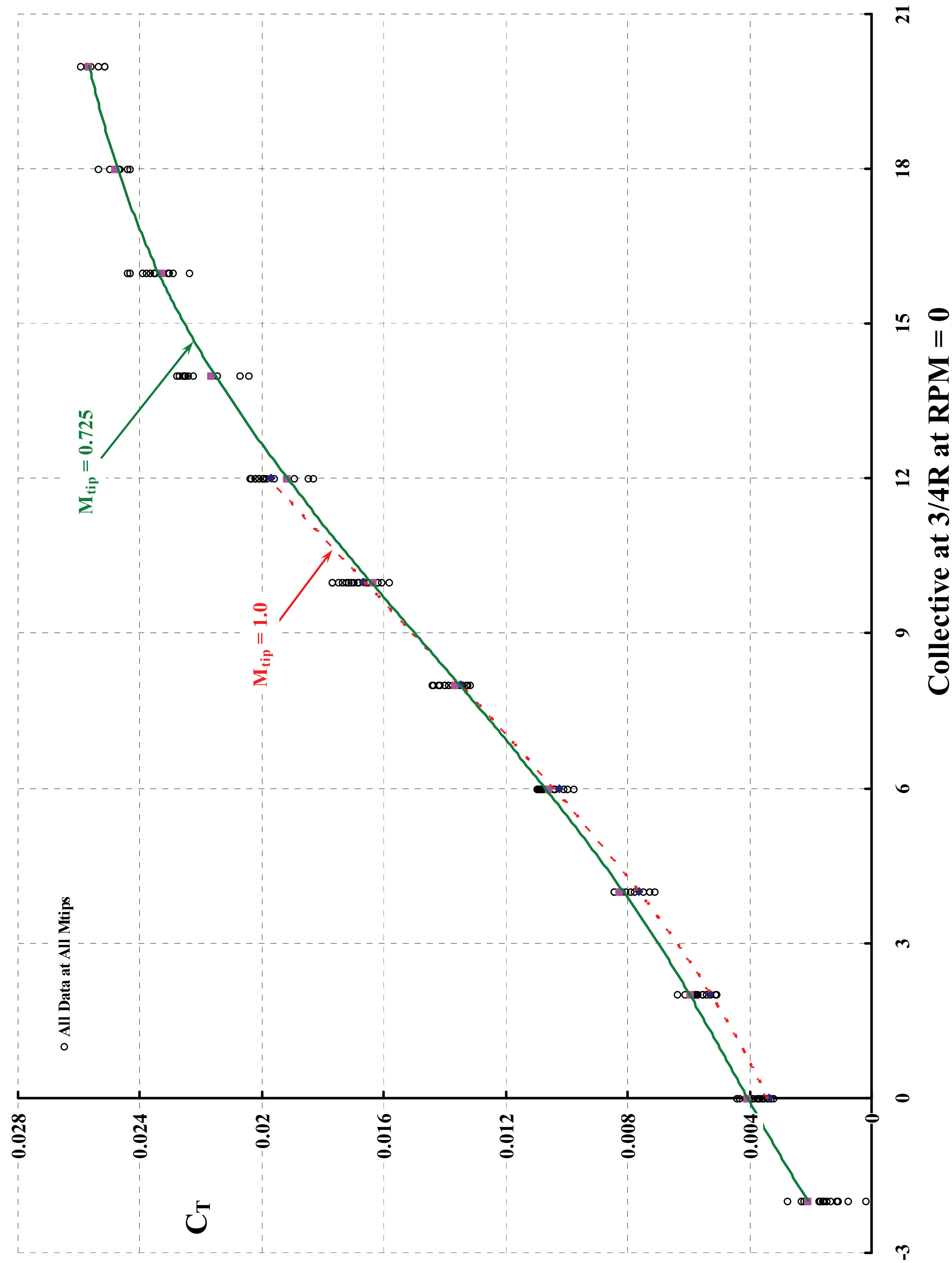

Figure D-11. Initial full-scale propeller (2FE16A3-4A) test results at WADC—thrust coefficient vs. collective pitch.

Table D–1. Initial Full-Scale Propeller (2FE16A3-4A) Test Results at WADC

DATA SET Number 6

Page	Point	V tip	M tip	Coll.	CT	CQ	Ideal CP	FM	CT/CP
68	Not	825	0.725	-2.0	0.002068	0.000356	0.000474	0.1866	5.80
69	Applicable	825	0.725	0.0	0.004081	0.000442	0.001315	0.4170	9.23
70		824	0.725	2.0	0.005919	0.000566	0.002297	0.5688	10.45
71		824	0.725	4.0	0.008252	0.000799	0.003782	0.6637	10.33
72		824	0.725	6.0	0.010574	0.001090	0.005485	0.7053	9.70
73		821	0.725	8.0	0.013650	0.001538	0.008046	0.7333	8.87
74		826	0.725	10.0	0.016339	0.001990	0.010536	0.7422	8.21
75		818	0.725	12.0	0.019156	0.002665	0.013376	0.7035	7.19
76		822	0.725	14.0	0.021648	0.003413	0.016069	0.6599	6.34
77		816	0.725	16.0	0.023286	0.004218	0.017927	0.5958	5.52
78		820	0.725	18.0	0.024788	0.005095	0.019690	0.5417	4.87
79		825	0.725	20.0	0.025666	0.005618	0.020744	0.5176	4.57
68		854	0.750	-2.0	0.001962	0.000358	0.000438	0.1714	5.47
69		854	0.750	0.0	0.004028	0.000446	0.001290	0.4058	9.04
70		853	0.750	2.0	0.005907	0.000571	0.002290	0.5624	10.35
71		852	0.750	4.0	0.008257	0.000803	0.003786	0.6607	10.28
72		852	0.750	6.0	0.010645	0.001102	0.005541	0.7047	9.66
73		849	0.750	8.0	0.013738	0.001561	0.008123	0.7294	8.80
74		854	0.750	10.0	0.016531	0.002032	0.010723	0.7396	8.13
75		846	0.750	12.0	0.019411	0.002730	0.013643	0.7005	7.11
76		850	0.750	14.0	0.021833	0.003477	0.016276	0.6562	6.28
77		844	0.750	16.0	0.023411	0.004260	0.018072	0.5946	5.50
78		848	0.750	18.0	0.024929	0.005159	0.019858	0.5396	4.83
79		853	0.750	20.0	0.025790	0.005658	0.020894	0.5177	4.56
68		882	0.775	-2.0	0.001916	0.000366	0.000423	0.1620	5.23
69		882	0.775	0.0	0.003981	0.000451	0.001267	0.3944	8.84
70		881	0.775	2.0	0.005891	0.000575	0.002281	0.5559	10.24
71		880	0.775	4.0	0.008247	0.000807	0.003779	0.6564	10.22
72		880	0.775	6.0	0.010708	0.001110	0.005590	0.7063	9.65
73		878	0.775	8.0	0.013830	0.001583	0.008205	0.7267	8.74
74		883	0.775	10.0	0.016704	0.002067	0.010892	0.7385	8.08
75		875	0.775	12.0	0.019641	0.002788	0.013887	0.6982	7.04
76		878	0.775	14.0	0.022061	0.003548	0.016531	0.6532	6.22
77		872	0.775	16.0	0.023604	0.004333	0.018295	0.5918	5.45
78		876	0.775	18.0	0.025031	0.005202	0.019979	0.5383	4.81
68		911	0.800	-2.0	0.001752	0.000363	0.000370	0.1429	4.83
69		911	0.800	0.0	0.003923	0.000453	0.001240	0.3840	8.67
70		910	0.800	2.0	0.005868	0.000577	0.002268	0.5508	10.17
71		909	0.800	4.0	0.008217	0.000809	0.003758	0.6514	10.16
72		909	0.800	6.0	0.010722	0.001112	0.005601	0.7058	9.64
73		906	0.800	8.0	0.013927	0.001601	0.008292	0.7262	8.70
74		911	0.800	10.0	0.016879	0.002095	0.011063	0.7401	8.06
75		903	0.800	12.0	0.019891	0.002837	0.014153	0.6992	7.01

Page	Point	V tip	M tip	Coll.	CT	CQ	Ideal CP	FM	CT/CP
76	Not	907	0.800	14.0	0.022265	0.003601	0.016761	0.6524	6.18
77	Applicable	900	0.800	16.0	0.023699	0.004399	0.018405	0.5865	5.39
78		904	0.800	18.0	0.025133	0.005242	0.020102	0.5375	4.79
68		939	0.825	-2.0	0.001630	0.000363	0.000332	0.1282	4.49
69		939	0.825	0.0	0.003864	0.000455	0.001212	0.3736	8.50
70		938	0.825	2.0	0.005855	0.000581	0.002260	0.5448	10.07
71		937	0.825	4.0	0.008227	0.000813	0.003764	0.6491	10.12
72		937	0.825	6.0	0.010831	0.001121	0.005687	0.7114	9.67
73		934	0.825	8.0	0.014037	0.001624	0.008390	0.7243	8.64
74		940	0.825	10.0	0.017090	0.002135	0.011272	0.7401	8.01
75		931	0.825	12.0	0.020175	0.002898	0.014457	0.6994	6.96
76		935	0.825	14.0	0.022421	0.003669	0.016937	0.6471	6.11
77		929	0.825	16.0	0.024092	0.004474	0.018866	0.5911	5.39
68		968	0.850	-2.0	0.001610	0.000374	0.000326	0.1221	4.30
69		968	0.850	0.0	0.003775	0.000458	0.001170	0.3580	8.24
70		966	0.850	2.0	0.005821	0.000590	0.002241	0.5321	9.86
71		966	0.850	4.0	0.008226	0.000817	0.003764	0.6457	10.07
72		966	0.850	6.0	0.010870	0.001134	0.005718	0.7069	9.59
73		962	0.850	8.0	0.014207	0.001654	0.008543	0.7242	8.59
74		968	0.850	10.0	0.017316	0.002166	0.011496	0.7439	7.99
75		959	0.850	12.0	0.020320	0.002963	0.014613	0.6912	6.86
76		963	0.850	14.0	0.022472	0.003736	0.016995	0.6377	6.02
77		957	0.850	16.0	0.024405	0.004564	0.019234	0.5908	5.35
68		996	0.875	-2.0	0.001565	0.000384	0.000312	0.1139	4.07
69		996	0.875	0.0	0.003698	0.000459	0.001134	0.3466	8.06
70		995	0.875	2.0	0.005763	0.000597	0.002207	0.5182	9.65
71		994	0.875	4.0	0.008190	0.000824	0.003739	0.6365	9.94
72		994	0.875	6.0	0.010877	0.001141	0.005723	0.7034	9.54
73		991	0.875	8.0	0.014328	0.001683	0.008652	0.7205	8.51
74		997	0.875	10.0	0.017528	0.002228	0.011707	0.7364	7.87
75		987	0.875	12.0	0.020304	0.003019	0.014596	0.6777	6.73
76		992	0.875	14.0	0.022512	0.003811	0.017040	0.6267	5.91
68		1,025	0.900	-2.0	0.001544	0.000393	0.000306	0.1091	3.93
69		1,025	0.900	0.0	0.003654	0.000462	0.001115	0.3384	7.92
70		1,023	0.900	2.0	0.005726	0.000607	0.002186	0.5049	9.43
71		1,022	0.900	4.0	0.008174	0.000830	0.003728	0.6299	9.85
72		1,022	0.900	6.0	0.010879	0.001158	0.005725	0.6929	9.39
73		1,019	0.900	8.0	0.014326	0.001716	0.008651	0.7065	8.35
74		1,025	0.900	10.0	0.017669	0.002296	0.011849	0.7233	7.69
75		1,016	0.900	12.0	0.020229	0.003081	0.014515	0.6604	6.57
76		1,020	0.900	14.0	0.022624	0.003855	0.017168	0.6242	5.87
68		1,053	0.925	-2.0	0.001441	0.000411	0.000276	0.0942	3.51
69		1,053	0.925	0.0	0.003639	0.000465	0.001107	0.3335	7.82
70		1,052	0.925	2.0	0.005665	0.000621	0.002151	0.4856	9.12

Page	Point	V tip	M tip	Coll.	CT	CQ	Ideal CP	FM	CT/CP
71	Not	1,051	0.925	4.0	0.008336	0.000848	0.003840	0.6349	9.83
72	Applicable	1,051	0.925	6.0	0.010817	0.001187	0.005675	0.6705	9.12
73		1,047	0.925	8.0	0.014212	0.001758	0.008547	0.6817	8.09
74		1,054	0.925	10.0	0.017378	0.002338	0.011557	0.6930	7.43
75		1,044	0.925	12.0	0.020091	0.003130	0.014367	0.6433	6.42
68		1,081	0.950	-2.0	0.001317	0.000440	0.000241	0.0768	2.99
69		1,081	0.950	0.0	0.003563	0.000478	0.001073	0.3146	7.45
70		1,080	0.950	2.0	0.005587	0.000641	0.002107	0.4606	8.71
71		1,079	0.950	4.0	0.008044	0.000880	0.003640	0.5798	9.14
72		1,079	0.950	6.0	0.010654	0.001226	0.005548	0.6345	8.69
73		1,076	0.950	8.0	0.013951	0.001790	0.008313	0.6511	7.79
74		1,082	0.950	10.0	0.017074	0.002355	0.011255	0.6699	7.25
75		1,072	0.950	12.0	0.020009	0.003193	0.014279	0.6269	6.27
68		1,112	0.975	-2.0	0.001165	0.000481	0.000200	0.0585	2.42
69		1,110	0.975	0.0	0.003474	0.000507	0.001033	0.2855	6.85
70		1,109	0.975	2.0	0.005470	0.000663	0.002041	0.4317	8.25
71		1,108	0.975	4.0	0.007864	0.000914	0.003518	0.5397	8.61
72		1,108	0.975	6.0	0.010436	0.001263	0.005379	0.5970	8.26
73		1,104	0.975	8.0	0.013755	0.001830	0.008139	0.6234	7.52
74		1,111	0.975	10.0	0.016875	0.002394	0.011060	0.6477	7.05
75		1,100	0.975	12.0	0.019873	0.003242	0.014134	0.6111	6.13
68		1,138	1.000	-2.0	0.000844	0.000521	0.000124	0.0333	1.62
69		1,138	1.000	0.0	0.003378	0.000545	0.000990	0.2548	6.20
70		1,137	1.000	2.0	0.005320	0.000683	0.001958	0.4019	7.79
71		1,136	1.000	4.0	0.007640	0.000945	0.003369	0.4996	8.08
72		1,136	1.000	6.0	0.010248	0.001298	0.005234	0.5652	7.89
73		1,132	1.000	8.0	0.013502	0.001867	0.007915	0.5943	7.23
74		1,139	1.000	10.0	0.016668	0.002440	0.010857	0.6237	6.83
75		1,128	1.000	12.0	0.019707	0.003284	0.013957	0.5958	6.00

Appendix E

Final Full-Scale Propeller for XC-142A (WADC Test)

This appendix contains:

1. General discussion.
2. Propeller configuration (figs. E-1 to E-5).
3. Performance data of C_P versus C_T and C_T versus 3/4 radius collective from the WADC test (figs. E-6 through E-9, and table E-1).

1. General Discussion

See Appendix D.

2. Propeller Configuration

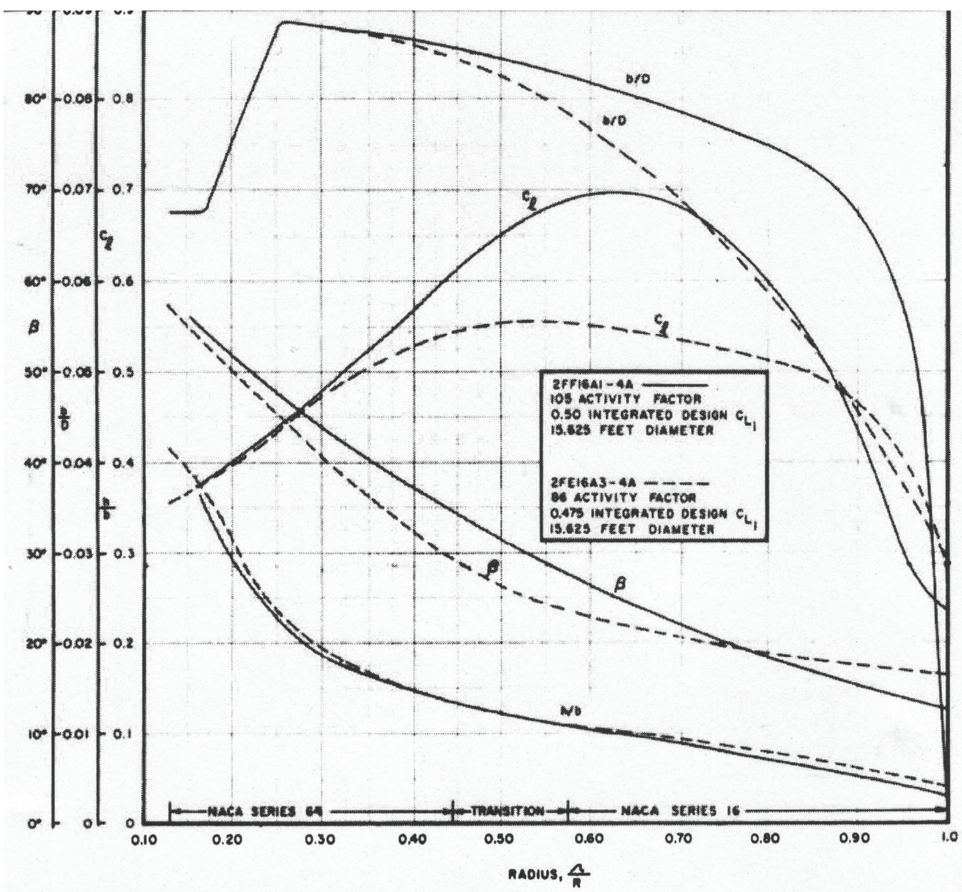

Figure E-1. Final full-scale propeller (2FF16A1-4A) for the XC-142A. Follow the solid lines. (This figure uses propeller nomenclature as shown the table below.)

Parameter	Proprotor	Propeller
Diameter	D	D
Radius	R	R
Blade chord	c	b
Blade number	b	N or B
Airfoil thickness	t	h
Blade width ratio	Rarely used	b/D
Airfoil thickness ratio	t/c	h/b
Blade pitch angle	θ	β_0
Blade radial station	r or x = r/R	r or x = r/R

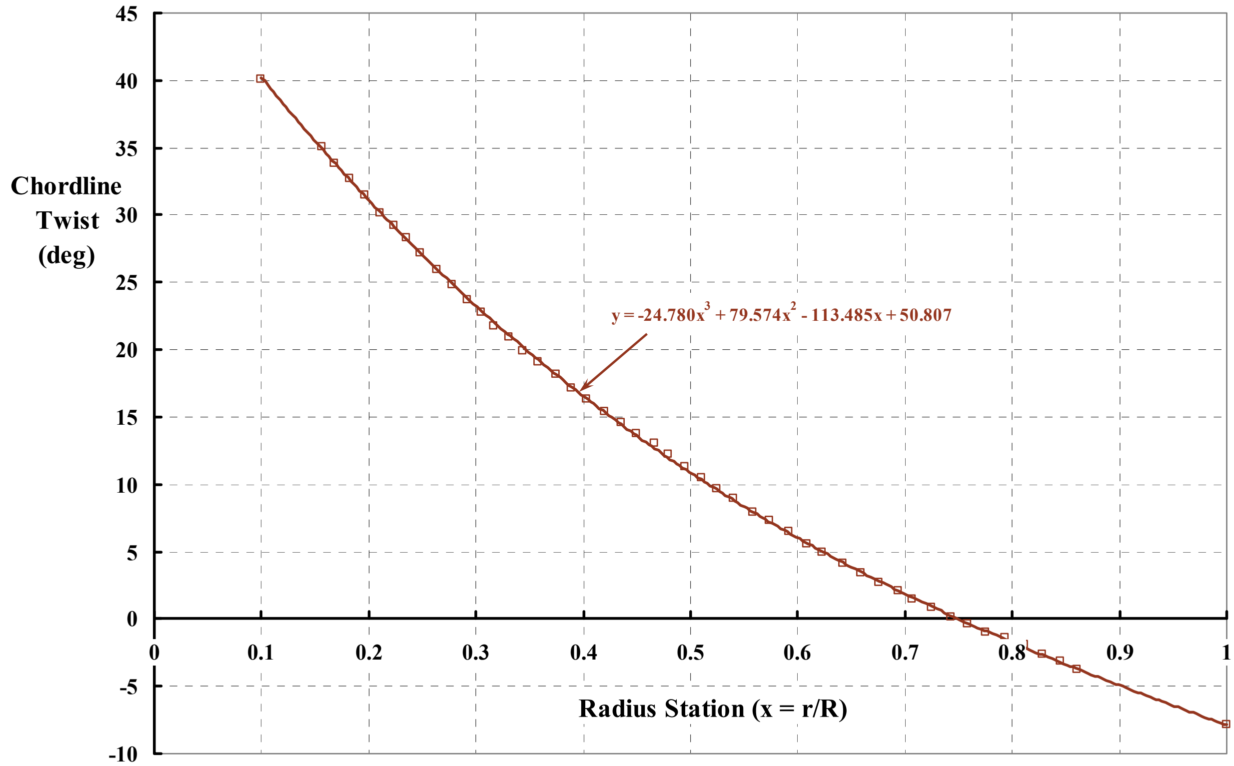

Figure E-2. Final full-scale propeller (2FF16A1-4A) for the XC-142A—twist vs. radius station.

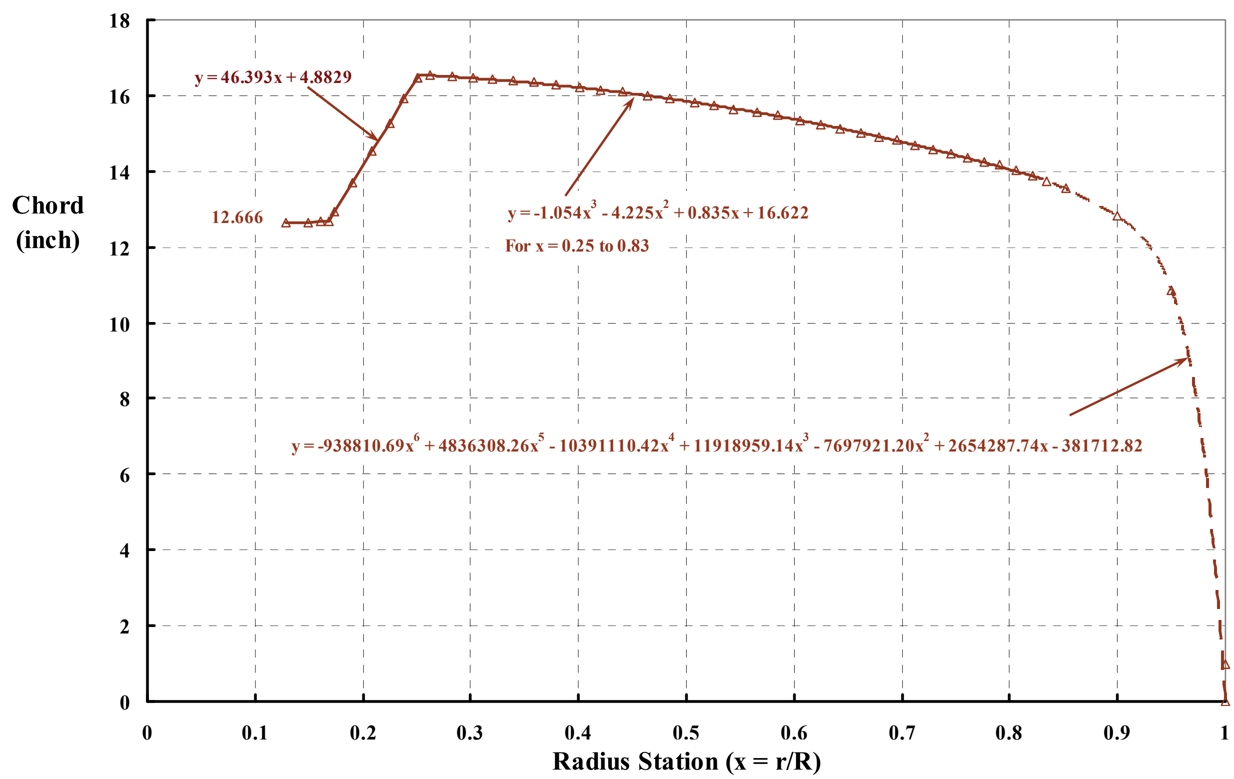

Figure E-3. Final full-scale propeller (2FF16A1-4A) for the XC-142A—chord vs. radius station.

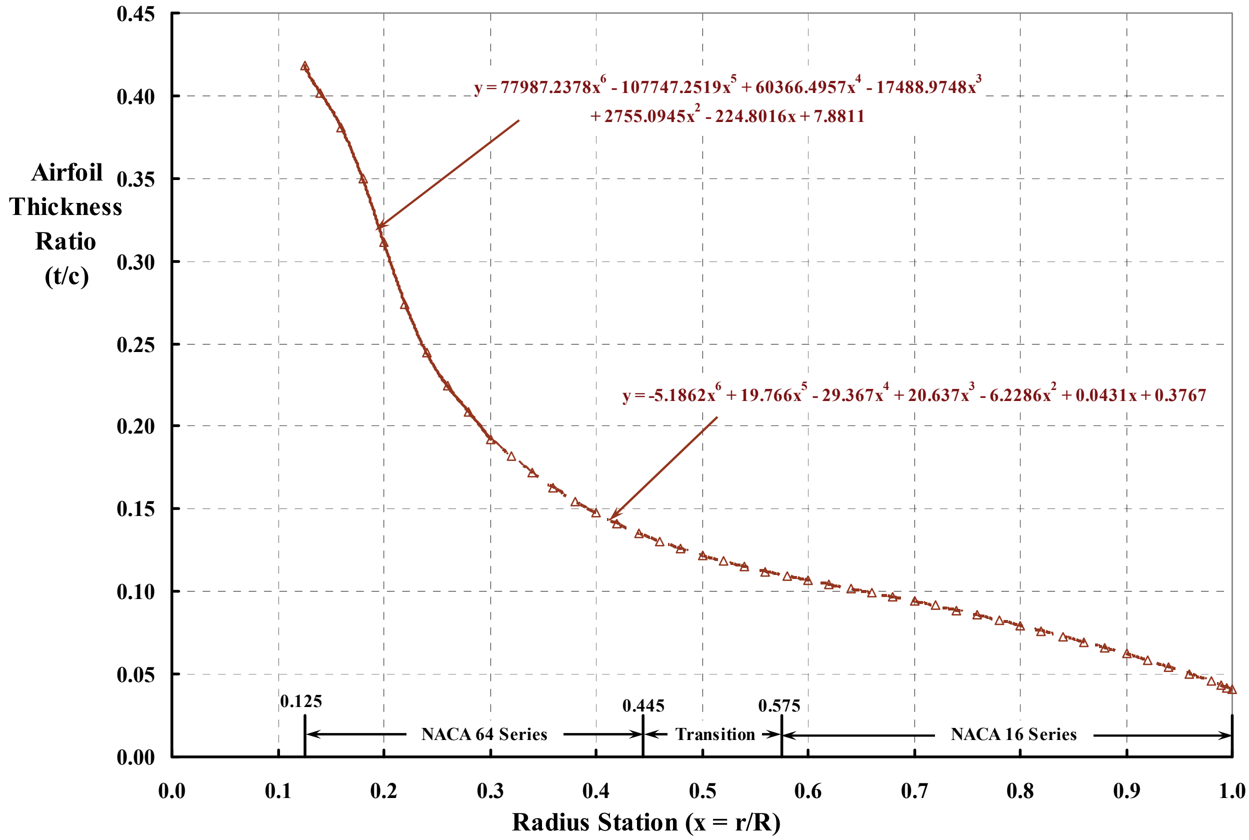

Figure E-4. Final full-scale propeller (2FF16A1-4A) for the XC-142A—airfoil thickness ratio vs. radius station.

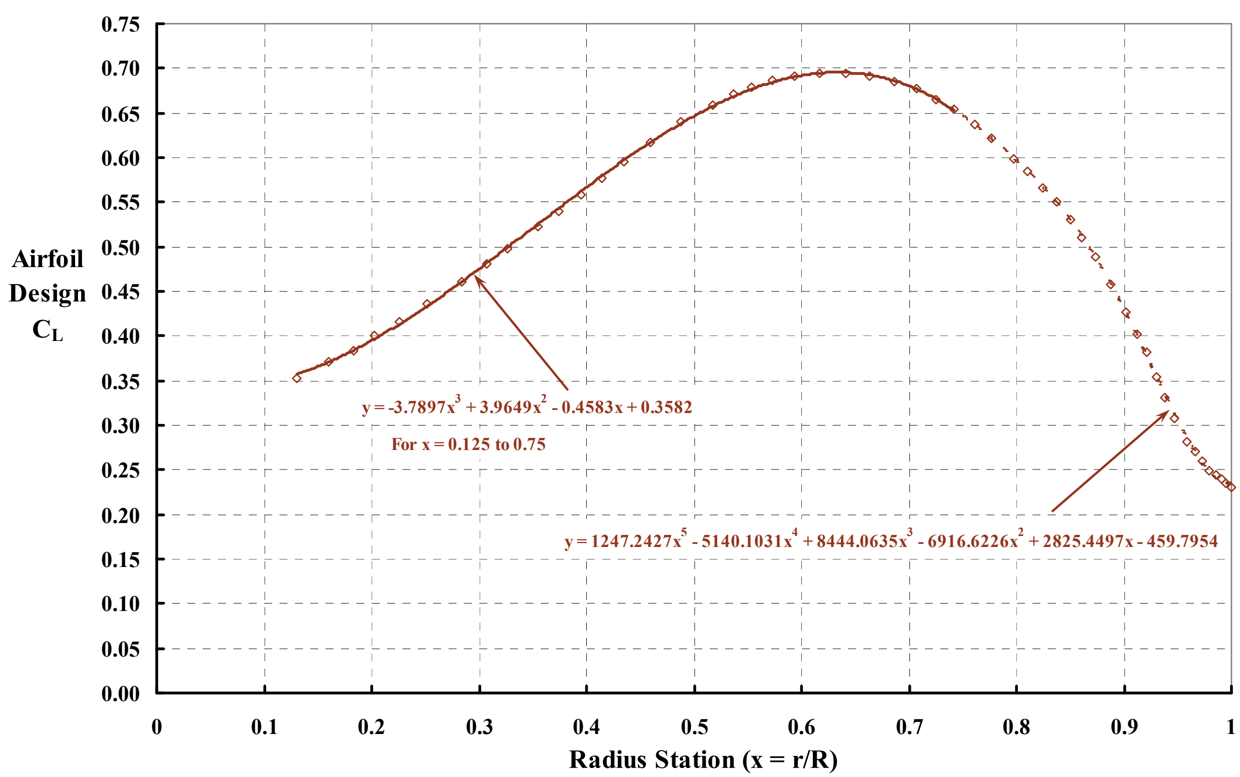

Figure E-5. Final full-scale propeller (2FF16A1-4A) for the XC-142A—airfoil design C_L vs. radius station.

3. Performance Data

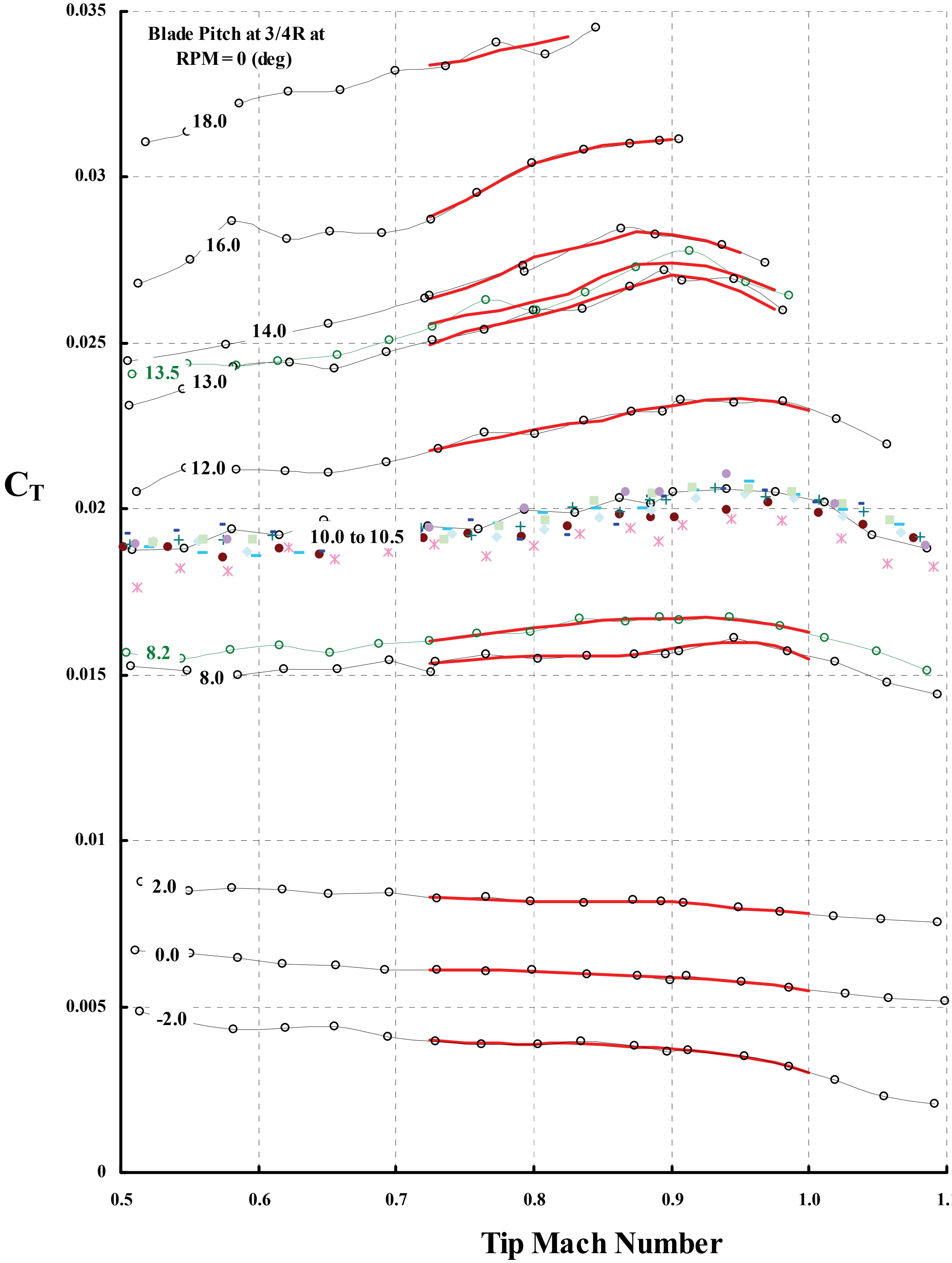

Figure E-6. Final full-scale propeller (2FF16A1-4A) test results at WADC—thrust coefficient vs. tip Mach number.

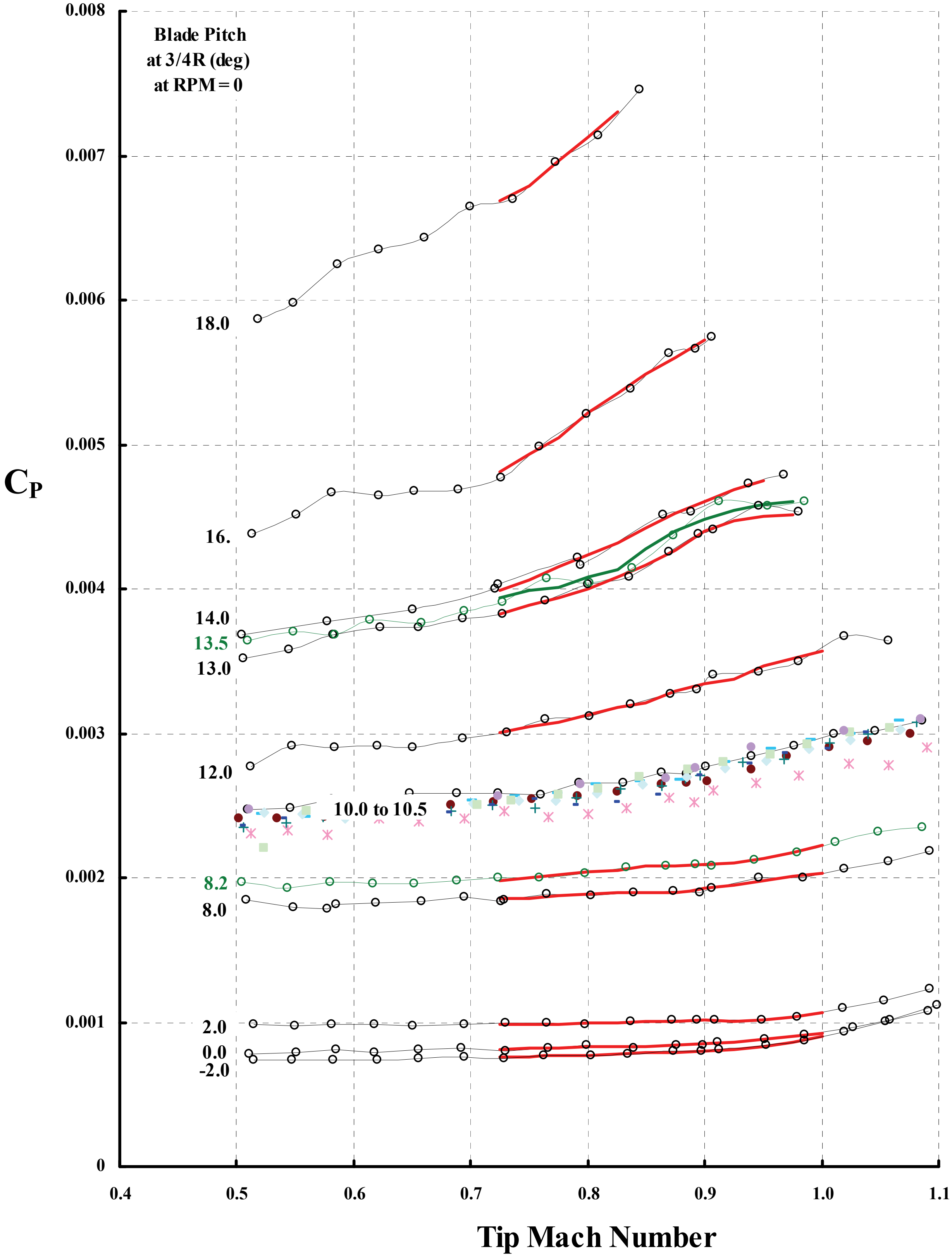

Figure E-7. Final full-scale propeller (2FF16A1-4A) test results at WADC—power coefficient vs. tip Mach number.

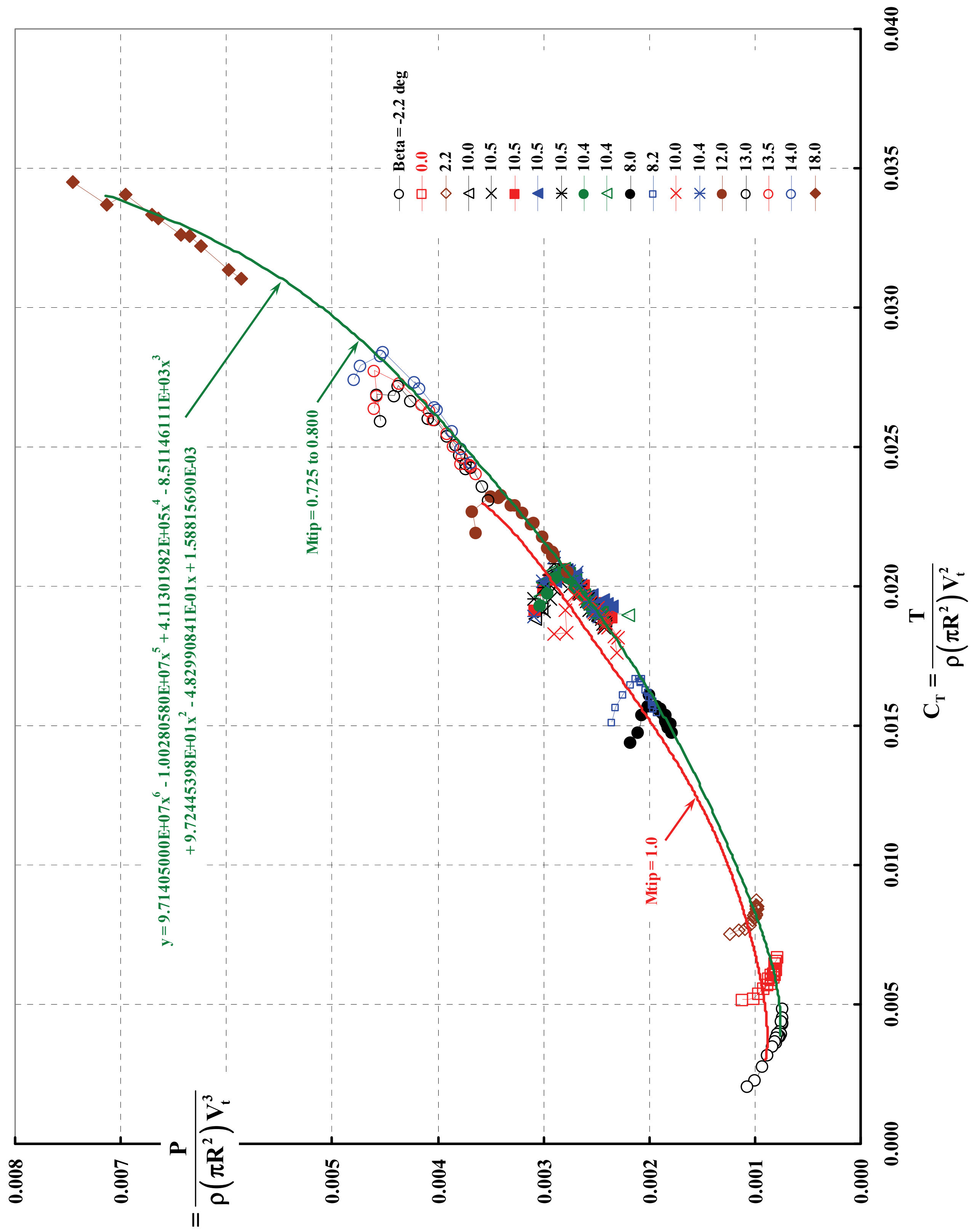

Figure E-8. Final full-scale propeller (2FF16A1-4A) test results at WADC—power vs. thrust coefficient.

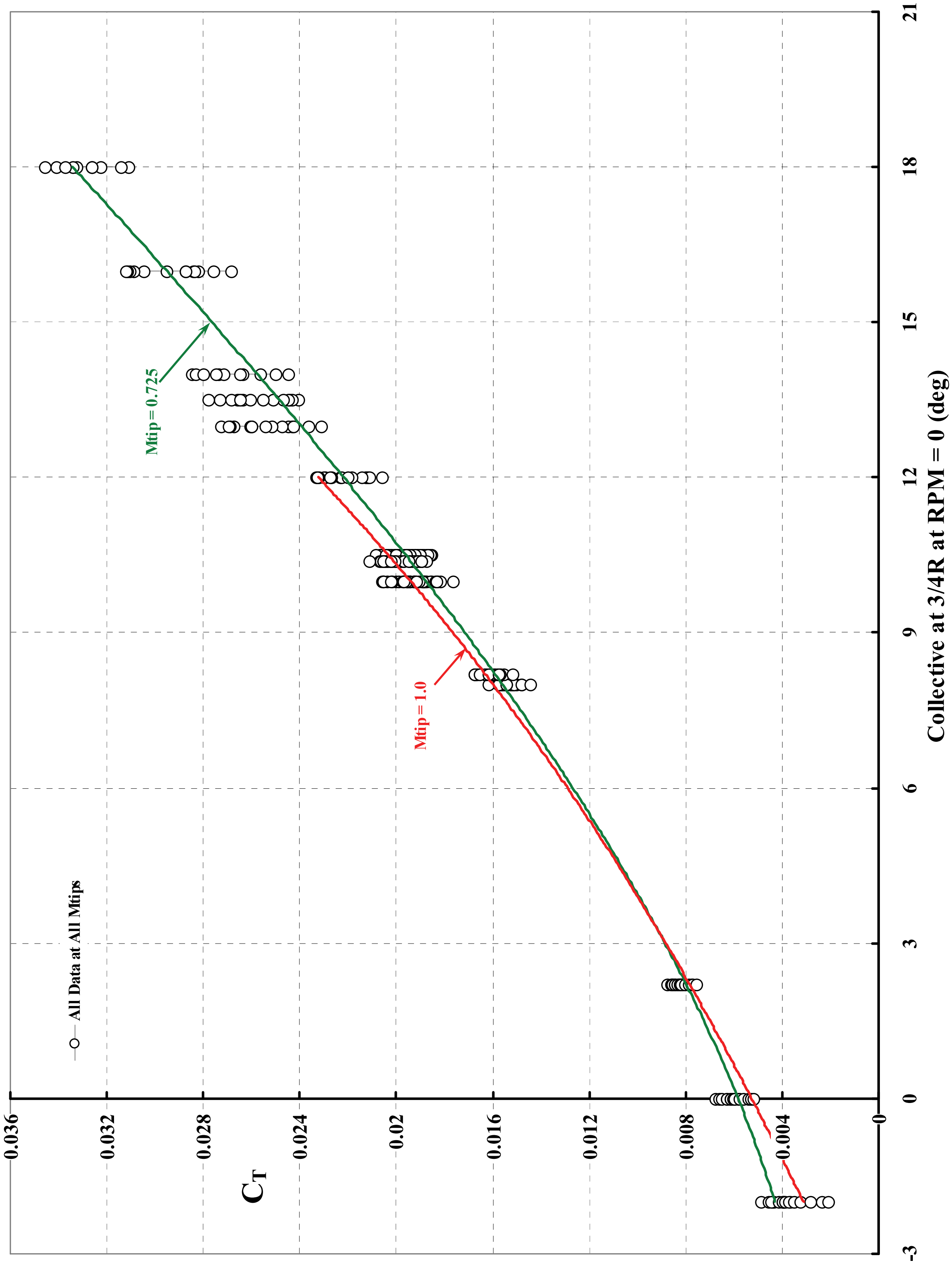

Figure E-9. Final full-scale propeller (2FF16A1-4A) test results at WADC—thrust coefficient vs. collective pitch.

Table E–1. Final Full-Scale Propeller (2FF16A1-4A) Test Results at WADC

DATA SET Number 23

Page	Point	V tip (fps)	M tip	Coll.	CT	CQ	Ideal CP	FM	CT/CP
222	Not	814	0.725	-2.0	0.003994	0.000756	0.001043	0.2360	5.28
223	Applicable	813	0.725	0.0	0.006102	0.000815	0.001970	0.4136	7.49
224		815	0.725	2.2	0.008306	0.000988	0.003128	0.5420	8.41
233		820	0.725	8.0	0.016006	0.001983	0.008368	0.7221	8.07
232		815	0.725	8.0	0.015352	0.001858	0.007861	0.7242	8.27
225		822	0.725	10.0	0.019482	0.002578	0.011237	0.7460	7.56
234		817	0.725	10.0	0.018726	0.002431	0.010589	0.7455	7.70
230		824	0.725	10.4	0.019169	0.002524	0.010967	0.7437	7.60
231		824	0.725	10.4	0.019052	0.002517	0.010867	0.7388	7.57
235		821	0.725	10.4	0.019540	0.002572	0.011287	0.7512	7.60
226		825	0.725	10.5	0.019124	0.002531	0.010928	0.7389	7.55
227		826	0.725	10.5	0.019177	0.002481	0.010973	0.7570	7.73
228		828	0.725	10.5	0.019431	0.002503	0.011193	0.7654	7.76
229		824	0.725	10.5	0.019285	0.002545	0.011067	0.7441	7.58
236		817	0.725	12.0	0.021747	0.003005	0.013252	0.7547	7.24
238		815	0.725	13.0	0.024968	0.003831	0.016303	0.7284	6.52
239		814	0.725	13.5	0.025599	0.003937	0.016924	0.7358	6.50
237		822	0.725	14.0	0.026352	0.003988	0.017676	0.7587	6.61
240		818	0.725	16.0	0.028826	0.004808	0.020223	0.7198	6.00
241		806	0.725	18.0	0.033364	0.006692	0.025182	0.6440	4.99
222		842	0.750	-2.0	0.003886	0.000761	0.001001	0.2252	5.11
223		841	0.750	0.0	0.006096	0.000822	0.001967	0.4094	7.41
224		843	0.750	2.2	0.008273	0.000990	0.003110	0.5377	8.36
233		848	0.750	8.0	0.016155	0.002002	0.008485	0.7252	8.07
232		843	0.750	8.0	0.015418	0.001861	0.007911	0.7276	8.29
225		851	0.750	10.0	0.019530	0.002591	0.011278	0.7450	7.54
234		845	0.750	10.0	0.018738	0.002430	0.010599	0.7465	7.71
230		852	0.750	10.4	0.019153	0.002527	0.010953	0.7419	7.58
231		852	0.750	10.4	0.019208	0.002546	0.011000	0.7393	7.54
235		849	0.750	10.4	0.019672	0.002596	0.011401	0.7516	7.58
226		853	0.750	10.5	0.019204	0.002547	0.010997	0.7388	7.54
227		854	0.750	10.5	0.019287	0.002505	0.011068	0.7562	7.70
228		857	0.750	10.5	0.019436	0.002515	0.011197	0.7620	7.73
229		852	0.750	10.5	0.019477	0.002578	0.011232	0.7458	7.56
236		845	0.750	12.0	0.021996	0.003050	0.013480	0.7564	7.21
238		843	0.750	13.0	0.025351	0.003891	0.016679	0.7337	6.52
239		842	0.750	13.5	0.025846	0.003990	0.017170	0.7364	6.48
237		851	0.750	14.0	0.026660	0.004063	0.017988	0.7577	6.56
240		846	0.750	16.0	0.029311	0.004930	0.020736	0.7199	5.95
241		833	0.750	18.0	0.033524	0.006790	0.025364	0.6393	4.94
222		870	0.775	-2.0	0.003906	0.000765	0.001009	0.2256	5.10
223		869	0.775	0.0	0.006082	0.000823	0.001960	0.4077	7.39
224		872	0.775	2.2	0.008199	0.000989	0.003068	0.5308	8.29
233		876	0.775	8.0	0.016286	0.002017	0.008588	0.7287	8.07
232		872	0.775	8.0	0.015522	0.001876	0.007991	0.7289	8.27
225		879	0.775	10.0	0.019646	0.002609	0.011379	0.7465	7.53
234		873	0.775	10.0	0.018819	0.002434	0.010668	0.7502	7.73
230		880	0.775	10.4	0.019253	0.002545	0.011039	0.7424	7.57
231		880	0.775	10.4	0.019457	0.002578	0.011215	0.7444	7.55
235		878	0.775	10.4	0.019814	0.002622	0.011525	0.7524	7.56

Page	Point	V tip (fps)	M tip	Coll.	CT	CQ	Ideal CP	FM	CT/CP
226	Not	882	0.775	10.5	0.019204	0.002554	0.010997	0.7371	7.52
227	Applicable	883	0.775	10.5	0.019498	0.002536	0.011251	0.7593	7.69
228		886	0.775	10.5	0.019296	0.002517	0.011076	0.7532	7.67
229		880	0.775	10.5	0.019661	0.002603	0.011392	0.7489	7.55
236		873	0.775	12.0	0.022173	0.003080	0.013643	0.7581	7.20
238		872	0.775	13.0	0.025571	0.003939	0.016896	0.7342	6.49
239		870	0.775	13.5	0.025998	0.004012	0.017322	0.7389	6.48
237		879	0.775	14.0	0.027046	0.004159	0.018379	0.7563	6.50
240		875	0.775	16.0	0.029882	0.005046	0.021345	0.7240	5.92
241		861	0.775	18.0	0.033815	0.006966	0.025695	0.6313	4.85
222		898	0.800	-2.0	0.003878	0.000771	0.000998	0.2215	5.03
223		897	0.800	0.0	0.006074	0.000829	0.001956	0.4039	7.33
224		900	0.800	2.2	0.008170	0.000992	0.003052	0.5264	8.24
233		904	0.800	8.0	0.016427	0.002039	0.008700	0.7302	8.06
232		900	0.800	8.0	0.015566	0.001885	0.008025	0.7286	8.26
225		907	0.800	10.0	0.019847	0.002641	0.011553	0.7487	7.51
234		901	0.800	10.0	0.018938	0.002445	0.010770	0.7540	7.75
230		909	0.800	10.4	0.019369	0.002572	0.011139	0.7411	7.53
231		909	0.800	10.4	0.019669	0.002616	0.011399	0.7458	7.52
235		906	0.800	10.4	0.019999	0.002616	0.011687	0.7644	7.64
226		910	0.800	10.5	0.019318	0.002573	0.011095	0.7380	7.51
227		911	0.800	10.5	0.019598	0.002563	0.011337	0.7571	7.65
228		914	0.800	10.5	0.019174	0.002512	0.010972	0.7475	7.63
229		909	0.800	10.5	0.019778	0.002624	0.011494	0.7497	7.54
236		902	0.800	12.0	0.022389	0.003132	0.013843	0.7566	7.15
238		900	0.800	13.0	0.025804	0.004003	0.017128	0.7322	6.45
239		898	0.800	13.5	0.026246	0.004077	0.017570	0.7376	6.44
237		907	0.800	14.0	0.027610	0.004233	0.018958	0.7665	6.52
240		903	0.800	16.0	0.030410	0.005219	0.021913	0.7185	5.83
241		889	0.800	18.0	0.034030	0.007133	0.025941	0.6224	4.77
222		926	0.825	-2.0	0.003892	0.000781	0.001003	0.2198	4.98
223		925	0.825	0.0	0.006030	0.000834	0.001935	0.3969	7.23
224		928	0.825	2.2	0.008167	0.000998	0.003050	0.5231	8.19
233		933	0.825	8.0	0.016514	0.002055	0.008769	0.7303	8.04
232		928	0.825	8.0	0.015577	0.001894	0.008034	0.7258	8.22
225		936	0.825	10.0	0.019961	0.002665	0.011654	0.7483	7.49
234		929	0.825	10.0	0.019019	0.002466	0.010838	0.7521	7.71
230		937	0.825	10.4	0.019482	0.002600	0.011237	0.7396	7.49
231		937	0.825	10.4	0.019936	0.002653	0.011632	0.7505	7.52
235		934	0.825	10.4	0.020162	0.002657	0.011830	0.7620	7.59
226		939	0.825	10.5	0.019434	0.002595	0.011195	0.7383	7.49
227		940	0.825	10.5	0.019758	0.002596	0.011476	0.7567	7.61
228		943	0.825	10.5	0.019178	0.002526	0.010975	0.7435	7.59
229		937	0.825	10.5	0.019839	0.002632	0.011547	0.7508	7.54
236		930	0.825	12.0	0.022573	0.003181	0.014014	0.7541	7.10
238		928	0.825	13.0	0.026057	0.004079	0.017381	0.7293	6.39
239		926	0.825	13.5	0.026495	0.004138	0.017821	0.7370	6.40
237		936	0.825	14.0	0.027841	0.004320	0.019196	0.7604	6.44
240		931	0.825	16.0	0.030695	0.005352	0.022222	0.7106	5.73
241		917	0.825	18.0	0.034238	0.007303	0.026179	0.6135	4.69
222		954	0.850	-2.0	0.003861	0.000787	0.000991	0.2156	4.91
223		953	0.850	0.0	0.005966	0.000833	0.001904	0.3911	7.16

Page	Point	V tip (fps)	M tip	Coll.	CT	CQ	Ideal CP	FM	CT/CP
224	Not	956	0.850	2.2	0.008153	0.001004	0.003042	0.5183	8.12
233	Applicable	961	0.850	8.0	0.016627	0.002078	0.008860	0.7298	8.00
232		956	0.850	8.0	0.015585	0.001898	0.008040	0.7248	8.21
225		964	0.850	10.0	0.020161	0.002701	0.011829	0.7494	7.46
234		958	0.850	10.0	0.019196	0.002493	0.010990	0.7545	7.70
230		966	0.850	10.4	0.019753	0.002646	0.011472	0.7420	7.47
231		966	0.850	10.4	0.020248	0.002701	0.011906	0.7544	7.50
235		962	0.850	10.4	0.020364	0.002708	0.012009	0.7588	7.52
226		967	0.850	10.5	0.019602	0.002626	0.011340	0.7391	7.46
227		968	0.850	10.5	0.020042	0.002643	0.011725	0.7591	7.58
228		971	0.850	10.5	0.019502	0.002580	0.011254	0.7466	7.56
229		966	0.850	10.5	0.019998	0.002661	0.011686	0.7517	7.52
236		958	0.850	12.0	0.022664	0.003211	0.014099	0.7514	7.06
238		956	0.850	13.0	0.026418	0.004169	0.017743	0.7284	6.34
239		954	0.850	13.5	0.027005	0.004274	0.018338	0.7344	6.32
237		964	0.850	14.0	0.028034	0.004421	0.019396	0.7509	6.34
240		959	0.850	16.0	0.030957	0.005489	0.022507	0.7018	5.64
222		982	0.875	-2.0	0.003785	0.000790	0.000962	0.2084	4.79
223		981	0.875	0.0	0.005919	0.000840	0.001882	0.3832	7.04
224		984	0.875	2.2	0.008170	0.001009	0.003052	0.5175	8.10
233		989	0.875	8.0	0.016677	0.002085	0.008899	0.7306	8.00
232		984	0.875	8.0	0.015602	0.001901	0.008053	0.7251	8.21
225		992	0.875	10.0	0.020235	0.002722	0.011894	0.7477	7.43
234		986	0.875	10.0	0.019222	0.002523	0.011012	0.7472	7.62
230		994	0.875	10.4	0.019931	0.002686	0.011627	0.7409	7.42
231		994	0.875	10.4	0.020402	0.002740	0.012042	0.7522	7.45
235		991	0.875	10.4	0.020649	0.002741	0.012261	0.7656	7.53
226		996	0.875	10.5	0.019746	0.002647	0.011466	0.7414	7.46
227		997	0.875	10.5	0.020171	0.002670	0.011838	0.7589	7.56
228		1,000	0.875	10.5	0.020015	0.002651	0.011701	0.7555	7.55
229		994	0.875	10.5	0.020158	0.002704	0.011826	0.7485	7.45
236		986	0.875	12.0	0.022978	0.003290	0.014393	0.7487	6.98
238		984	0.875	13.0	0.026731	0.004266	0.018060	0.7245	6.27
239		982	0.875	13.5	0.027359	0.004399	0.018700	0.7274	6.22
237		992	0.875	14.0	0.028372	0.004527	0.019747	0.7465	6.27
240		987	0.875	16.0	0.031058	0.005604	0.022618	0.6907	5.54
222		1,010	0.900	-2.0	0.003706	0.000801	0.000932	0.1993	4.63
223		1,009	0.900	0.0	0.005875	0.000850	0.001861	0.3745	6.91
224		1,012	0.900	2.2	0.008164	0.001011	0.003048	0.5161	8.08
233		1,017	0.900	8.0	0.016704	0.002093	0.008921	0.7296	7.98
232		1,012	0.900	8.0	0.015795	0.001929	0.008203	0.7279	8.19
225		1,021	0.900	10.0	0.020402	0.002764	0.012042	0.7456	7.38
234		1,014	0.900	10.0	0.019367	0.002570	0.011137	0.7418	7.54
230		1,022	0.900	10.4	0.020159	0.002723	0.011827	0.7435	7.40
231		1,022	0.900	10.4	0.020560	0.002774	0.012182	0.7514	7.41
235		1,019	0.900	10.4	0.020852	0.002790	0.012443	0.7633	7.47
226		1,024	0.900	10.5	0.019816	0.002676	0.011527	0.7373	7.41
227		1,025	0.900	10.5	0.020374	0.002712	0.012017	0.7583	7.51
228		1,028	0.900	10.5	0.020462	0.002726	0.012095	0.7593	7.51
229		1,022	0.900	10.5	0.020377	0.002750	0.012020	0.7481	7.41
236		1,014	0.900	12.0	0.023091	0.003341	0.014500	0.7429	6.91
238		1,012	0.900	13.0	0.027046	0.004405	0.018379	0.7141	6.14
239		1,010	0.900	13.5	0.027434	0.004484	0.018777	0.7167	6.12

Page	Point	V tip (fps)	M tip	Coll.	CT	CQ	Ideal CP	FM	CT/CP
237	Not	1,021	0.900	14.0	0.028278	0.004606	0.019650	0.7301	6.14
240	Applicable	1,016	0.900	16.0	0.031132	0.005726	0.022698	0.6784	5.44
222		1,038	0.925	-2.0	0.003637	0.000811	0.000906	0.1912	4.48
223		1,037	0.925	0.0	0.005821	0.000863	0.001835	0.3641	6.75
224		1,040	0.925	2.2	0.008068	0.001007	0.002995	0.5090	8.01
233		1,046	0.925	8.0	0.016727	0.002104	0.008940	0.7272	7.95
232		1,040	0.925	8.0	0.015931	0.001950	0.008309	0.7294	8.17
225		1,049	0.925	10.0	0.020546	0.002811	0.012169	0.7408	7.31
234		1,042	0.925	10.0	0.019635	0.002615	0.011369	0.7440	7.51
230		1,051	0.925	10.4	0.020366	0.002763	0.012010	0.7440	7.37
231		1,051	0.925	10.4	0.020629	0.002805	0.012243	0.7469	7.35
235		1,047	0.925	10.4	0.020822	0.002840	0.012416	0.7481	7.33
226		1,053	0.925	10.5	0.019959	0.002720	0.011652	0.7332	7.34
227		1,054	0.925	10.5	0.020493	0.002759	0.012123	0.7520	7.43
228		1,057	0.925	10.5	0.020647	0.002786	0.012260	0.7532	7.41
229		1,051	0.925	10.5	0.020615	0.002814	0.012231	0.7439	7.33
236		1,042	0.925	12.0	0.023281	0.003378	0.014679	0.7438	6.89
238		1,040	0.925	13.0	0.026940	0.004471	0.018271	0.6994	6.03
239		1,038	0.925	13.5	0.027326	0.004546	0.018666	0.7027	6.01
237		1,049	0.925	14.0	0.028085	0.004686	0.019449	0.7103	5.99
222		1,067	0.950	-2.0	0.003479	0.000833	0.000848	0.1742	4.18
223		1,065	0.950	0.0	0.005744	0.000883	0.001799	0.3487	6.50
224		1,068	0.950	2.2	0.007961	0.001016	0.002935	0.4942	7.83
233		1,074	0.950	8.0	0.016637	0.002131	0.008867	0.7122	7.81
232		1,068	0.950	8.0	0.015972	0.001979	0.008341	0.7212	8.07
225		1,077	0.950	10.0	0.020701	0.002875	0.012307	0.7326	7.20
234		1,070	0.950	10.0	0.019812	0.002681	0.011523	0.7357	7.39
230		1,079	0.950	10.4	0.020385	0.002814	0.012027	0.7315	7.24
231		1,079	0.950	10.4	0.020619	0.002855	0.012235	0.7333	7.22
235		1,076	0.950	10.4	0.020677	0.002884	0.012286	0.7290	7.17
226		1,081	0.950	10.5	0.020119	0.002789	0.011792	0.7237	7.21
227		1,082	0.950	10.5	0.020510	0.002809	0.012137	0.7394	7.30
228		1,086	0.950	10.5	0.020515	0.002811	0.012142	0.7394	7.30
229		1,079	0.950	10.5	0.020623	0.002870	0.012238	0.7299	7.19
236		1,071	0.950	12.0	0.023331	0.003462	0.014726	0.7280	6.74
238		1,068	0.950	13.0	0.026582	0.004503	0.017909	0.6806	5.90
239		1,067	0.950	13.5	0.027020	0.004580	0.018353	0.6859	5.90
237		1,077	0.950	14.0	0.027728	0.004748	0.019079	0.6877	5.84
222		1,095	0.975	-2.0	0.003301	0.000861	0.000784	0.1557	3.83
223		1,093	0.975	0.0	0.005640	0.000903	0.001750	0.3316	6.24
224		1,096	0.975	2.2	0.007876	0.001038	0.002888	0.4762	7.59
233		1,102	0.975	8.0	0.016498	0.002172	0.008757	0.6899	7.60
232		1,096	0.975	8.0	0.015219	0.001930	0.007758	0.6881	7.89
225		1,106	0.975	10.0	0.020531	0.002920	0.012156	0.7125	7.03
234		1,099	0.975	10.0	0.019720	0.002718	0.011443	0.7206	7.26
230		1,108	0.975	10.4	0.020347	0.002859	0.011993	0.7180	7.12
231		1,108	0.975	10.4	0.020567	0.002902	0.012188	0.7187	7.09
235		1,104	0.975	10.4	0.020494	0.002933	0.012124	0.7074	6.99
226		1,110	0.975	10.5	0.020089	0.002841	0.011766	0.7088	7.07
227		1,110	0.975	10.5	0.020483	0.002860	0.012114	0.7248	7.16
228		1,114	0.975	10.5	0.020448	0.002860	0.012082	0.7230	7.15
229		1,108	0.975	10.5	0.020569	0.002922	0.012190	0.7140	7.04

Page	Point	V tip (fps)	M tip	Coll.	CT	CQ	Ideal CP	FM	CT/CP
236	Not	1,099	0.975	12.0	0.023225	0.003520	0.014626	0.7110	6.60
238	Applicable	1,096	0.975	13.0	0.026038	0.004510	0.017362	0.6589	5.77
239		1,095	0.975	13.5	0.026626	0.004606	0.017953	0.6672	5.78
222		1,123	1.000	-2.0	0.002996	0.000900	0.000678	0.1289	3.33
223		1,121	1.000	0.0	0.005493	0.000925	0.001682	0.3112	5.94
224		1,125	1.000	2.2	0.007786	0.001066	0.002839	0.4557	7.30
233		1,130	1.000	8.0	0.016282	0.002223	0.008585	0.6611	7.33
232		1,125	1.000	8.0	0.014984	0.001954	0.007579	0.6639	7.67
225		1,134	1.000	10.0	0.020184	0.002963	0.011850	0.6843	6.81
234		1,127	1.000	10.0	0.019361	0.002732	0.011132	0.6973	7.09
230		1,136	1.000	10.4	0.020159	0.002904	0.011827	0.6970	6.94
231		1,136	1.000	10.4	0.020369	0.002943	0.012013	0.6985	6.92
235		1,132	1.000	10.4	0.020224	0.002973	0.011885	0.6841	6.80
226		1,138	1.000	10.5	0.019962	0.002886	0.011654	0.6912	6.92
227		1,139	1.000	10.5	0.020297	0.002911	0.011949	0.7026	6.97
228		1,143	1.000	10.5	0.020333	0.002913	0.011981	0.7040	6.98
229		1,136	1.000	10.5	0.020369	0.002969	0.012013	0.6925	6.86
236		1,127	1.000	12.0	0.022984	0.003573	0.014399	0.6896	6.43

Appendix F

0.15-Scale, Three-Bladed Proprotor for JVX Configuration of V-22 (Bell Helicopter Test)

This appendix contains:

1. Introduction.
2. Proprotor configuration (figs. F-1 to F-4, and table F-1).
3. Performance data of C_P versus C_T and C_T versus 3/4 radius collective for the Bell Helicopter test (figs. F-5 and F-6, and table F-2).

1. Introduction

During May of 1994, Bell Helicopter Textron Inc. (BHTI) conducted checkout of two 0.15-Mach-scaled JVX model proprotors. This initiated subsequent testing in the NASA Langley Research Center 14- by 22-Foot Subsonic Wind Tunnel from June 13 to July 29, 1994. The purpose of the wind tunnel test was to quantify and compare acoustic, aerodynamics, and Blade Vortex Interaction (BVI) characteristics of two similar tiltrotor rotor systems with a different number of blades but of equal solidity.

The debugging and checkout of BHTI's Power Force Model was conducted at Bell's facility. This provided hover performance data for both the three- and the four-bladed configurations (fig. F-1 and table F-2). This appendix includes data on the three-bladed wide-chord proprotor, which was included in the complete data report (ref. 20).

2. Proprotor Configuration

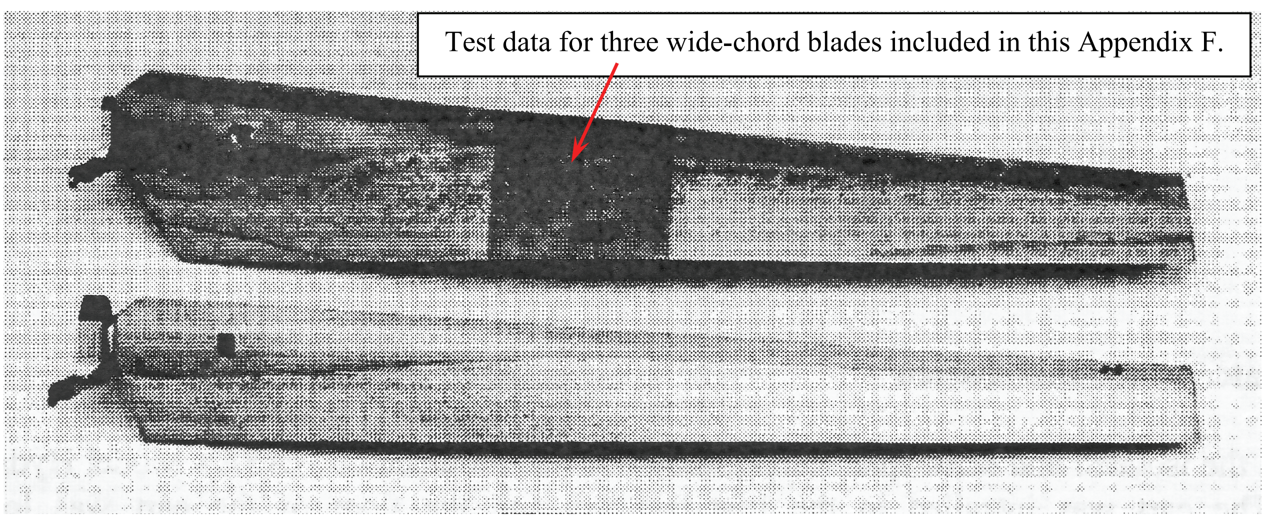

Figure F-1. Three wide-chord blades versus four narrow-chord blades were tested at small scale (5.7 feet diameter).

Table F-1. Comparative Geometry of Three- and Four-Bladed Proprotors

Parameter	Value
Rotor Diameter	68.4 inch
Blade Twist	-47.5 degrees
Blade Airfoils	0.15 Scaled JVX
Thrust Weighted Solidity	0.114 (JVX)
Blade Planform	Linear Tapered Swept
Blade Chord at tip:	
3-Bladed Rotor	3.60 inch
4-Bladed Rotor	2.70 inch
Aerodynamic Reference Blade Chord:	
3-Bladed Rotor	4.09 inch
4-Bladed Rotor	3.07 inch
Hub Precone	2 degrees
Blade Pitch Flap Coupling	45 degrees
Maximum Control System Travels	+15 to -5 deg F/A Cyclic
(3/4 radius)	-9 to +10 deg Lateral Cyclic
	-5 to +24 deg Collective
Maximum Rotor Flapping Angle	12 degrees
Operating Rotor Speed	2647 RPM
Operating Tip Speed	790 ft/sec
Maximum (110%) Rotor Speed	2911 RPM
Maximum Power (at 2650 RPM)	150 HP
Maximum Design Thrust (Ct = 0.023)	1053 lb

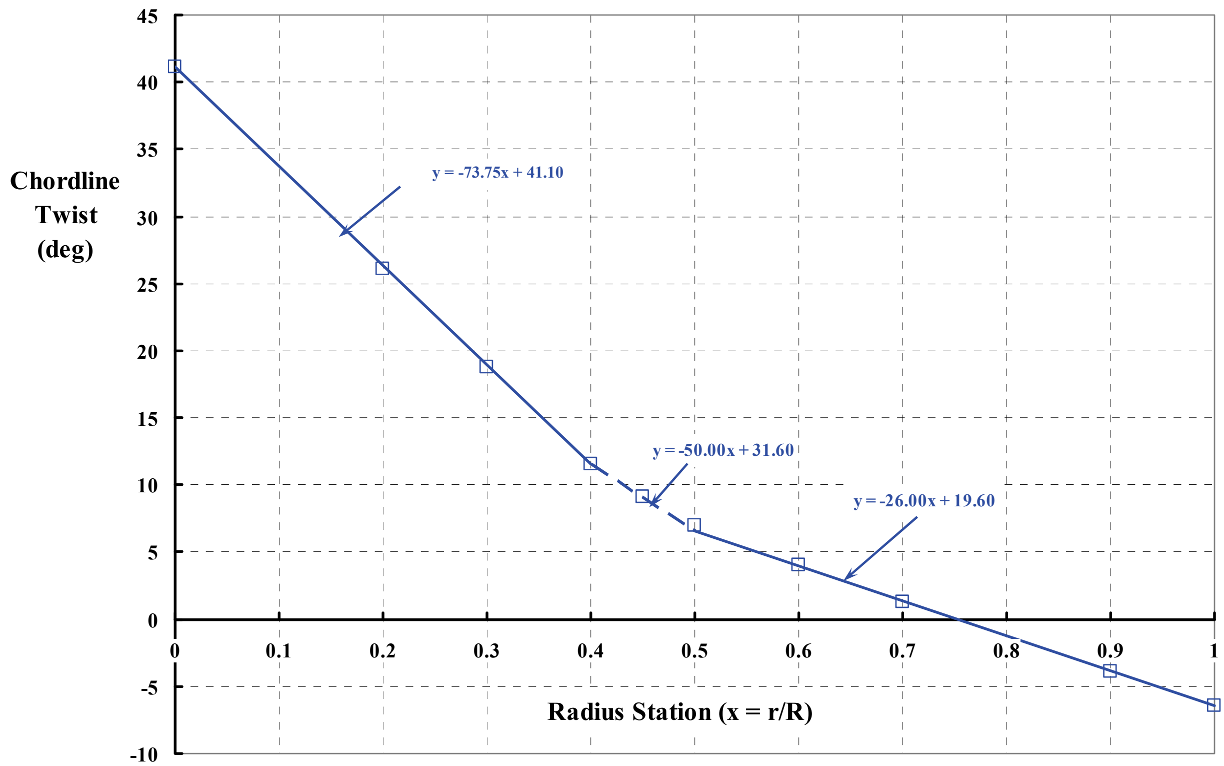

Figure F-2. The 0.15-scale JVX proprotor (three blades)—twist vs. radius station.

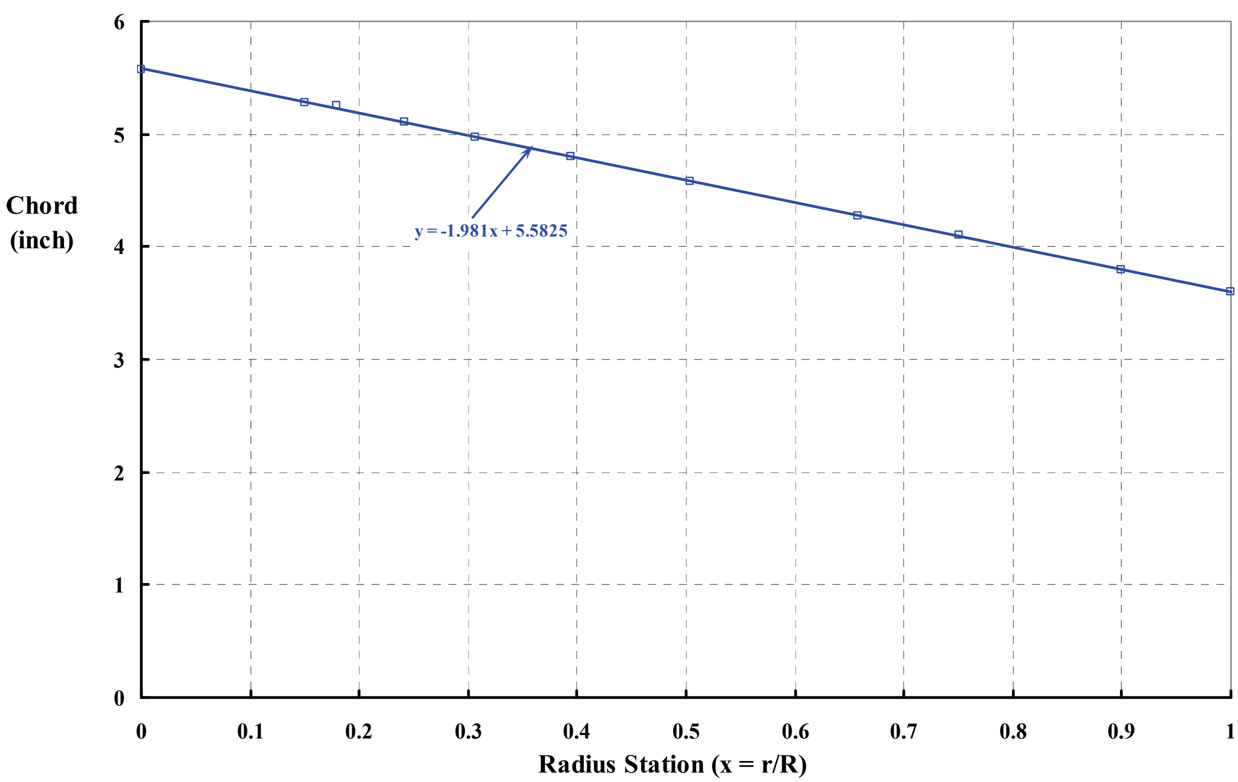

Figure F-3. The 0.15-scale JVX proprotor (three blades)—chord vs. radius station.

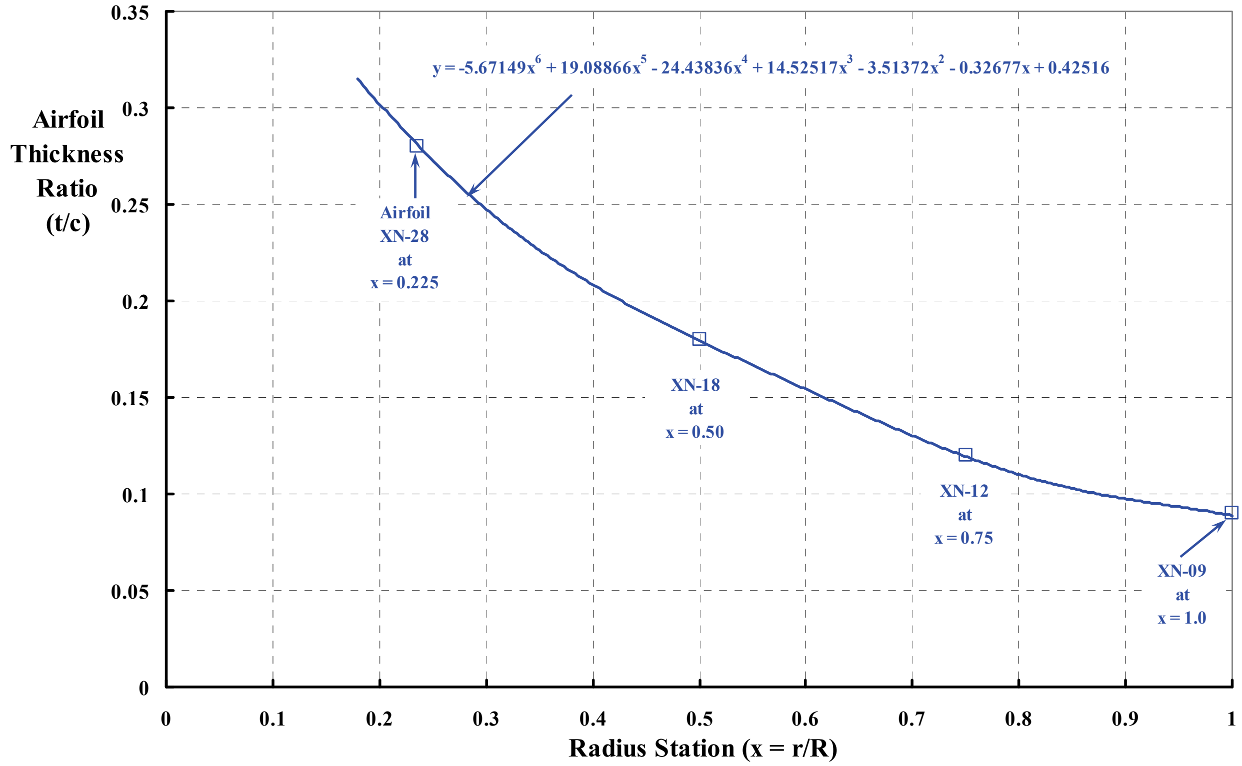

Figure F-4. The 0.15-scale JVX proprotor (three blades)—airfoil thickness ratio vs. radius station.

3. Performance Data

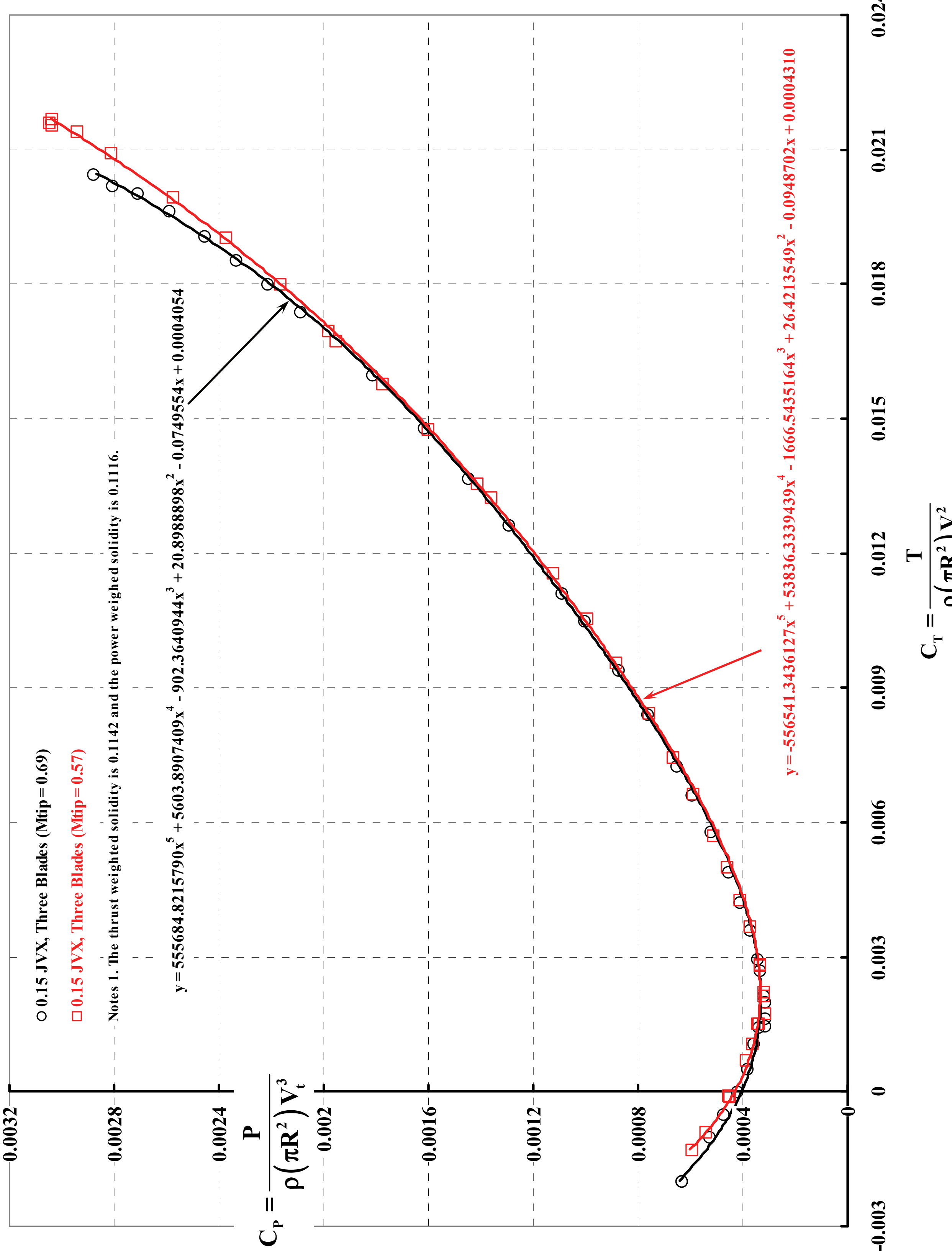

Figure F-5. The 0.15-scale JVX three-bladed proprotor test results on BHTI test stand—power vs. thrust coefficient.

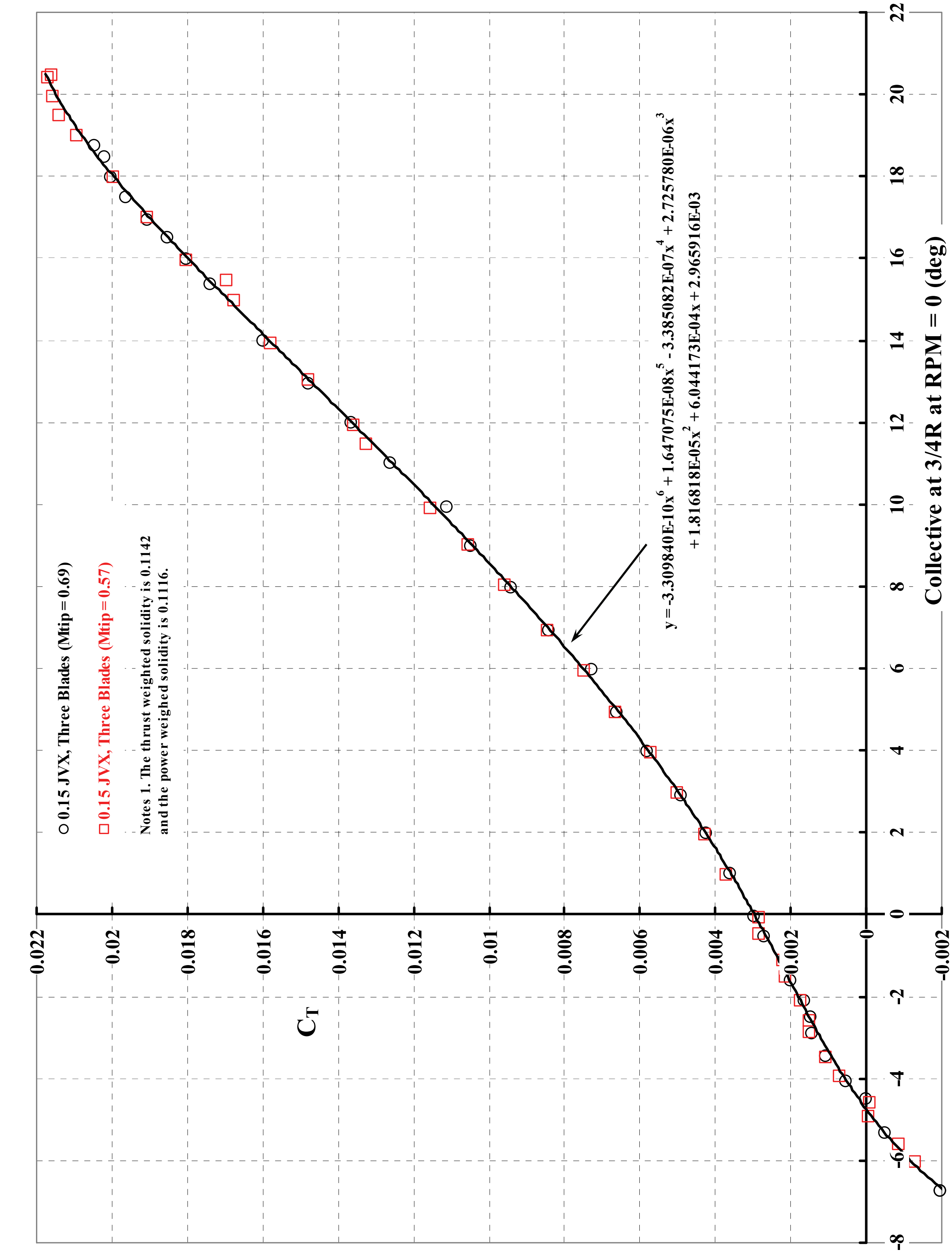

Figure F-6. The 0.15-scale JVX three-bladed proprotor test results on BHTI test stand—thrust coefficient vs. collective pitch.

Table F–2. The 0.15-Scale JVX Three-Bladed Proprotor Test Results on BHTI Test Stand

RUN	Record	V tip (fps)	M tip	Coll.	CT	CP	Ideal CP	FM	CT/CP
42	460	789.9	0.692	-6.71	-0.001974	0.000630	0.000062	0.0985	-3.14
42	461	789.2	0.692	-6.71	-0.001982	0.000631	0.000062	0.0989	-3.14
42	462	790.0	0.693	-5.96	-0.000995	0.000524	0.000022	0.0423	-1.90
42	464	790.6	0.693	-5.29	-0.000493	0.000473	0.000008	0.0164	-1.04
42	465	790.6	0.693	-4.45	0.000001	0.000419	0.000000	0.0000	0.00
42	466	790.3	0.693	-4.05	0.000523	0.000379	0.000008	0.0223	1.38
42	467	790.3	0.693	-3.44	0.001069	0.000356	0.000025	0.0694	3.00
42	468	790.6	0.693	-2.88	0.001446	0.000337	0.000039	0.1155	4.29
42	469	790.6	0.693	-2.46	0.001486	0.000313	0.000040	0.1295	4.75
42	470	789.9	0.693	-2.07	0.001650	0.000312	0.000047	0.1522	5.30
42	471	790.6	0.693	-1.58	0.001994	0.000314	0.000063	0.2007	6.36
42	472	789.9	0.693	-1.03	0.002140	0.000316	0.000070	0.2212	6.76
42	473	789.2	0.692	-0.50	0.002705	0.000332	0.000099	0.2999	8.15
42	474	790.3	0.692	-0.02	0.002976	0.000341	0.000115	0.3369	8.73
42	475	788.9	0.691	1.04	0.003610	0.000371	0.000153	0.4130	9.72
42	476	790.3	0.692	2.00	0.004235	0.000408	0.000195	0.4776	10.38
42	477	790.3	0.692	2.93	0.004899	0.000454	0.000242	0.5344	10.80
42	478	789.6	0.692	4.01	0.005805	0.000522	0.000313	0.5988	11.11
42	479	789.6	0.692	4.97	0.006615	0.000591	0.000380	0.6434	11.19
42	480	788.9	0.691	6.01	0.007264	0.000652	0.000438	0.6710	11.13
42	481	789.9	0.692	6.95	0.008418	0.000763	0.000546	0.7155	11.03
42	482	789.2	0.692	8.01	0.009401	0.000874	0.000645	0.7378	10.76
42	483	789.2	0.692	9.00	0.010488	0.001004	0.000759	0.7568	10.45
42	484	789.2	0.690	9.98	0.011105	0.001087	0.000828	0.7613	10.22
42	485	788.2	0.689	11.05	0.012630	0.001292	0.001004	0.7767	9.77
42	486	791.3	0.692	12.01	0.013670	0.001445	0.001130	0.7821	9.46
42	487	790.3	0.691	12.98	0.014802	0.001615	0.001273	0.7883	9.16
42	488	789.9	0.691	14.02	0.015993	0.001814	0.001430	0.7883	8.82
42	490	789.2	0.690	15.39	0.017394	0.002085	0.001622	0.7780	8.34
42	491	789.9	0.691	16.00	0.018019	0.002210	0.001710	0.7737	8.15
42	492	789.2	0.690	16.53	0.018542	0.002334	0.001785	0.7650	7.95
42	493	790.6	0.690	16.97	0.019078	0.002454	0.001863	0.7592	7.77
42	494	789.9	0.689	17.52	0.019627	0.002588	0.001944	0.7513	7.58
42	495	789.2	0.688	18.01	0.020027	0.002707	0.002004	0.7403	7.40
42	496	788.9	0.688	18.51	0.020203	0.002807	0.002031	0.7233	7.20
42	497	789.2	0.688	18.78	0.020458	0.002879	0.002069	0.7188	7.11
43	498	656.2	0.574	-6.02	-0.001297	0.000592	0.000033	0.0558	-2.19
43	499	656.2	0.574	-5.57	-0.000877	0.000539	0.000018	0.0341	-1.63
43	500	656.7	0.574	-4.90	-0.000080	0.000454	0.000001	0.0011	-0.18
43	501	656.4	0.574	-4.57	-0.000096	0.000450	0.000001	0.0015	-0.21
43	502	656.2	0.574	-3.90	0.000718	0.000387	0.000014	0.0351	1.86
43	503	656.4	0.574	-3.47	0.001079	0.000361	0.000025	0.0695	2.99
43	504	657.4	0.575	-2.83	0.001515	0.000338	0.000042	0.1232	4.48
43	505	656.9	0.575	-2.55	0.001517	0.000343	0.000042	0.1217	4.42
43	506	656.7	0.574	-2.07	0.001751	0.000315	0.000052	0.1643	5.55
43	507	657.4	0.575	-1.48	0.002153	0.000318	0.000071	0.2224	6.78
43	508	656.7	0.574	-1.08	0.002218	0.000317	0.000074	0.2329	6.99

RUN	Record	V tip (fps)	M tip	Coll.	CT	CP	Ideal CP	FM	CT/CP
43	509	657.4	0.575	-0.44	0.002842	0.000334	0.000107	0.3207	8.51
43	510	657.4	0.575	-0.05	0.002828	0.000332	0.000106	0.3205	8.52
43	511	656.9	0.575	0.99	0.003697	0.000371	0.000159	0.4279	9.95
43	512	658.1	0.576	1.99	0.004283	0.000408	0.000198	0.4863	10.51
43	513	657.1	0.575	2.99	0.005002	0.000457	0.000250	0.5474	10.95
43	514	656.7	0.574	3.97	0.005724	0.000511	0.000306	0.5990	11.20
43	515	656.7	0.574	4.97	0.006639	0.000588	0.000383	0.6503	11.29
43	516	656.9	0.575	5.96	0.007476	0.000665	0.000457	0.6875	11.24
43	517	656.4	0.574	6.96	0.008448	0.000758	0.000549	0.7245	11.15
43	518	655.5	0.573	8.04	0.009576	0.000880	0.000663	0.7534	10.89
43	519	655.9	0.574	9.03	0.010548	0.000992	0.000766	0.7724	10.64
43	520	655.9	0.574	9.94	0.011568	0.001121	0.000880	0.7846	10.32
43	522	655.5	0.573	11.51	0.013262	0.001359	0.001080	0.7949	9.76
43	523	656.4	0.574	11.96	0.013577	0.001414	0.001119	0.7910	9.60
43	524	655.5	0.573	13.06	0.014776	0.001602	0.001270	0.7928	9.22
43	525	655.7	0.573	13.95	0.015796	0.001774	0.001404	0.7912	8.90
43	526	655.0	0.572	14.99	0.016746	0.001951	0.001532	0.7856	8.58
43	527	655.7	0.572	15.49	0.016966	0.001982	0.001563	0.7885	8.56
43	528	655.9	0.573	15.97	0.018023	0.002164	0.001711	0.7906	8.33
43	529	654.7	0.572	17.02	0.019047	0.002372	0.001859	0.7837	8.03
43	530	655.7	0.572	18.00	0.019948	0.002576	0.001992	0.7734	7.74
43	531	655.7	0.572	19.01	0.020934	0.002811	0.002142	0.7619	7.45
43	532	655.9	0.573	19.50	0.021412	0.002942	0.002216	0.7531	7.28
43	533	655.0	0.572	19.96	0.021564	0.003038	0.002239	0.7370	7.10
43	534	655.2	0.572	20.49	0.021614	0.003044	0.002247	0.7382	7.10
43	535	655.9	0.573	20.45	0.021688	0.003035	0.002259	0.7443	7.15

Appendix G

0.15-Scale, Four-Bladed Proprotor for JVX Configuration of V-22 (Bell Helicopter Test)

This appendix contains:

1. Introduction.
2. Proprotor configuration (figs. G-1 to G-4, and table G-1).
3. Performance data of C_P versus C_T and C_T versus 3/4 radius collective for the Bell Helicopter test (figs. G-5 and G-6, and table G-2).

1. Introduction

During May of 1994, Bell Helicopter Textron Inc. (BHTI) conducted checkout of two 0.15-Mach-scaled JVX model proprotors. This initiated subsequent testing in the NASA Langley Research Center 14- by 22-Foot Subsonic Wind Tunnel from June 13 to July 29, 1994. The purpose of the wind tunnel test was to quantify and compare acoustic, aerodynamics, and Blade Vortex Interaction (BVI) characteristics of two similar tiltrotor rotor systems with a different number of blades but of equal solidity.

The debugging and checkout of BHTI's Power Force Model was conducted at Bell's facility. This provided hover performance data for both the three- and the four-bladed configurations (fig. G-1 and table G-2). This appendix includes data on the four-bladed narrow-cord proprotor**,** which was included in the complete data report (ref. 20).

2. Proprotor Configuration

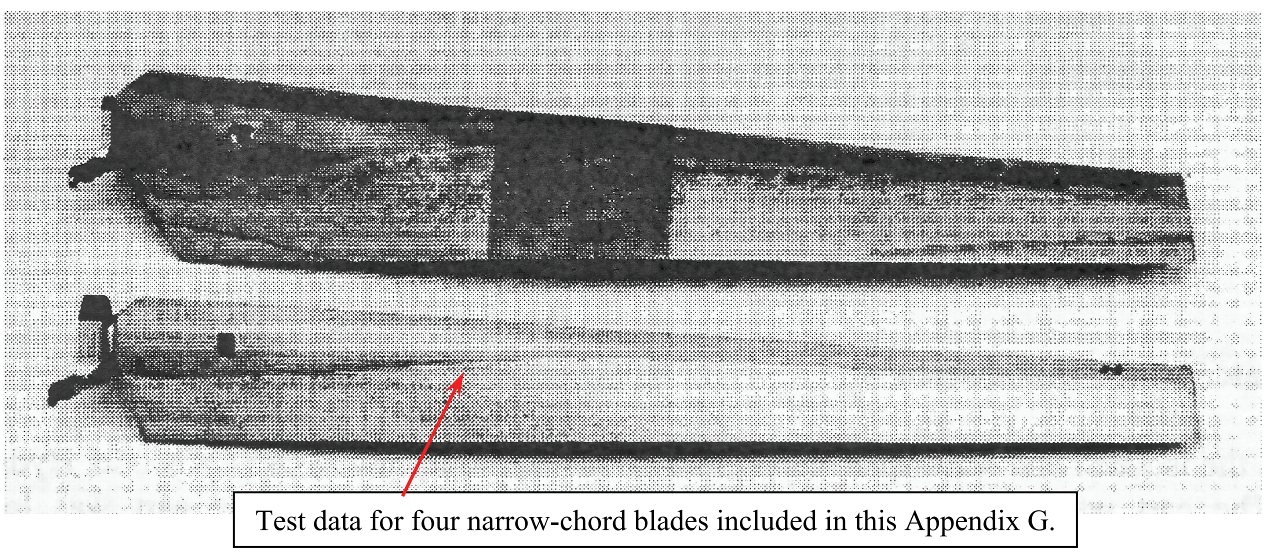

Figure G-1. Three wide-chord blades versus four narrow-chord blades were tested at small scale (5.7 feet diameter).

Table G-1. Comparative Geometry of Three- and Four-Bladed Proprotors

Parameter	Value
Rotor Diameter	68.4 inch
Blade Twist	-47.5 degrees
Blade Airfoils	0.15 Scaled JVX
Thrust Weighted Solidity	0.114 (JVX)
Blade Planform	Linear Tapered Swept
Blade Chord at tip:	
3-Bladed Rotor	3.60 inch
4-Bladed Rotor	2.70 inch
Aerodynamic Reference Blade Chord:	
3-Bladed Rotor	4.09 inch
4-Bladed Rotor	3.07 inch
Hub Precone	2 degrees
Blade Pitch Flap Coupling	45 degrees
Maximum Control System Travels	+15 to -5 deg F/A Cyclic
(3/4 radius)	-9 to +10 deg Lateral Cyclic
	-5 to +24 deg Collective
Maximum Rotor Flapping Angle	12 degrees
Operating Rotor Speed	2647 RPM
Operating Tip Speed	790 ft/sec
Maximum (110%) Rotor Speed	2911 RPM
Maximum Power (at 2650 RPM)	150 HP
Maximum Design Thrust (Ct = 0.023)	1053 lb

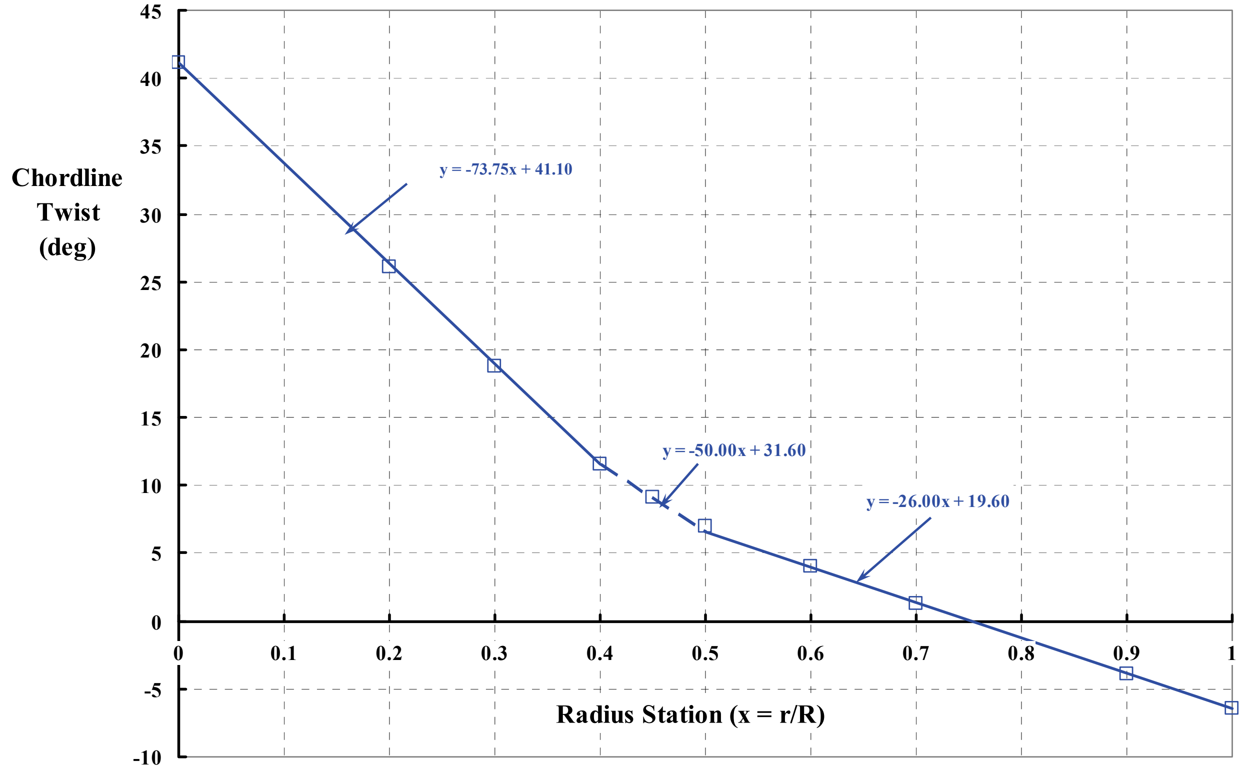

Figure G-2. The 0.15-scale JVX proprotor (four blades)—twist vs. radius station.

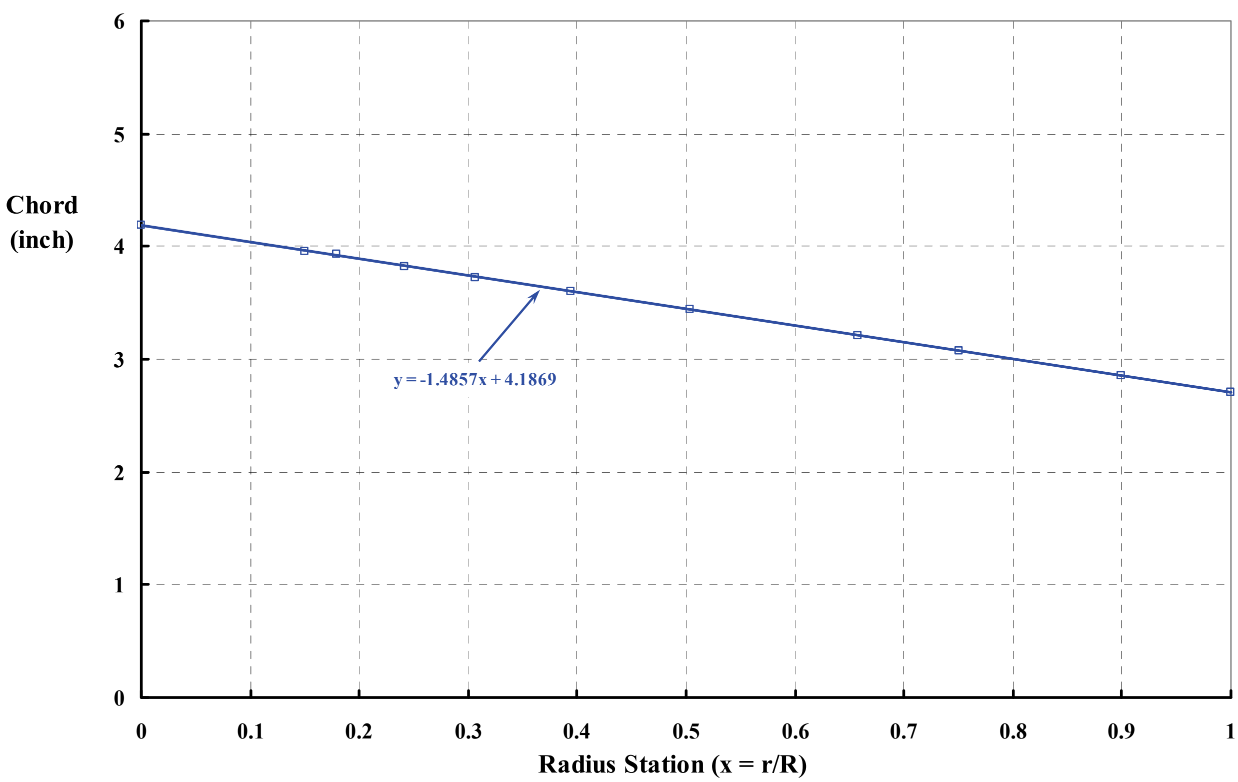

Figure G-3. The 0.15-scale JVX proprotor (four blades)—chord vs. radius station.

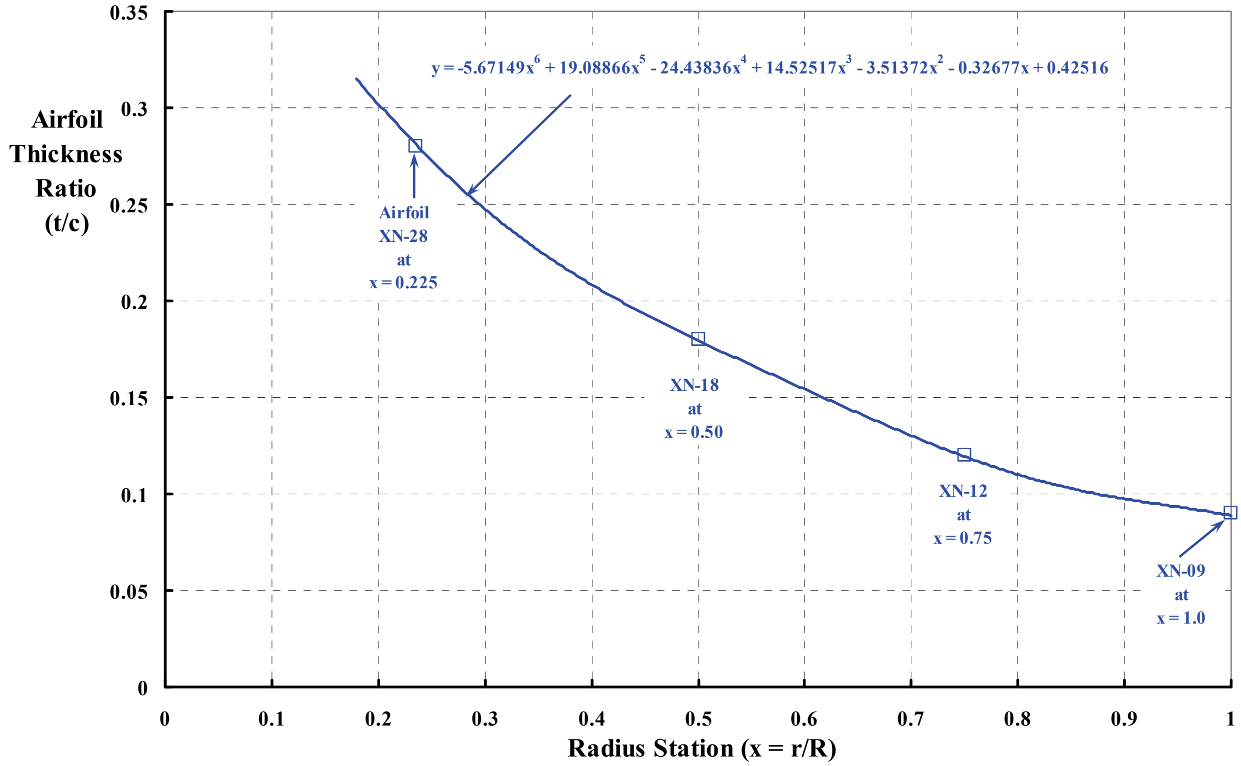

Figure G-4. The 0.15-scale JVX proprotor (four blades)—airfoil thickness ratio vs. radius station.

3. Performance Data

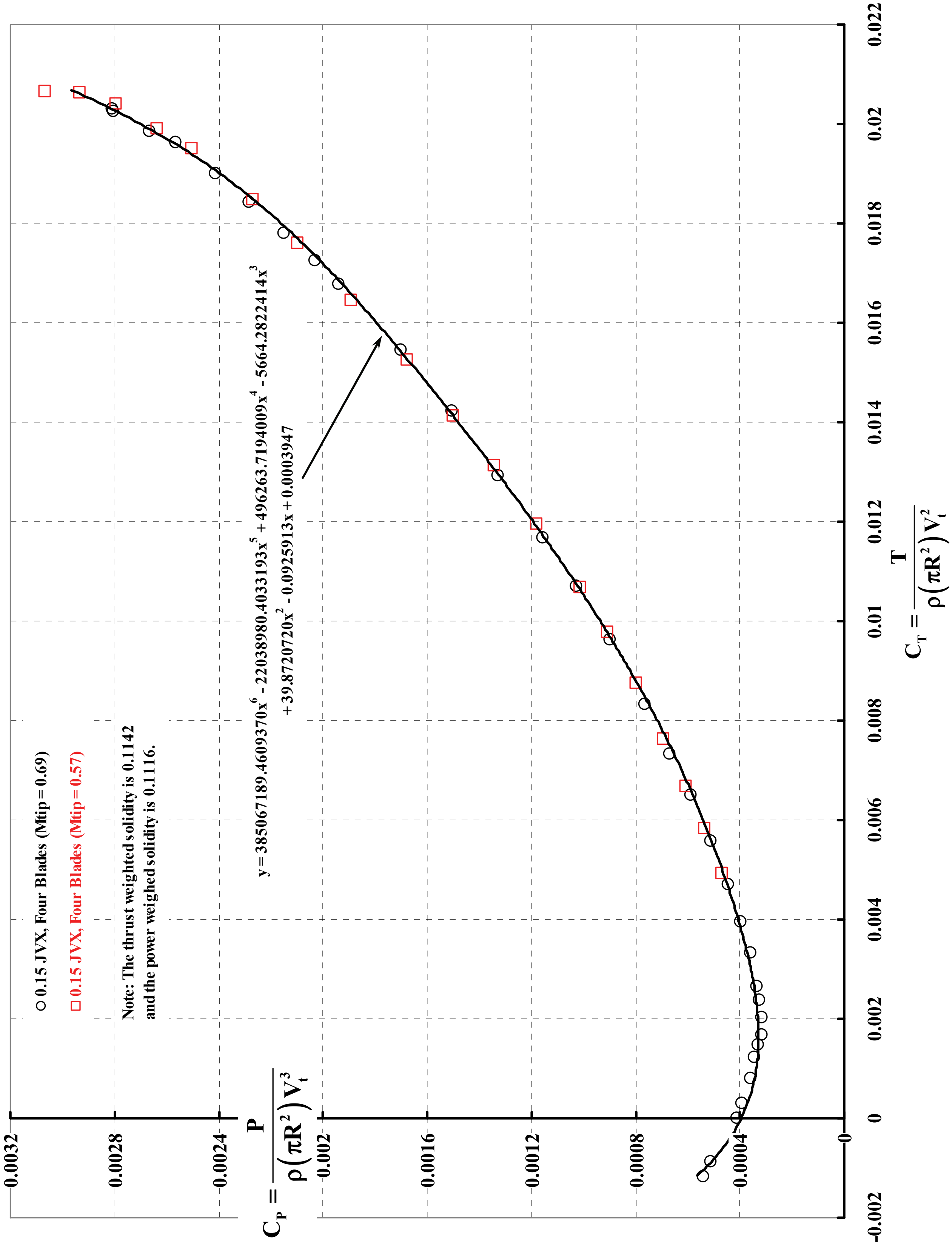

Figure G-5. The 0.15-scale JVX four-bladed proprotor test results on BHTI test stand—power vs. thrust coefficient.

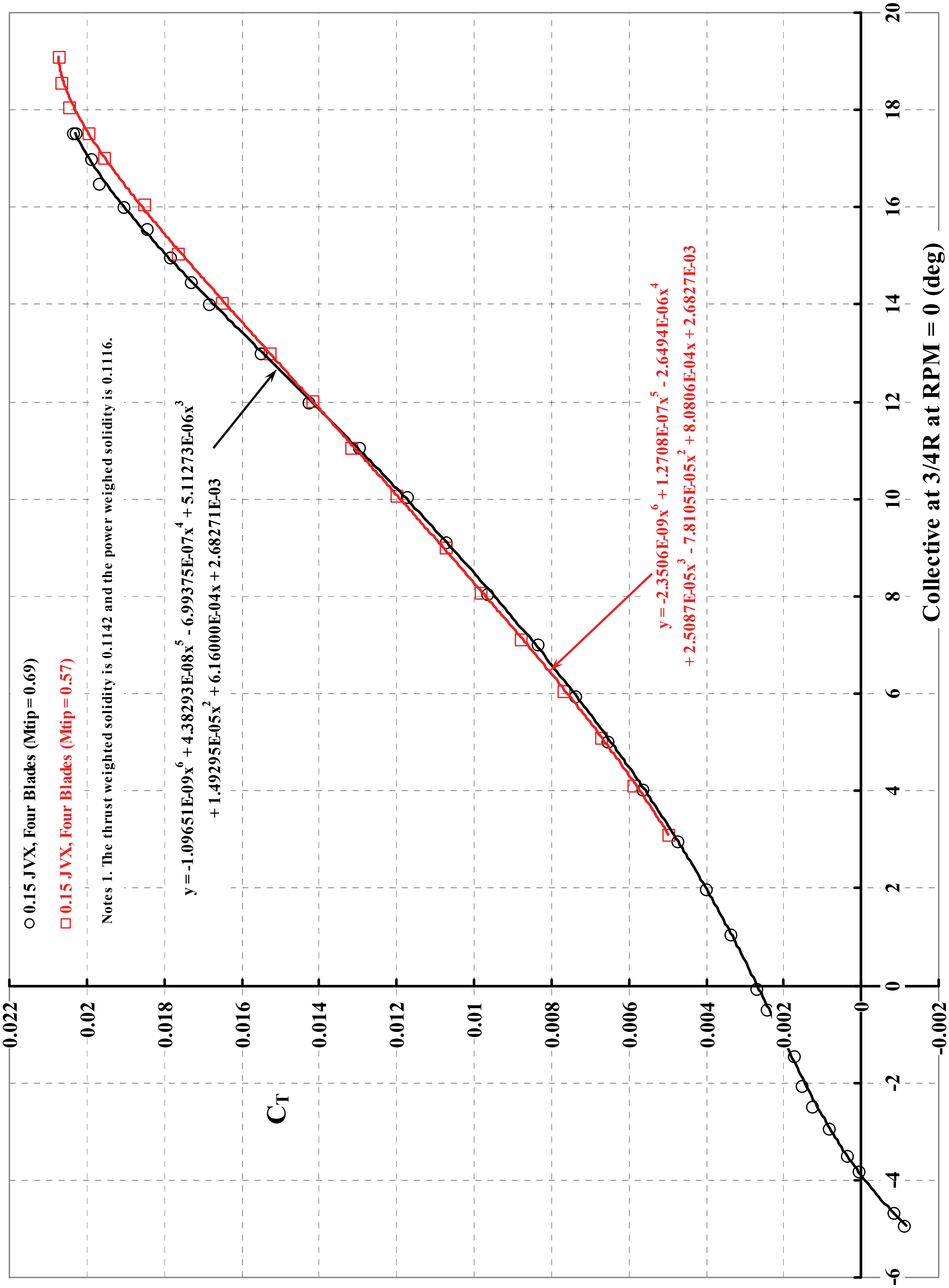

Figure G-6. The 0.15-scale JVX four-bladed proprotor test results on BHTI test stand—thrust coefficient vs. collective pitch.

Table G–2. The 0.15-scale JVX Four-Bladed Proprotor Test Results on BHTI Test Stand

RUN	Point	V tip (fps)	M tip	Coll.	CT	CP	Ideal CP	FM	CT/CP
50	579	790.4	0.697	-4.94	-0.001140	0.000538	0.000027	0.0505	-2.12
50	580	789.9	0.697	-4.68	-0.000859	0.000510	0.000018	0.0349	-1.68
50	581	790.4	0.697	-3.81	0.000036	0.000410	0.000000	0.0004	0.09
50	582	790.1	0.697	-3.50	0.000327	0.000392	0.000004	0.0107	0.83
50	583	789.5	0.696	-2.95	0.000816	0.000359	0.000016	0.0459	2.27
50	584	789.5	0.696	-2.48	0.001245	0.000343	0.000031	0.0907	3.63
50	585	789.6	0.696	-2.06	0.001507	0.000330	0.000041	0.1251	4.56
50	586	789.6	0.696	-1.45	0.001712	0.000313	0.000050	0.1599	5.46
50	587	790.7	0.697	-0.90	0.002044	0.000315	0.000065	0.2077	6.50
50	588	791.2	0.698	-0.49	0.002411	0.000327	0.000084	0.2558	7.37
50	589	790.6	0.697	-0.05	0.002669	0.000333	0.000097	0.2926	8.01
50	590	791.3	0.698	1.05	0.003340	0.000360	0.000137	0.3788	9.27
50	591	791.1	0.698	1.99	0.003986	0.000397	0.000178	0.4479	10.03
50	592	790.9	0.698	2.96	0.004734	0.000446	0.000230	0.5162	10.61
50	593	790.8	0.697	4.02	0.005609	0.000513	0.000297	0.5794	10.94
50	594	790.4	0.697	5.03	0.006524	0.000590	0.000373	0.6320	11.06
50	595	790.9	0.697	5.96	0.007344	0.000668	0.000445	0.6665	11.00
50	596	789.9	0.696	7.02	0.008344	0.000764	0.000539	0.7058	10.93
50	597	790.4	0.696	8.06	0.009648	0.000896	0.000670	0.7479	10.77
50	598	790.1	0.696	9.12	0.010715	0.001026	0.000784	0.7643	10.44
50	599	789.7	0.696	10.05	0.011708	0.001156	0.000896	0.7748	10.13
50	600	790.6	0.697	11.05	0.012949	0.001326	0.001042	0.7858	9.77
50	601	789.4	0.696	11.98	0.014249	0.001506	0.001203	0.7987	9.46
50	602	789.4	0.694	12.99	0.015475	0.001699	0.001361	0.8010	9.11
50	603	789.8	0.695	14.02	0.016812	0.001937	0.001541	0.7957	8.68
50	604	790.3	0.695	14.48	0.017274	0.002031	0.001605	0.7904	8.50
50	605	789.1	0.694	14.96	0.017830	0.002148	0.001683	0.7839	8.30
50	606	789.2	0.694	15.55	0.018440	0.002284	0.001771	0.7754	8.08
50	607	789.5	0.693	16.01	0.019028	0.002410	0.001856	0.7700	7.89
50	608	789.4	0.693	16.48	0.019658	0.002566	0.001949	0.7596	7.66
50	609	790.1	0.694	17.00	0.019872	0.002666	0.001981	0.7429	7.45
50	610	788.1	0.692	17.51	0.020316	0.002811	0.002048	0.7285	7.23
50	611	788.1	0.692	17.52	0.020276	0.002804	0.002042	0.7280	7.23
51	643	657.1	0.573	3.11	0.004962	0.000466	0.000247	0.5303	10.65
51	644	656.4	0.572	4.12	0.005842	0.000534	0.000316	0.5915	10.94
51	645	655.9	0.572	5.11	0.006699	0.000606	0.000388	0.6401	11.06
51	646	656.4	0.571	6.06	0.007658	0.000693	0.000474	0.6840	11.05
51	647	655.9	0.571	7.13	0.008770	0.000797	0.000581	0.7288	11.01
51	648	655.7	0.571	8.07	0.009808	0.000906	0.000687	0.7583	10.83
51	649	656.7	0.571	9.02	0.010697	0.001015	0.000782	0.7710	10.54
51	650	655.5	0.570	10.08	0.011980	0.001178	0.000927	0.7873	10.17
51	651	655.9	0.570	11.05	0.013152	0.001342	0.001066	0.7947	9.80
51	652	655.9	0.570	12.03	0.014153	0.001499	0.001191	0.7941	9.44
51	653	656.2	0.571	12.99	0.015263	0.001678	0.001333	0.7946	9.10
51	654	655.7	0.570	14.04	0.016485	0.001889	0.001497	0.7922	8.73
51	655	655.5	0.570	15.05	0.017627	0.002095	0.001655	0.7899	8.41
51	656	655.9	0.570	16.06	0.018498	0.002270	0.001779	0.7838	8.15
51	657	655.5	0.569	17.03	0.019518	0.002505	0.001928	0.7697	7.79
51	658	656.2	0.570	17.52	0.019927	0.002634	0.001989	0.7552	7.57
51	659	655.2	0.569	18.05	0.020435	0.002794	0.002066	0.7393	7.31
51	660	655.5	0.569	18.57	0.020638	0.002934	0.002096	0.7144	7.03
51	661	654.7	0.568	19.09	0.020685	0.003067	0.002104	0.6858	6.74

Appendix H

0.2364-Scale Proprotor A for Boeing Vertol Model 160 (WADC Test)

This appendix contains:

1. General discussion (figs. H-1 and H-2).
2. Proprotor configuration (figs. H-3 to H-5).
3. Performance data of C_P versus C_T and C_T versus 3/4 radius collective for the WADC test (figs. H-6 and H-7, and table H-1).

1. General Discussion

The following discussion (edited from references 20 through 24) is applicable to this Appendix H and to Appendices I and J as well.

Model rotor performance tests in the hover mode were carried out (during February, 1968) in the Air Force Propulsion Laboratory at Wright-Patterson Air Force Base, on Propeller Test Stand Number 3 with three scaled-model, low-disc-loading three-bladed rotors. The blade geometry was the same for each set, but different twist distributions were incorporated. The rotor diameter was 13 feet. The tests were initiated to substantiate Boeing's propeller/rotor performance calculations, and with proposed tests in the cruise mode, to aid in establishing the proper blade configuration for the large tiltrotor, Model 160 project. Thrust and power measurements were recorded for a range of RPM values and blade pitch angles.

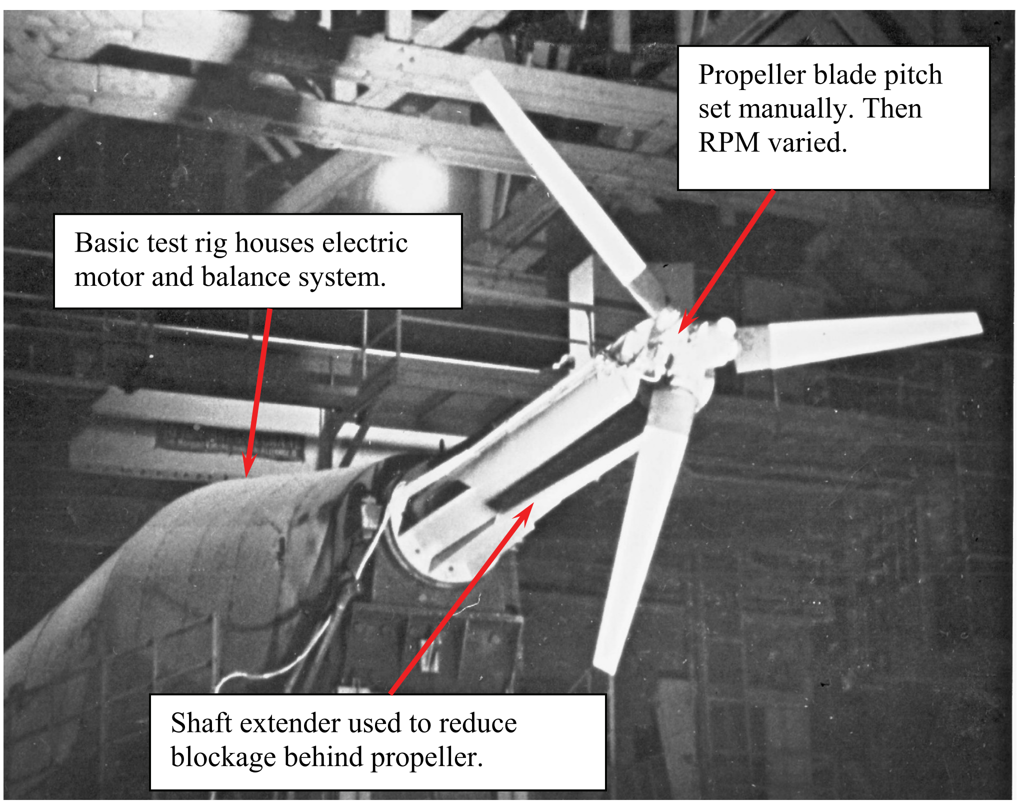

Figure H-1. WADC propeller test Rig #3.

The test model consisted of a geometrically scaled 13-foot-diameter, three-bladed rotor mounted in a Curtiss-Wright electrically operated propeller hub with a remotely controllable pitch capability. The C-W C5325D-A20 hub was compatible with the predicted blade loads and moments for the blade RPMs required.

Three sets of solid aluminum blades were tested. The blade sets, designated A (Appendix H), B (Appendix I), and C (Appendix J), were geometrically similar but had different overall nominal twist values as follows: A twist = –40°; B twist = –36°; C twist = –29°. (The basic blade set was Set B). Each blade set was complete with hub, power unit, and slip-ring assembly.

The Curtiss-Wright hub had an available pitch range from beta at the 3/4 radius station of 0° to 70°, with an accuracy of ±0.1° for the three blades at any specified angle. For the subject hover test phase however, the range of pitch angles covered was only from 4° to 18°. Identical root-end cuffs were fitted to all blades, as defined in Boeing Drawing SK-18082, to provide the correct root-end chord. The cuffs were fabricated from foamed plastic with a fiberglass skin and were molded around the blade root-end. The cuffs were not removed during the test period. The complete test program was run without the spinner, but with the blade root-end cuffs fitted.

The hub was mounted on a special splined adapter shaft. Because of the very large cross-sectional area of the test stand (fig. H-1), an extension shaft with support, approximately 1 rotor diameter long, was fitted to the rig to minimize interference effects due to slipstream blockage as shown with figure H-2. The adapter shaft was designed to mate with the upstream end of the extension shaft, and the slip-ring brush gear and support were mounted on the faceplate of the shaft extension support.

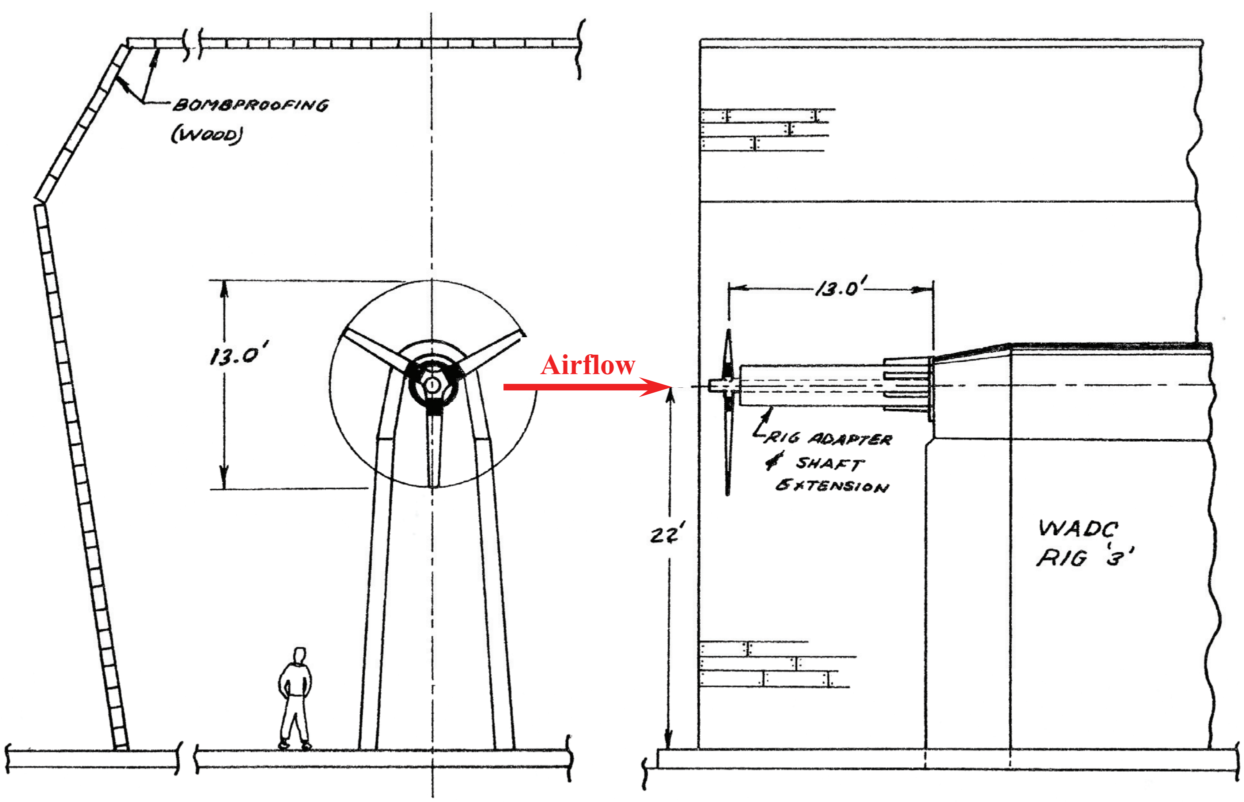

Figure H-2. WADC Rig #3 had an open face and a standard enclosure to provide safety. Reference 15 discusses tests results with the enclosure removed versus results with the standard enclosure in place.

The test stand shaft is horizontal and at a height of about 23 feet above ground. Considerable clearance exists between the blade tip path and the safety walls and roof, and no interference effects are anticipated. The maximum usable HP is 2700 and the maximum RPM capability is 4250. The propeller test rig has the capability of providing thrust and power measurements, under continuous running conditions. The thrust measuring system consists of axial load cells mounted integral with, and at the aft end of, the drive shaft. The axial load (thrust) is transmitted hydraulically to the control room, and is read-out on a circular thrust scale in pounds. The thrust scale used for the present tests has a full-scale capability of 15,000 pounds, and is subdivided such that the smallest division, approximately 3/32 inches wide, is equivalent to 25 pounds thrust.

The WADC procedure for determination of rotor power involves wattage measurements to derive total rig power consumption, and large order corrections. To check the validity of the WADC power data, and to achieve a possible higher degree of accuracy at low power levels, a supplementary system was incorporated employing a strain-gauge torque bridge mounted on the adapter shaft, with a visual read-out on the Digital Voltmeter. Visual read-out of the rig shaft RPM was provided by WADC.

All the test blades were instrumented with strain-gauge systems to provide measurements of blade torsion, flap-wise bending-moment, and chordwise bending-moment. (During testing only the strain-gauge instrumentation on one blade per set was connected). The gauge outputs were transferred via a modified Breeze slip-ring assembly to a C.E.C. system amplifier system. The blade pitch setting (defined as the blade angle at 75% radius), was measured by a pre-calibrated potentiometer mounted on the hub casing, driven, via a gear, by a rack attached to one of the blade clamps. The blade pitch read-out was accomplished on a Digital Voltmeter. Dynamic balancing instrumentation comprised 2-MB velocity pick-ups mounted mutually at right angles on the upstream end of the extension shaft support. The inputs from these pick-ups were also monitored on the oscillograph. A modified contactor system was adapted to provide a 1/rev blade azimuth location indication on the C.E.C. oscillograph trace.

Thrust and torque (power) measurements were made on the three blade sets over a range of blade tip speeds from 550 to 950 ft/sec (808 to 1395 RPM), for blade pitch angles at the 3/4 radius station from 4 to 18 degrees. The onset of stall flutter imposed a maximum blade pitch angle of 18 degrees and restricted the higher tip speeds at pitch settings greater than 12 degrees.

All the results have been corrected to sea level standard conditions, i.e., To = 15°C, Po = 29.92 inches Hg. Blade tip speeds have been reduced to tip Mach number based on the local speed of sound, in feet per second, $65.8\sqrt{{}^\circ K}$. Data accuracy based on the various repeat runs are as follows:

Thrust, ±1.5% to 2%.

Horsepower, ±1% to 2%.

RPM, ±2%.

The *absolute* reading accuracy on the thrust scale, because of the range of the scale used and scale pointer movement, is estimated to be about ±10 pounds. Several repeat runs were performed, especially at or near the design condition (collective pitch at 3/4 radius station = 11 degrees, RPM = 1102, tip speed = 750 ft/sec), to establish a confidence level in the data and generally investigate repeatability.

2. Proprotor Configuration

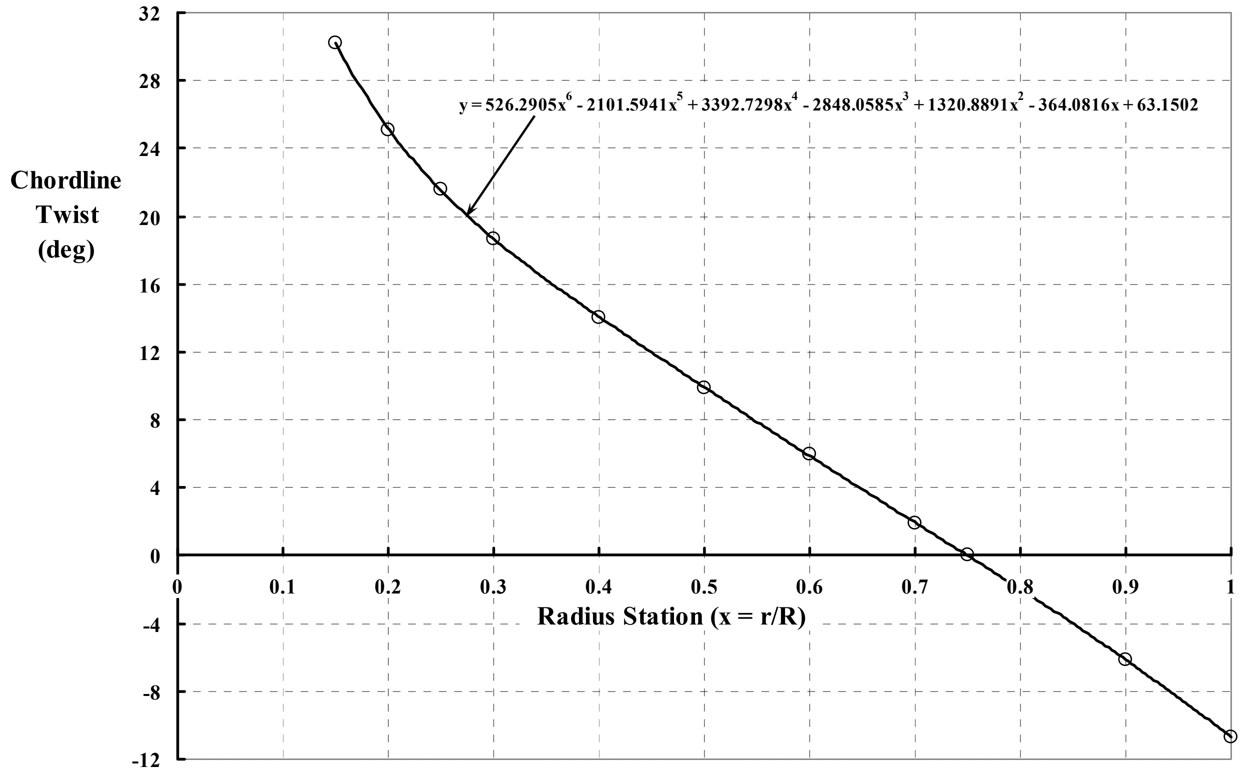

Figure H-3. The 0.2364-scale Proprotor A for Boeing Vertol Model 160—twist vs. radius station.

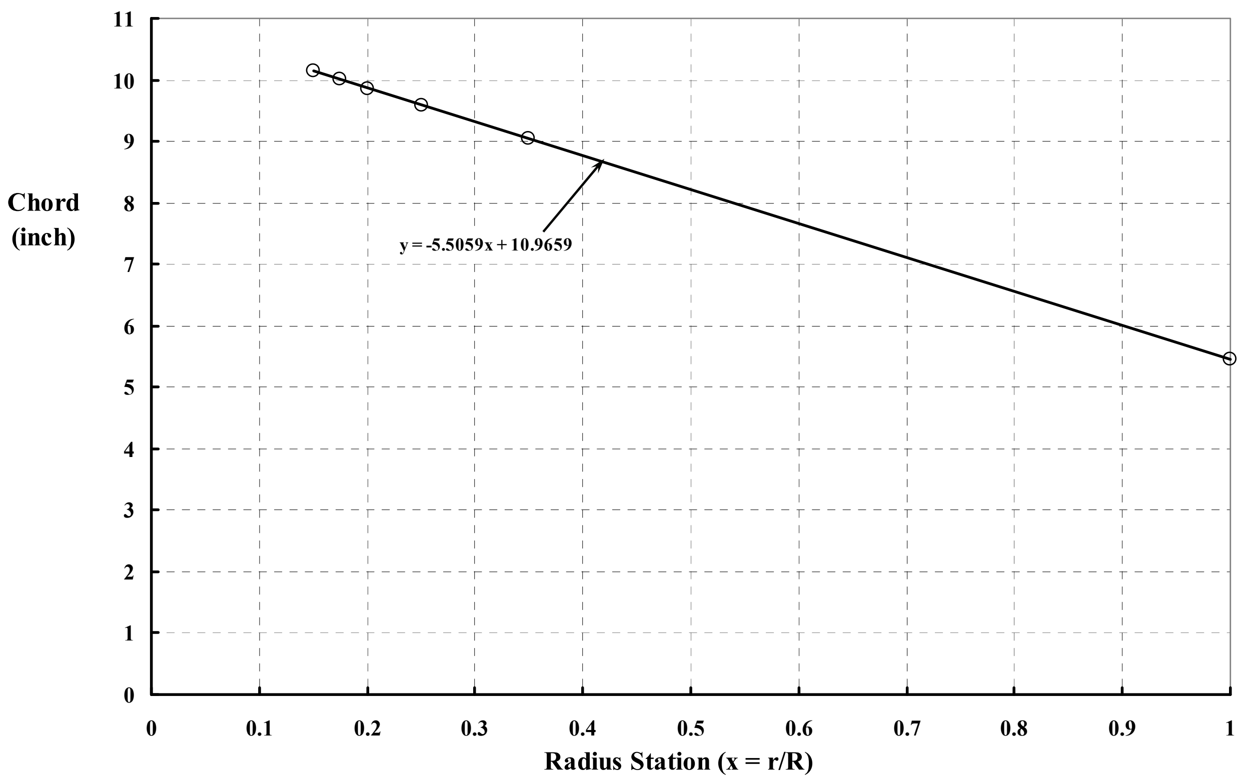

Figure H-4. The 0.2364-scale Proprotor A for Boeing Vertol Model 160—chord vs. radius station.

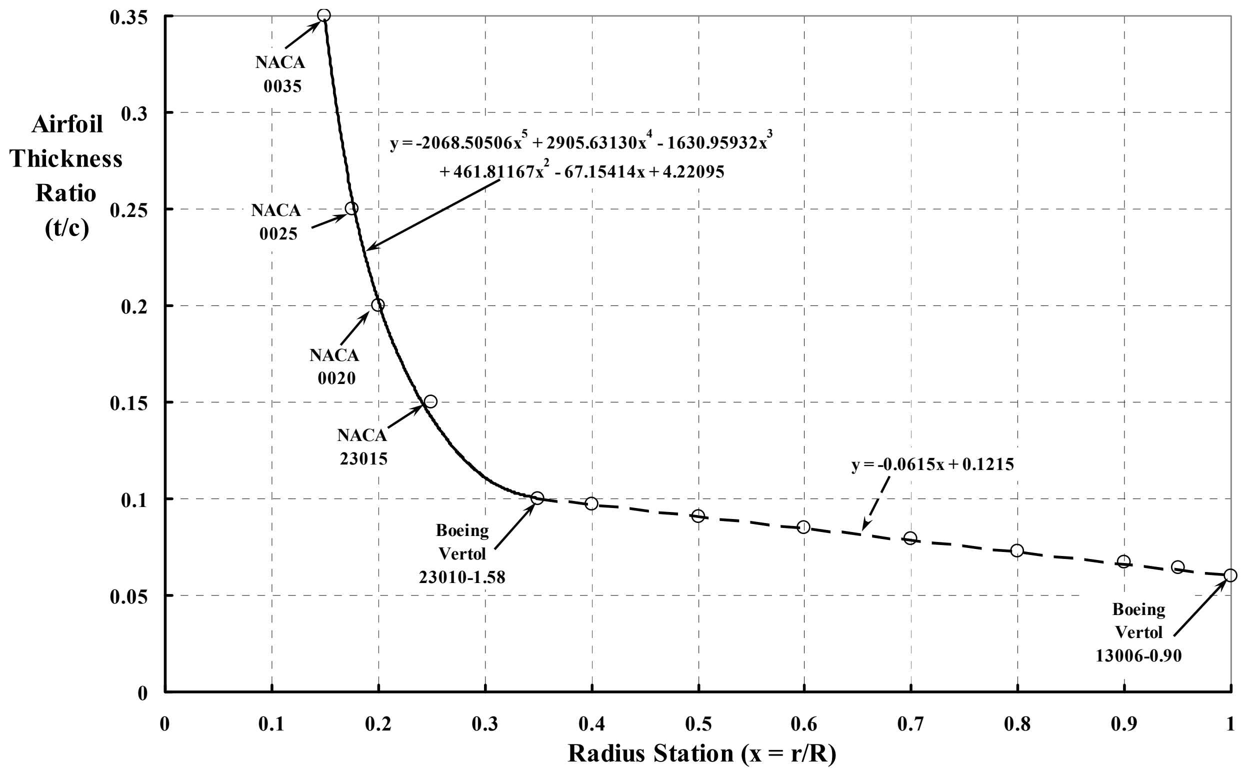

Figure H-5. The 0.2364-scale Proprotor A for Boeing Vertol Model 160—airfoil thickness ratio vs. radius station. The Boeing Vertol 23010-1.58 is a NACA 23010 with increased nose radius. The Boeing Vertol 13006-0.90 is a NACA 13006 with increased nose radius.

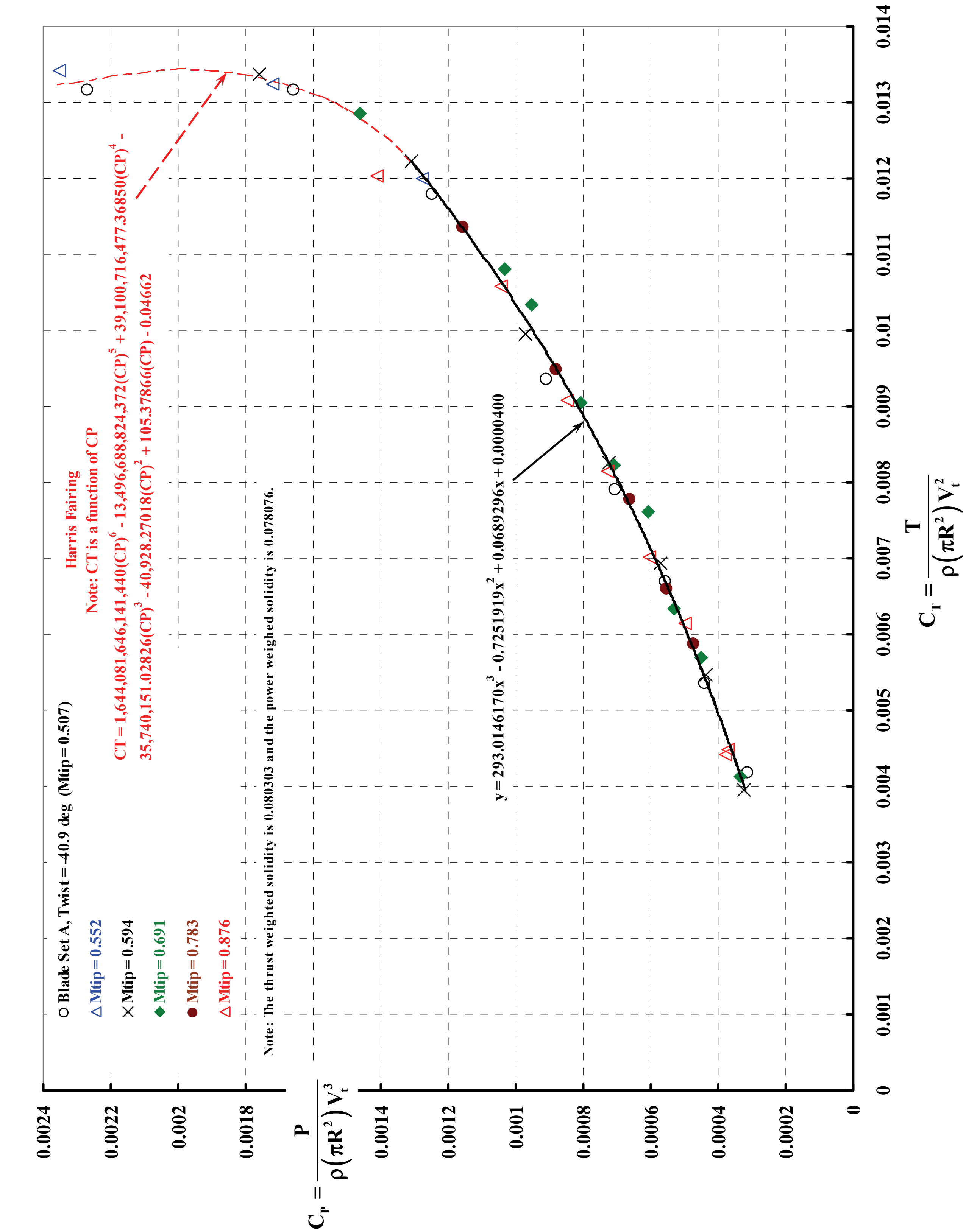

Figure H-6. The 0.2364-scale Proprotor A (for Boeing Vertol Model 160) test results at WADC—power vs. thrust coefficient.

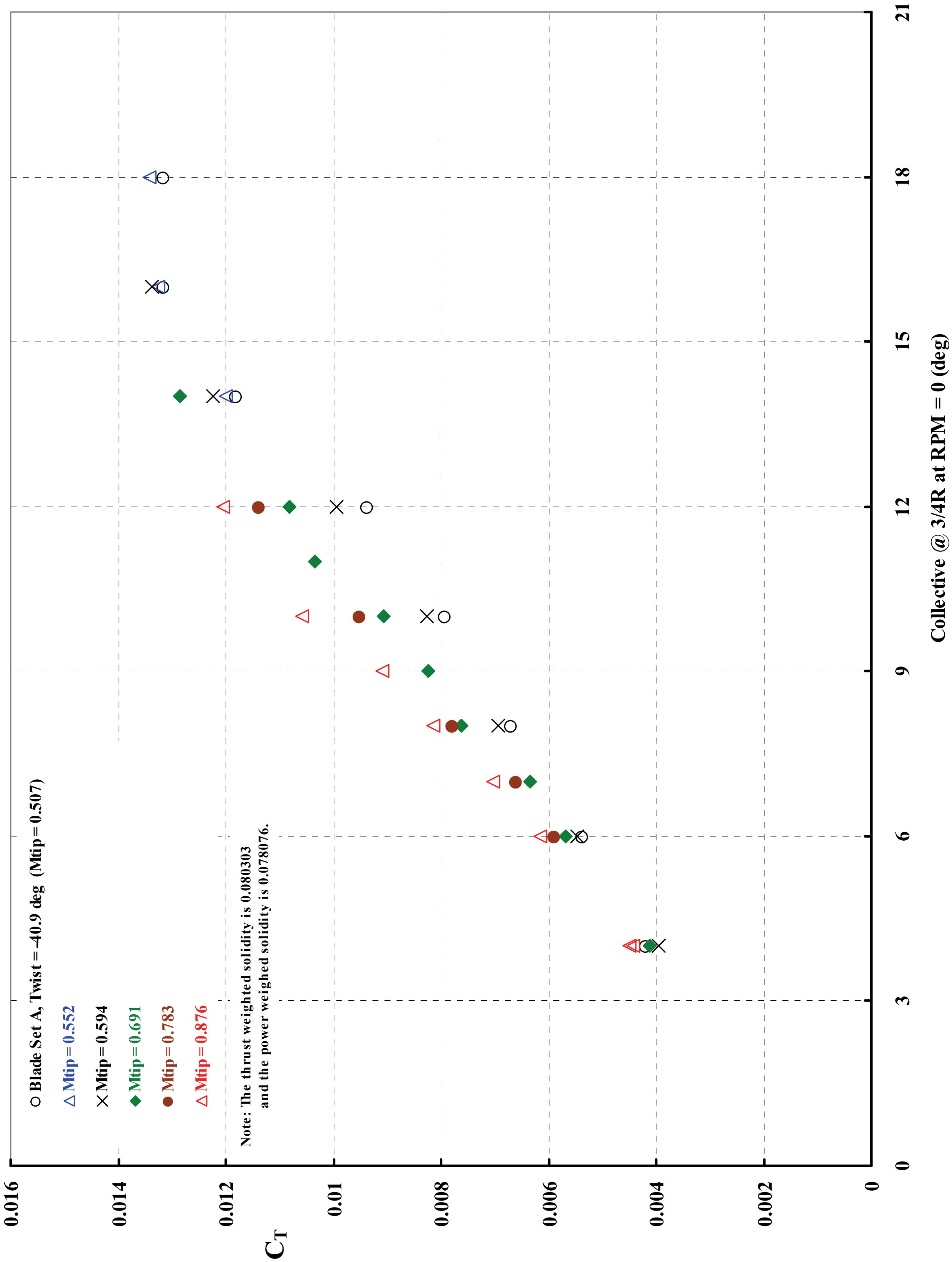

Figure H-7. The 0.2364-scale Proprotor A (for Boeing Vertol Model 160) test results at WADC—thrust coefficient vs. collective pitch.

Table H–1. The 0.2364-Scale Proprotor A (for Boeing Vertol Model 160) Test Results at WADC

Page	Point	V tip (fps)	M tip	Coll.	CT	CP	Ideal CP	FM	CT/CP
40	4	550.0	0.507	4	0.004193	0.000314	0.000192	0.6111	13.35
40	6	550.0	0.507	6	0.005367	0.000439	0.000278	0.6327	12.21
40	8	550.0	0.507	8	0.006708	0.000558	0.000389	0.6967	12.03
40	10	548.6	0.505	10	0.007921	0.000705	0.000498	0.7066	11.23
41	12	550.0	0.507	12	0.009366	0.000911	0.000641	0.7037	10.28
41	14	550.0	0.507	14	0.011804	0.001246	0.000907	0.7279	9.47
41	16	549.3	0.506	16	0.013172	0.001659	0.001069	0.6443	7.94
41	18	549.3	0.506	18	0.013172	0.002270	0.001069	0.4708	5.80
41	14	598.3	0.551	14	0.011998	0.001277	0.000929	0.7276	9.39
41	16	599.0	0.552	16	0.013249	0.001719	0.001078	0.6275	7.71
41	18	599.0	0.552	18	0.013417	0.002351	0.001099	0.4674	5.71
40	4	644.6	0.594	4	0.003948	0.000325	0.000175	0.5399	12.15
40	6	644.6	0.594	6	0.005470	0.000435	0.000286	0.6578	12.58
40	8	644.6	0.594	8	0.006928	0.000572	0.000408	0.7128	12.11
40	10	643.9	0.593	10	0.008256	0.000724	0.000530	0.7332	11.41
41	12	645.3	0.595	12	0.009946	0.000972	0.000701	0.7213	10.23
41	14	644.6	0.594	14	0.012230	0.001310	0.000956	0.7301	9.34
41	16	644.6	0.594	16	0.013378	0.001762	0.001094	0.6211	7.59
40	4	750.1	0.691	4	0.004128	0.000336	0.000188	0.5577	12.27
40	6	750.8	0.692	6	0.005689	0.000453	0.000303	0.6705	12.57
40	7	749.4	0.691	7	0.006334	0.000530	0.000356	0.6729	11.96
40	8	750.8	0.692	8	0.007611	0.000609	0.000470	0.7710	12.50
40	9	750.1	0.691	9	0.008231	0.000710	0.000528	0.7441	11.60
40	10	750.1	0.691	10	0.009056	0.000807	0.000609	0.7549	11.22
41	11	750.1	0.691	11	0.010346	0.000954	0.000744	0.7804	10.85
41	12	749.4	0.691	12	0.010811	0.001034	0.000795	0.7687	10.46
41	14	750.1	0.691	14	0.012862	0.001462	0.001031	0.7056	8.80
40	6	850.9	0.784	6	0.005883	0.000471	0.000319	0.6768	12.48
40	7	849.5	0.783	7	0.006605	0.000551	0.000380	0.6888	11.99
40	8	850.2	0.784	8	0.007792	0.000662	0.000486	0.7343	11.76
40	10	849.5	0.783	10	0.009508	0.000878	0.000656	0.7463	10.82
41	12	849.5	0.783	12	0.011378	0.001157	0.000858	0.7417	9.83
40	4 (R)	949.5	0.875	4	0.004425	0.000378	0.000208	0.5503	11.70
40	4	950.9	0.876	4	0.004489	0.000370	0.000213	0.5743	12.12
40	6	950.2	0.876	6	0.006150	0.000500	0.000341	0.6821	12.30
40	7	950.2	0.876	7	0.007018	0.000604	0.000416	0.6882	11.62
40	8	950.9	0.876	8	0.008153	0.000729	0.000521	0.7142	11.19
40	9	949.5	0.875	9	0.009082	0.000849	0.000612	0.7210	10.70
40	10	950.2	0.876	10	0.010579	0.001044	0.000769	0.7367	10.13
41	12	950.9	0.876	12	0.012036	0.001410	0.000934	0.6622	8.54

Appendix I

0.2364-Scale Proprotor B for Boeing Vertol Model 160 (WADC Test)

This appendix contains:

1. General discussion.
2. Proprotor configuration (figs. I-1 to I-3).
3. Performance data of C_P versus C_T and C_T versus 3/4 radius collective for the WADC test (figs. I-4 and I-5, and table I-1).

1. General Discussion

See Appendix H.

2. Proprotor Configuration

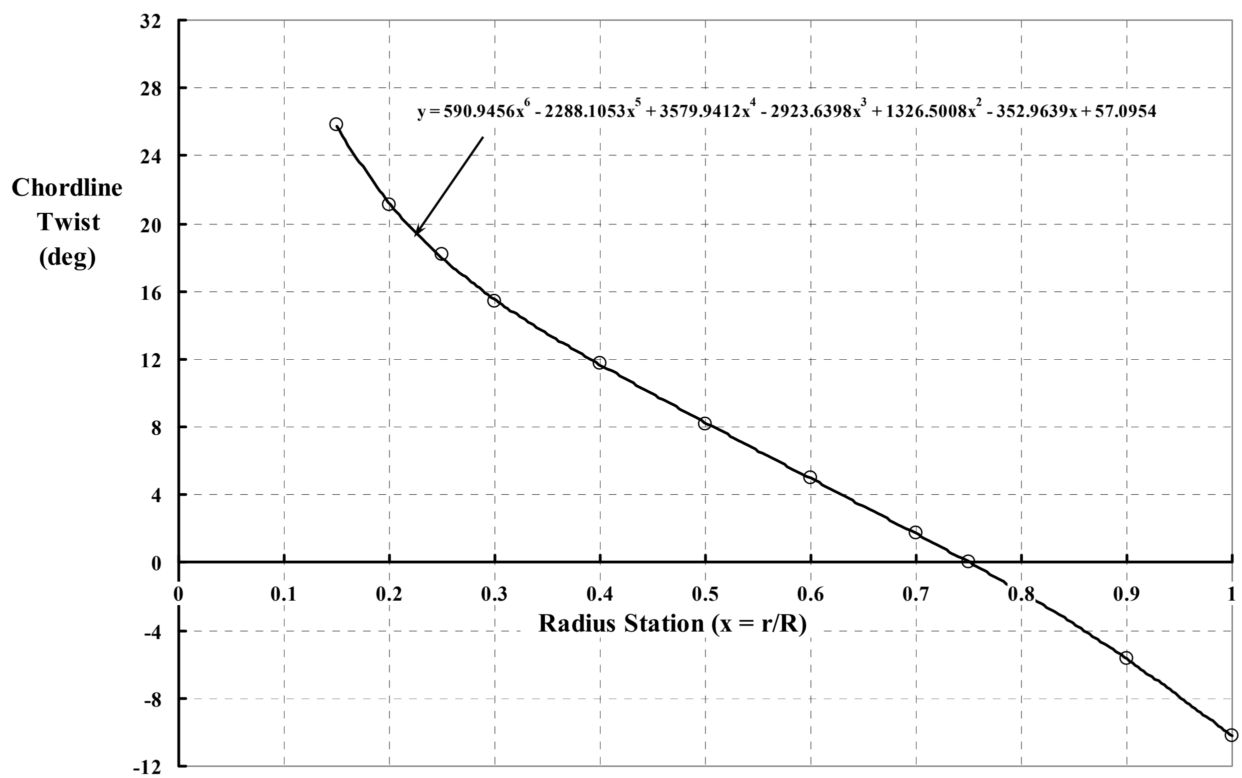

Figure I-1. The 0.2364-scale Proprotor B for Boeing Vertol Model 160—twist vs. radius station.

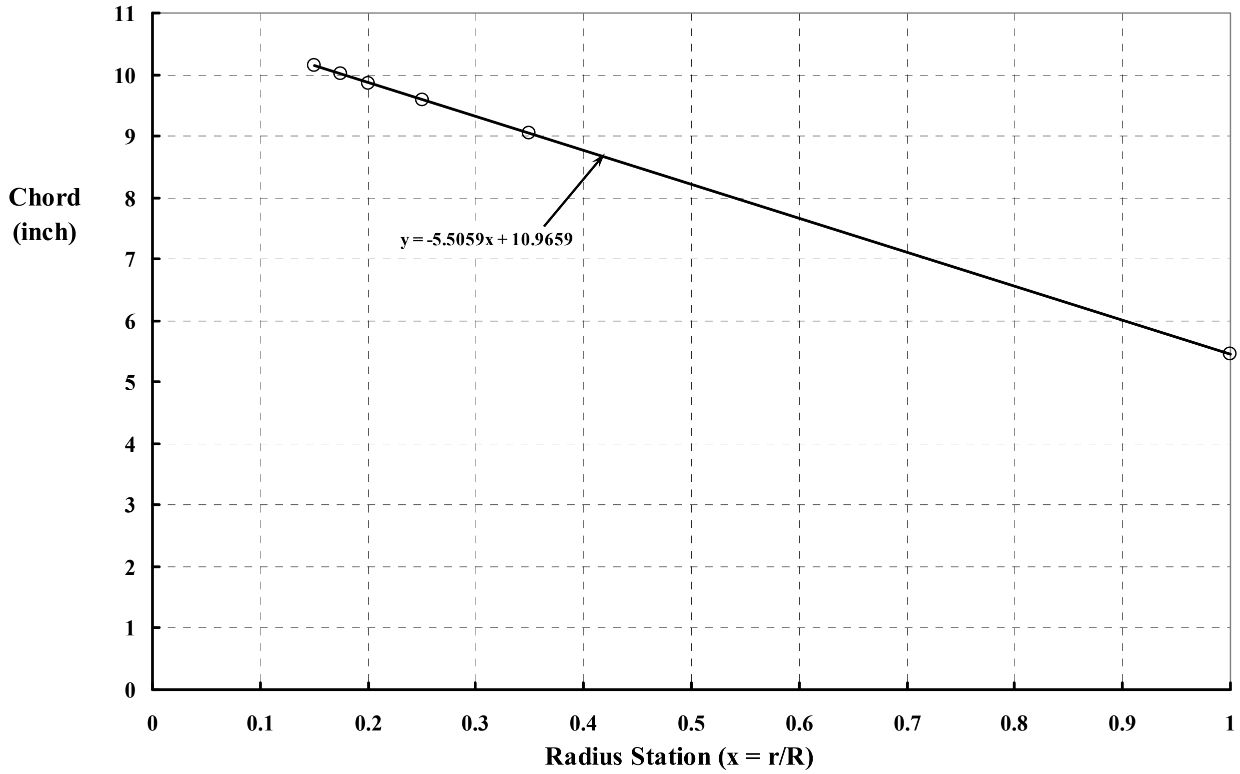

Figure I-2. The 0.2364-scale Proprotor B for Boeing Vertol Model 160—chord vs. radius station.

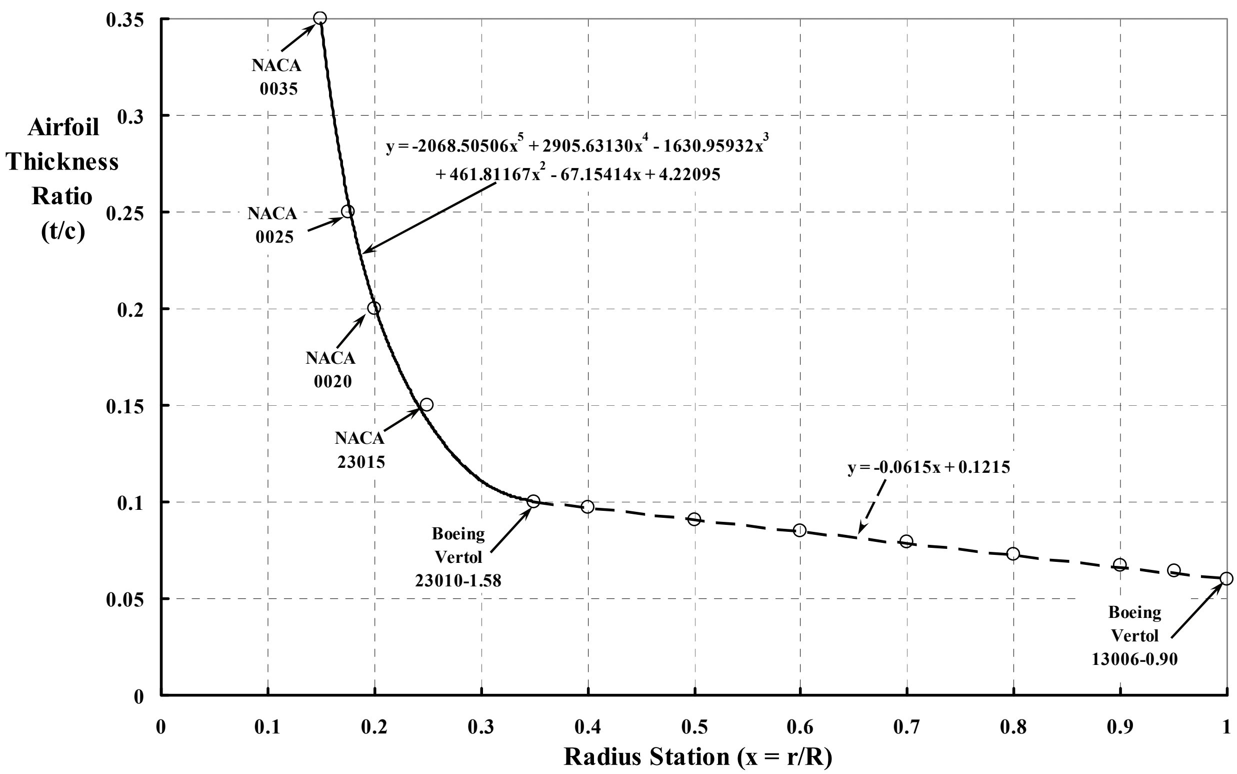

Figure I-3. The 0.2364-scale Proprotor B for Boeing Vertol Model 160—airfoil thickness ratio vs. radius station. The Boeing Vertol 23010-1.58 is a NACA 23010 with increased nose radius. The Boeing Vertol 13006-0.90 is a NACA 13006 with increased nose radius.

3. Performance Data

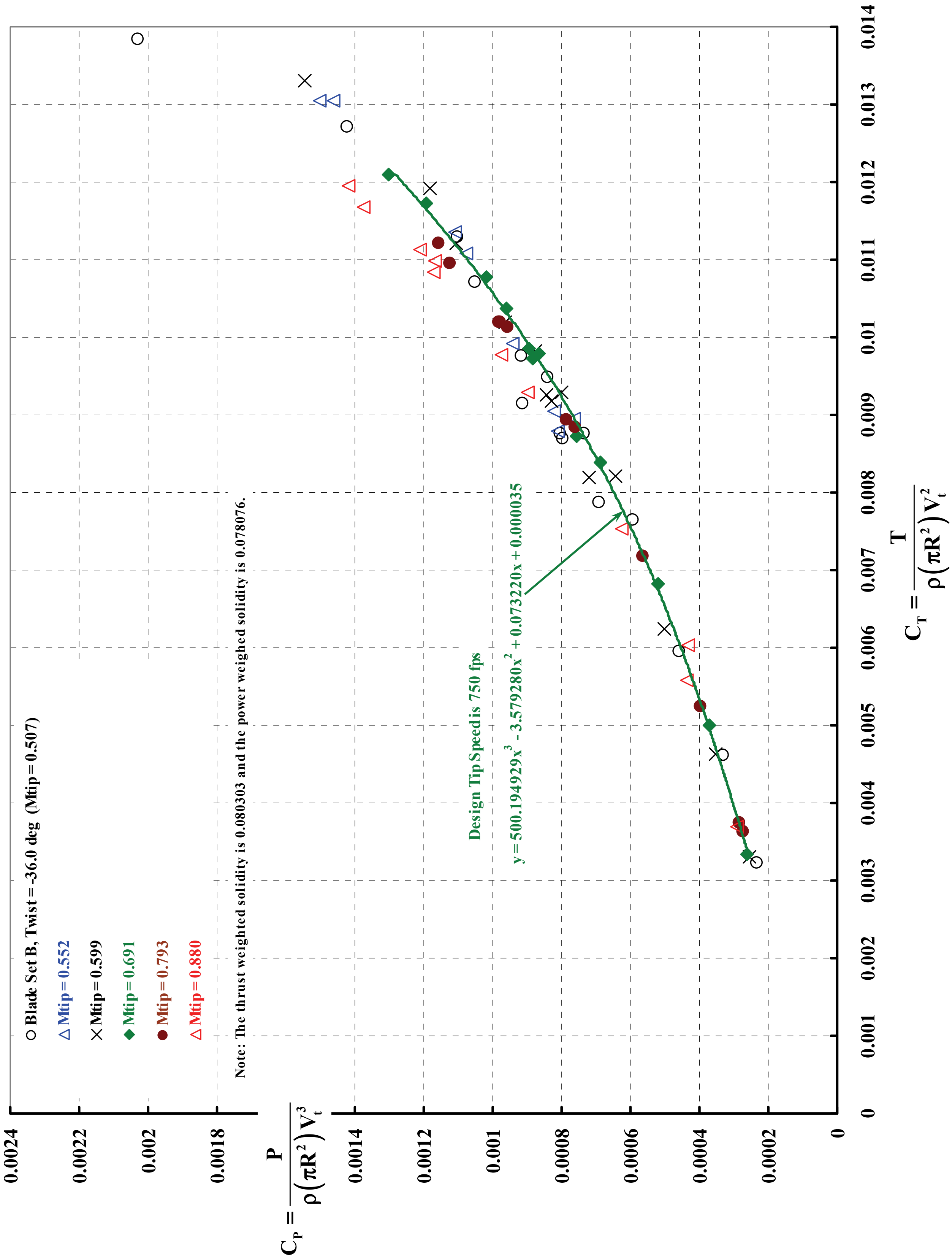

Figure I-4. The 0.2364-scale Proprotor B (for Boeing Vertol Model 160) test results at WADC—power vs. thrust coefficient.

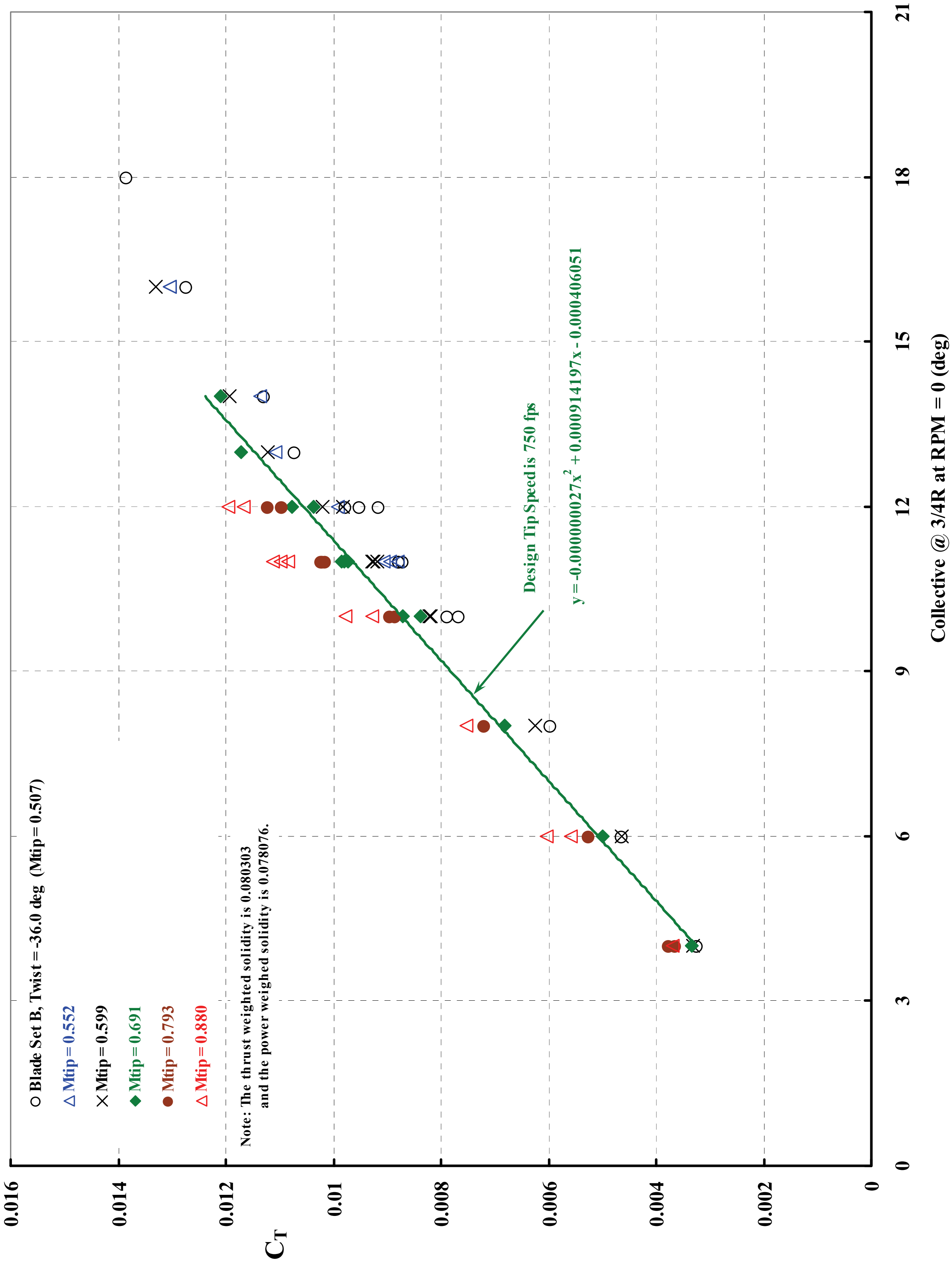

Figure I-5. The 0.2364-scale Proprotor B (for Boeing Vertol Model 160) test results at WADC—thrust coefficient vs. collective pitch.

Table I–1. The 0.2364-Scale Proprotor B (for Boeing Vertol Model 160) Test Results at WADC

Page	Point	V tip	M tip	Coll.	CT	CP	Ideal CP	FM	CT/CP
43	11 (R)	549.3	0.506	11	0.008772	0.000804	0.000581	0.7230	10.92
43	10(R)	550.0	0.507	10	0.007882	0.000691	0.000495	0.7160	11.41
43	11 (R)	550.0	0.507	11	0.008708	0.000795	0.000575	0.7224	10.95
44	12(R)	550.0	0.507	12	0.009159	0.000912	0.000620	0.6799	10.05
44	12(R)	550.0	0.507	12	0.009779	0.000917	0.000684	0.7460	10.67
42	4	549.3	0.513	4	0.003238	0.000232	0.000130	0.5606	13.93
42	6	549.3	0.513	6	0.004631	0.000332	0.000223	0.6709	13.94
42	8	549.3	0.513	8	0.005973	0.000457	0.000326	0.7148	13.08
42	10	550.0	0.514	10	0.007663	0.000593	0.000474	0.8005	12.93
43	11	549.3	0.510	11	0.008772	0.000736	0.000581	0.7891	11.91
44	12	550.0	0.514	12	0.009508	0.000840	0.000656	0.7803	11.32
44	13	549.3	0.506	13	0.010733	0.001052	0.000786	0.7471	10.20
44	14	550.0	0.510	14	0.011301	0.001101	0.000849	0.7719	10.27
44	16	549.3	0.510	16	0.012733	0.001422	0.001016	0.7146	8.96
44	18	550.0	0.510	18	0.013855	0.002029	0.001153	0.5685	6.83
43	11 (R)	599.0	0.552	11	0.008798	0.000811	0.000584	0.7199	10.85
43	11 (R)	599.9	0.552	11	0.009056	0.000823	0.000609	0.7405	11.00
44	12(R)	599.0	0.552	12	0.009921	0.000940	0.000699	0.7430	10.55
44	16 (R)	599.0	0.556	16	0.013043	0.001501	0.001053	0.7016	8.69
43	11	599.0	0.556	11	0.008953	0.000764	0.000599	0.7843	11.72
44	13	597.6	0.551	13	0.011082	0.001078	0.000825	0.7655	10.28
44	14	599.0	0.556	14	0.011353	0.001111	0.000855	0.7700	10.22
44	16	599.0	0.556	16	0.013043	0.001461	0.001053	0.7211	8.93
43	10(R)	650.0	0.599	10	0.008192	0.000721	0.000524	0.7271	11.36
43	11 (R)	650.0	0.599	11	0.009172	0.000831	0.000621	0.7477	11.04
43	11 (R)	650.7	0.600	11	0.009263	0.000844	0.000630	0.7466	10.97
44	12(R)	650.0	0.599	12	0.0101915	0.000962	0.000728	0.7562	10.59
42	4	650.0	0.607	4	0.003303	0.000254	0.000134	0.5280	12.99
42	6	649.4	0.607	6	0.004631	0.000353	0.000223	0.6311	13.11
42	8	650.0	0.607	8	0.006244	0.000500	0.000349	0.6975	12.48
42	10	650.7	0.608	10	0.008205	0.000644	0.000526	0.8156	12.73
43	11	650.0	0.603	11	0.009288	0.000800	0.000633	0.7913	11.61
44	12	649.4	0.607	12	0.009830	0.000878	0.000689	0.7854	11.20
44	13	650.0	0.599	13	0.011211	0.001107	0.000839	0.7584	10.13
44	14	650.7	0.604	14	0.011920	0.001182	0.000920	0.7787	10.09
44	16	646.0	0.599	16	0.013301	0.001544	0.001085	0.7025	8.61
44	12(R)	677.3	0.624	12	0.010385	0.000948	0.000748	0.7896	10.96
43	10(R)	750.1	0.692	10	0.008721	0.000756	0.000576	0.7617	11.54
43	11 (R)	749.4	0.691	11	0.009856	0.000894	0.000692	0.7736	11.02
43	11 (R)	750.1	0.692	11	0.009727	0.000884	0.000678	0.7673	11.00
44	12(R)	750.1	0.692	12	0.010772	0.001019	0.000791	0.7757	10.57
42	4	750.1	0.700	4	0.003341	0.000261	0.000137	0.5229	12.79
42	6	750.1	0.700	6	0.005005	0.000370	0.000250	0.6761	13.51

Page	Point	V tip	M tip	Coll.	CT	CP	Ideal CP	FM	CT/CP
42	8	750.1	0.700	8	0.006824	0.000520	0.000399	0.7662	13.12
42	10	750.1	0.700	10	0.008385	0.000687	0.000543	0.7899	12.20
43	11	749.4	0.695	11	0.009792	0.000865	0.000685	0.7918	11.32
44	12	750.8	0.701	12	0.010372	0.000961	0.000747	0.7773	10.79
44	13	749.4	0.691	13	0.011727	0.001192	0.000898	0.7532	9.84
44	14	750.8	0.697	14	0.012101	0.001303	0.000941	0.7226	9.29
42	4 (R)	849.5	0.793	4	0.003754	0.000285	0.000163	0.5707	13.17
42	10(R)	849.5	0.793	10	0.008953	0.000784	0.000599	0.7637	11.42
43	11 (R)	850.2	0.784	11	0.010217	0.000981	0.000730	0.7441	10.41
43	11 (R)	850.2	0.784	11	0.010204	0.000978	0.000729	0.7452	10.43
44	12(R)	850.2	0.784	12	0.011224	0.001157	0.000841	0.7268	9.70
42	4	849.5	0.793	4	0.003651	0.000273	0.000156	0.5704	13.35
42	6	849.5	0.793	6	0.005251	0.000397	0.000269	0.6775	13.22
42	8	848.8	0.793	8	0.007186	0.000565	0.000431	0.7623	12.72
42	10	849.5	0.793	10	0.008850	0.000759	0.000589	0.7753	11.66
43	11	849.5	0.788	11	0.010153	0.000958	0.000723	0.7554	10.60
44	12	849.5	0.793	12	0.010966	0.001125	0.000812	0.7216	9.75
42	6 (R)	949.5	0.881	6	0.005586	0.000435	0.000295	0.6782	12.83
43	10(R)	949.5	0.875	10	0.009779	0.000976	0.000684	0.7008	10.02
43	11 (R)	950.1	0.876	11	0.010978	0.001166	0.000813	0.6975	9.41
43	11 (R)	950.2	0.876	11	0.011133	0.001213	0.000831	0.6850	9.18
44	12(R)	949.5	0.875	12	0.011946	0.001418	0.000923	0.6511	8.42
42	4	948.8	0.886	4	0.003690	0.000292	0.000158	0.5428	12.64
42	6	949.5	0.887	6	0.006025	0.000431	0.000331	0.7669	13.97
42	8	950.2	0.887	8	0.007534	0.000627	0.000462	0.7374	12.01
42	10	949.5	0.887	10	0.009288	0.000897	0.000633	0.7058	10.36
43	11	950.2	0.882	11	0.010837	0.001172	0.000798	0.6806	9.25
44	12	949.5	0.887	12	0.011675	0.001374	0.000892	0.6490	8.49

Note: The letter (R) denotes a rerun data point.

Appendix J

0.2364-Scale Proprotor C for Boeing Vertol Model 160 (WADC Test)

This appendix contains:

1. General discussion.
2. Proprotor configuration (figs. J-1 to J-3).
3. Performance data of C_P versus C_T and C_T versus 3/4 radius collective for the WADC test (figs. J-4 and J-5, and table J-1).

1. General Discussion

See Appendix H.

2. Proprotor Configuration

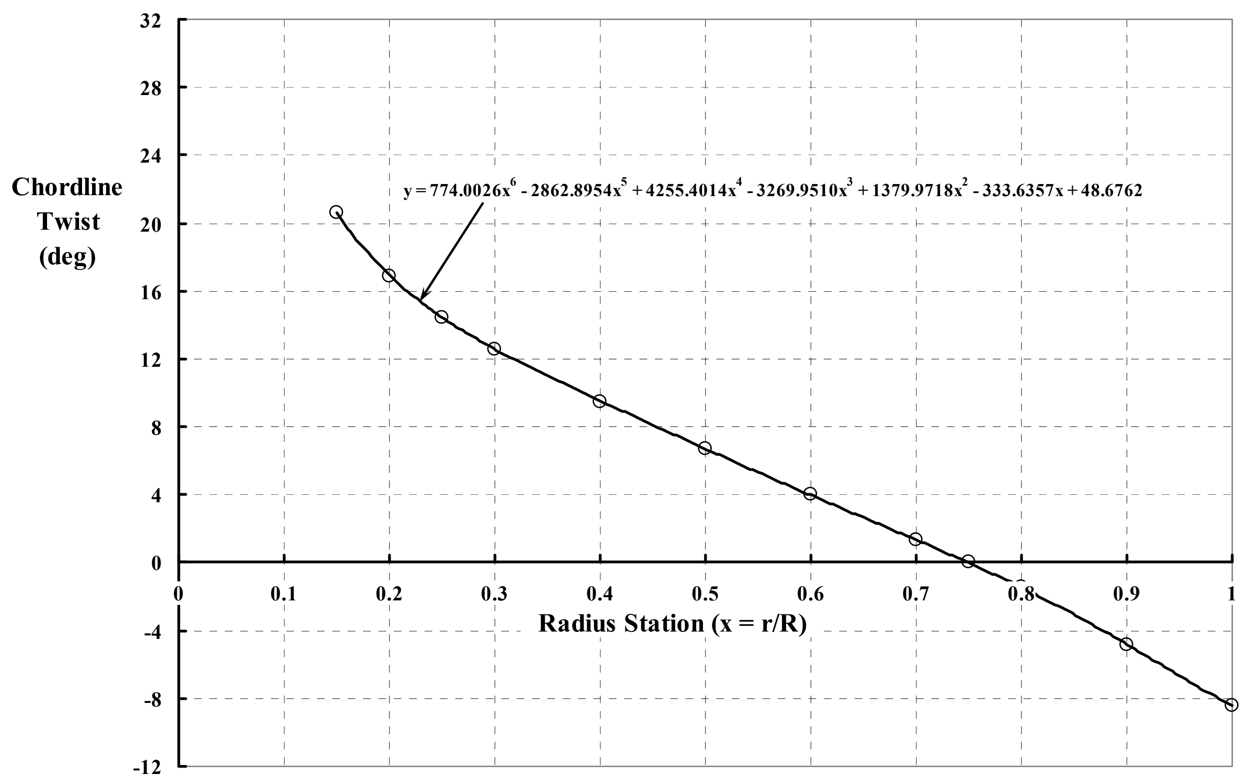

Figure J-1. The 0.2364-scale Proprotor C for Boeing Vertol Model 160—twist vs. radius station.

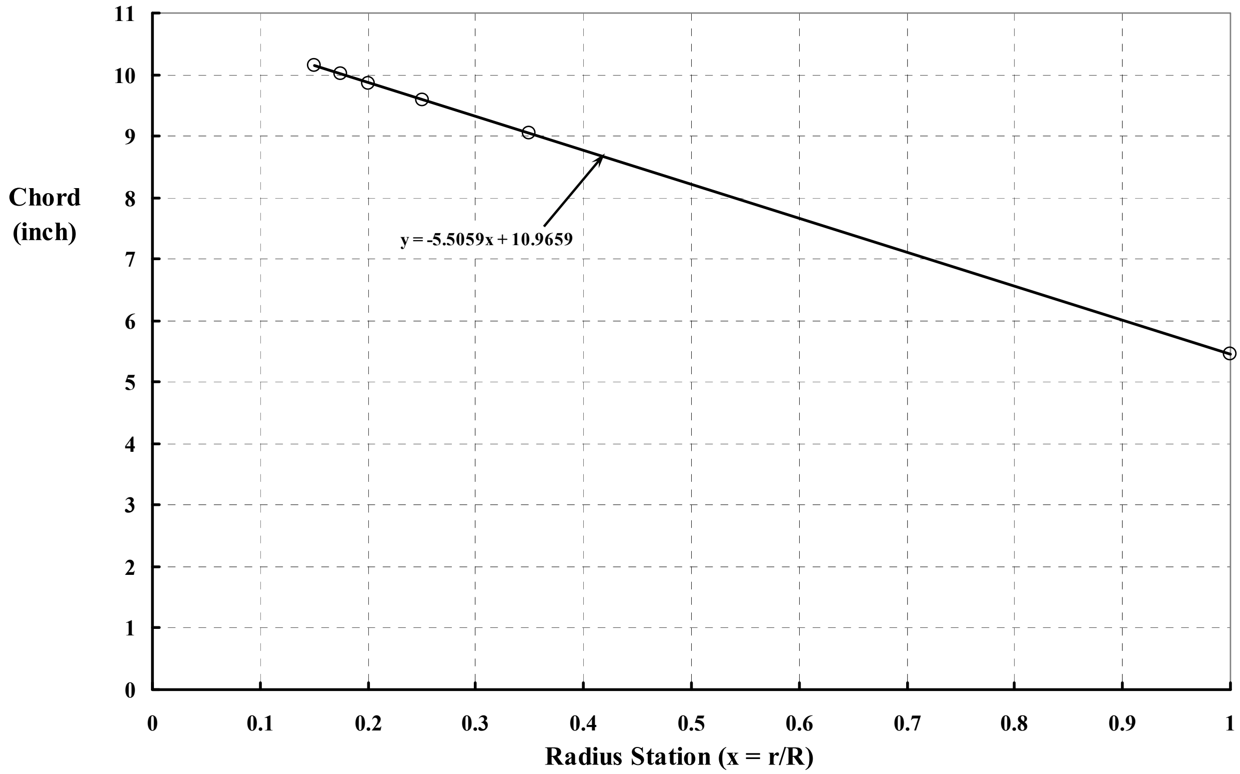

Figure J-2. The 0.2364-scale Proprotor C for Boeing Vertol Model 160—chord vs. radius station.

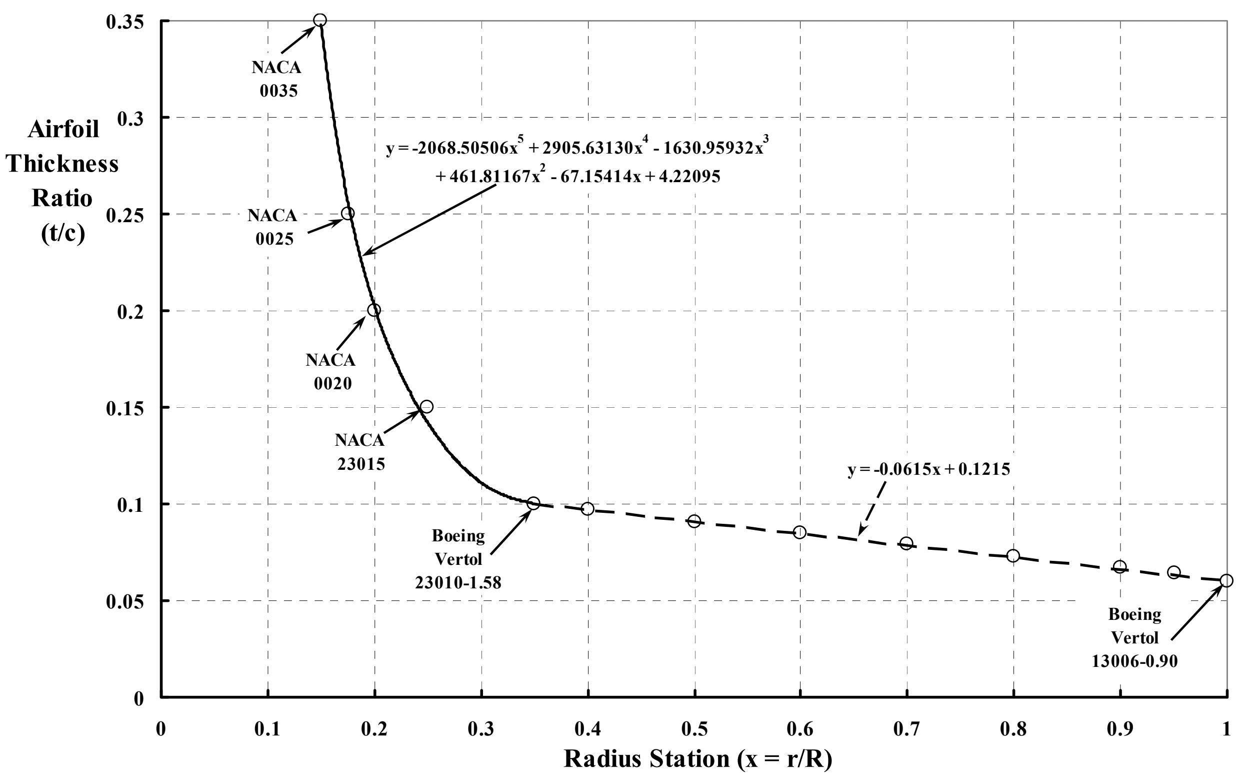

Figure J-3. The 0.2364-scale Proprotor C for Boeing Vertol Model 160—airfoil thickness ratio vs. radius station. The Boeing Vertol 23010-1.58 is a NACA 23010 with increased nose radius. The Boeing Vertol 13006-0.90 is a NACA 13006 with increased nose radius.

3. Performance Data

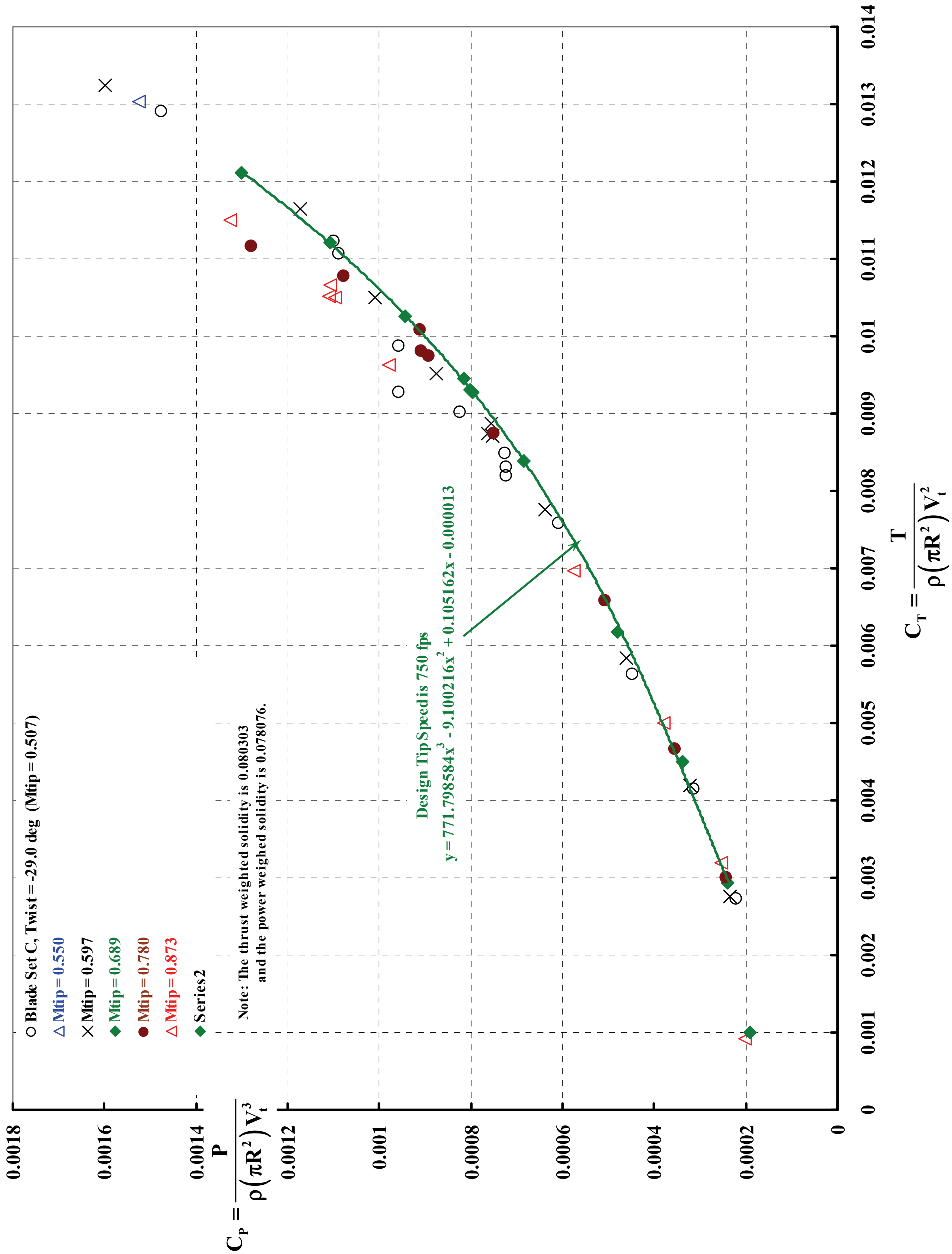

Figure J-4. The 0.2364-scale Proprotor C (for Boeing Vertol Model 160) test results at WADC—power vs. thrust coefficient.

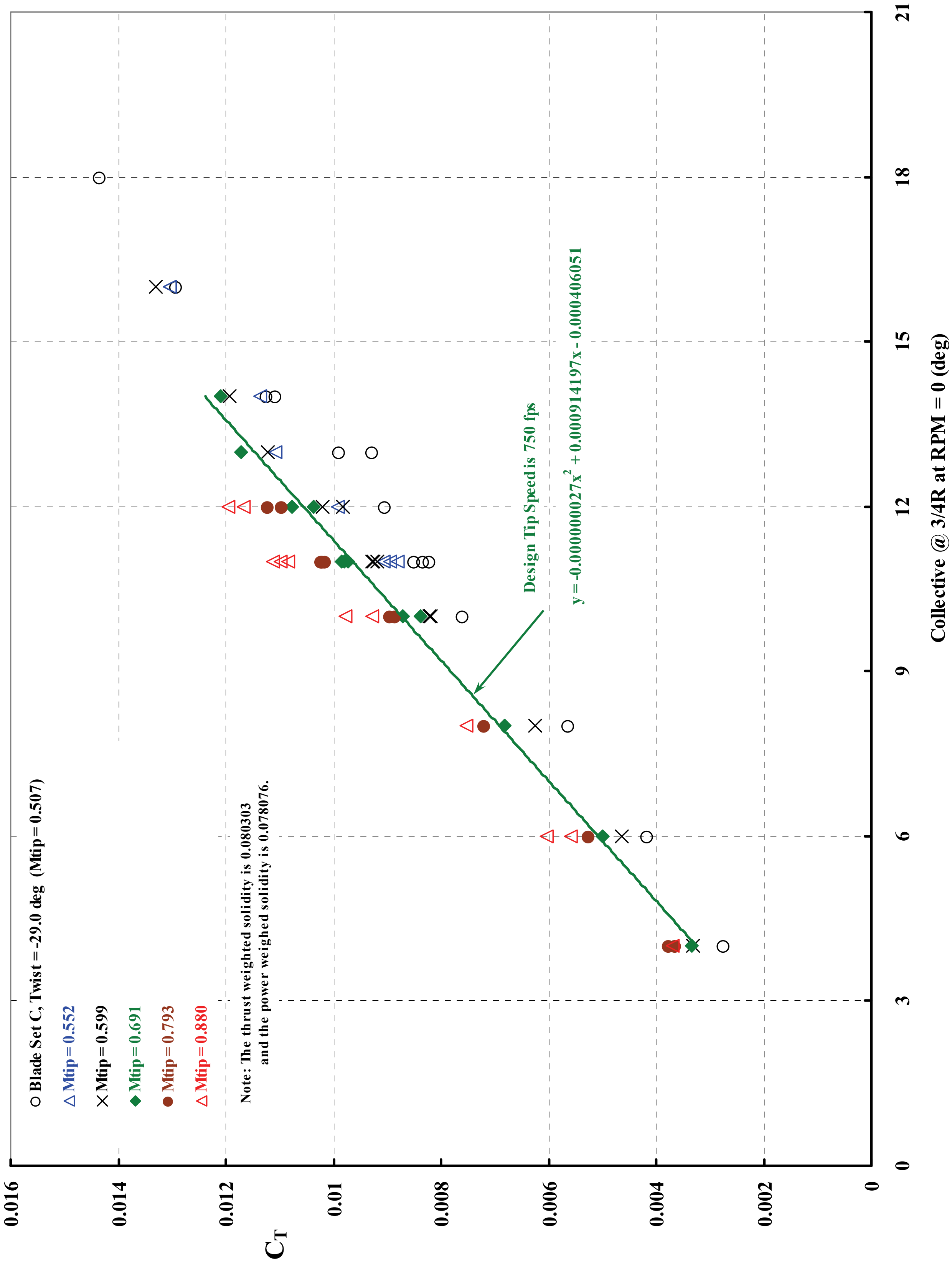

Figure J-5. The 0.2364-scale Proprotor C (for Boeing Vertol Model 160) test results at WADC—thrust coefficient vs. collective pitch.

Table J–1. The 0.2364-Scale Proprotor C (for Boeing Vertol Model 160) Test Results at WADC

Page	Point	V tip (fps)	M tip	Coll.	CT	CP	Ideal CP	FM	CT/CP
46	11 (R)	549.3	0.504	11	0.008502	0.000725	0.000554	0.7648	11.73
46	11(R)	550.0	0.505	11	0.008218	0.000722	0.000527	0.7293	11.38
47	14(R)	550.0	0.505	14	0.011236	0.001099	0.000842	0.7662	10.22
45	4	549.3	0.504	4	0.002735	0.000221	0.000101	0.4586	12.40
45	6	549.3	0.504	6	0.004167	0.000315	0.000190	0.6039	13.23
45	8	550.7	0.506	8	0.005638	0.000448	0.000299	0.6687	12.60
45	10	550.0	0.505	10	0.007598	0.000607	0.000468	0.7712	12.51
45	11	550.0	0.505	11	0.008321	0.000722	0.000537	0.7430	11.52
46	12	550.7	0.506	12	0.009030	0.000824	0.000607	0.7363	10.96
46	13	549.3	0.504	13	0.009288	0.000956	0.000633	0.6619	9.71
46	13	549.3	0.504	13	0.009895	0.000956	0.000696	0.7277	10.35
46	14	550.0	0.505	14	0.011082	0.001089	0.000825	0.7575	10.18
47	16	550.0	0.505	16	0.012926	0.001477	0.001039	0.7038	8.75
47	18	550.0	0.505	18	0.014345	0.001969	0.001215	0.6172	7.29
47	16	599.0	0.550	16	0.013030	0.001524	0.001052	0.6901	8.55
46	11 (R)	650.0	0.597	11	0.008876	0.000755	0.000591	0.7834	11.76
46	11(R)	649.4	0.596	11	0.008747	0.000763	0.000578	0.7577	11.46
45	4	650.0	0.597	4	0.002761	0.000234	0.000103	0.4374	11.77
45	6	650.0	0.597	6	0.004193	0.000323	0.000192	0.5940	12.97
45	8	650.7	0.597	8	0.005831	0.000461	0.000315	0.6828	12.64
45	10	650.7	0.597	10	0.007753	0.000638	0.000483	0.7565	12.15
45	11	650.7	0.597	11	0.008708	0.000752	0.000575	0.7638	11.58
46	12	650.0	0.597	12	0.009521	0.000875	0.000657	0.7507	10.88
46	13	650.0	0.597	13	0.010501	0.001009	0.000761	0.7545	10.41
46	14	650.0	0.597	14	0.011649	0.001173	0.000889	0.7578	9.93
47	16	649.4	0.596	16	0.013236	0.001597	0.001077	0.6743	8.29
47	0.1	750.1	0.689	0	0.000993	0.000190	0.000022	0.1167	5.24
45	4	750.1	0.689	4	0.002928	0.000239	0.000112	0.4681	12.23
45	6	750.1	0.689	6	0.004502	0.000338	0.000214	0.6313	13.31
45	8	750.1	0.689	8	0.006179	0.000479	0.000343	0.7174	12.91
45	10	750.1	0.689	10	0.008385	0.000685	0.000543	0.7927	12.24
45	11	751.5	0.690	11	0.009314	0.000802	0.000636	0.7922	11.61
46	11 (R)	750.8	0.690	11	0.009456	0.000815	0.000650	0.7977	11.60
46	11(R)	750.1	0.689	11	0.009276	0.000797	0.000632	0.7929	11.64
46	12	749.9	0.688	12	0.010256	0.000943	0.000734	0.7786	10.87
46	13	750.1	0.689	13	0.011211	0.001106	0.000839	0.7587	10.13
46	14	750.0	0.689	14	0.012114	0.001300	0.000943	0.7251	9.32
46	11 (R)	849.5	0.780	11	0.009830	0.000909	0.000689	0.7580	10.81
46	11(R)	850.2	0.781	11	0.009766	0.000893	0.000682	0.7641	10.93
45	4	849.5	0.780	4	0.003019	0.000244	0.000117	0.4808	12.38
45	6	849.5	0.780	6	0.004670	0.000355	0.000226	0.6353	13.15
45	8	848.8	0.779	8	0.006592	0.000507	0.000378	0.7469	13.01
45	10	848.8	0.779	10	0.008760	0.000749	0.000580	0.7740	11.69

Page	Point	V tip (fps)	M tip	Coll.	CT	CP	Ideal CP	FM	CT/CP
45	11	850.9	0.781	11	0.010101	0.000911	0.000718	0.7882	11.09
46	12	849.5	0.780	12	0.010785	0.001077	0.000792	0.7353	10.01
46	13	851.6	0.782	13	0.011172	0.001278	0.000835	0.6534	8.74
46	11 (R)	950.2	0.873	11	0.010514	0.001109	0.000762	0.6876	9.48
46	11(R)	950.2	0.873	11	0.010501	0.001096	0.000761	0.6940	9.58
47	0.1	950.9	0.873	0	0.000916	0.000202	0.000020	0.0968	4.52
45	4	948.8	0.871	4	0.003199	0.000255	0.000128	0.5026	12.57
45	6	949.5	0.872	6	0.004993	0.000378	0.000249	0.6595	13.20
45	8	950.2	0.873	8	0.006966	0.000574	0.000411	0.7157	12.13
45	10	949.5	0.872	10	0.009624	0.000979	0.000668	0.6816	9.83
45	11	949.5	0.872	11	0.010656	0.001107	0.000778	0.7028	9.63
46	12	949.5	0.872	12	0.011507	0.001327	0.000873	0.6579	8.67

Note: The letter (R) denotes a rerun data point.

Appendix K

5-Foot-Diameter Propeller, Hamilton Standard 212X-14 (Canadair Ltd. Test)

This appendix contains:

1. General discussion.
2. Propeller configuration (figs. K-1 to K-5).
3. Performance data of C_P versus C_T and C_T versus 3/4 radius collective from the Canadair Ltd. test (figs. K-6 through K-7, and table K-1).

1. General Discussion

Overview

Six, 5-foot-diameter, four-bladed propeller configurations were tested in hover as part of a U.S. Air Force–sponsored program titled Advanced V/STOL Propeller Technology. The Program Summary Report was published (AFFDL-TR-71-88 Volume XIV) in April of 1974. It was the last volume of a 14-volume set of reports dealing with a comprehensive experimental and theoretical research activity to define a propeller using *monocyclic as a tiltwing pitch control device.* The monocyclic approach to tiltwing pitch control would replace the tail-mounted, pitch control propeller used on the XV-142A.

The small-scale (5-foot-diameter) testing led to selection of a four-bladed design with an Activity Factor of 150 per blade (power weighted solidity of 0.24446) and NACA 65 series cambered airfoils with an integrated design lift coefficient of 0.5. The airfoil camber (with its associated airfoil design lift coefficient, CL_{design}) varied along the blade span. It is worth noting that propeller design engineers calculate a propeller blade's integrated design lift coefficient as:

$$(C_L) = 4\int_{x_c}^{1} CL_{design}\, x^3 dx \,,$$

which is a rarely seen parameter in rotorcraft literature.

The small-scale model testing was followed by testing with a 1/2-scale (13.2-foot-diameter) model, and feasibly of cyclic control was established by testing on the Air Force Aero Propulsion Laboratory (AFAPL) test Rig #2 located at WADC in Dayton, Ohio. Later, an LTV XC-142A propeller (15.625-foot-diameter Hamilton Standard 2FF16A1-4A) with a collective and cyclic pitch control system was tested in the NASA Ames 40- by 80-Foot Wind Tunnel during January and September 1970. This test gathered data for propeller operation simulating transition from hover to low-speed forward flight at a tip speed of 845 feet per second (1030 RPM). Cyclic pitch varied from 0 to ± 6 degrees.

2. Propeller Configuration

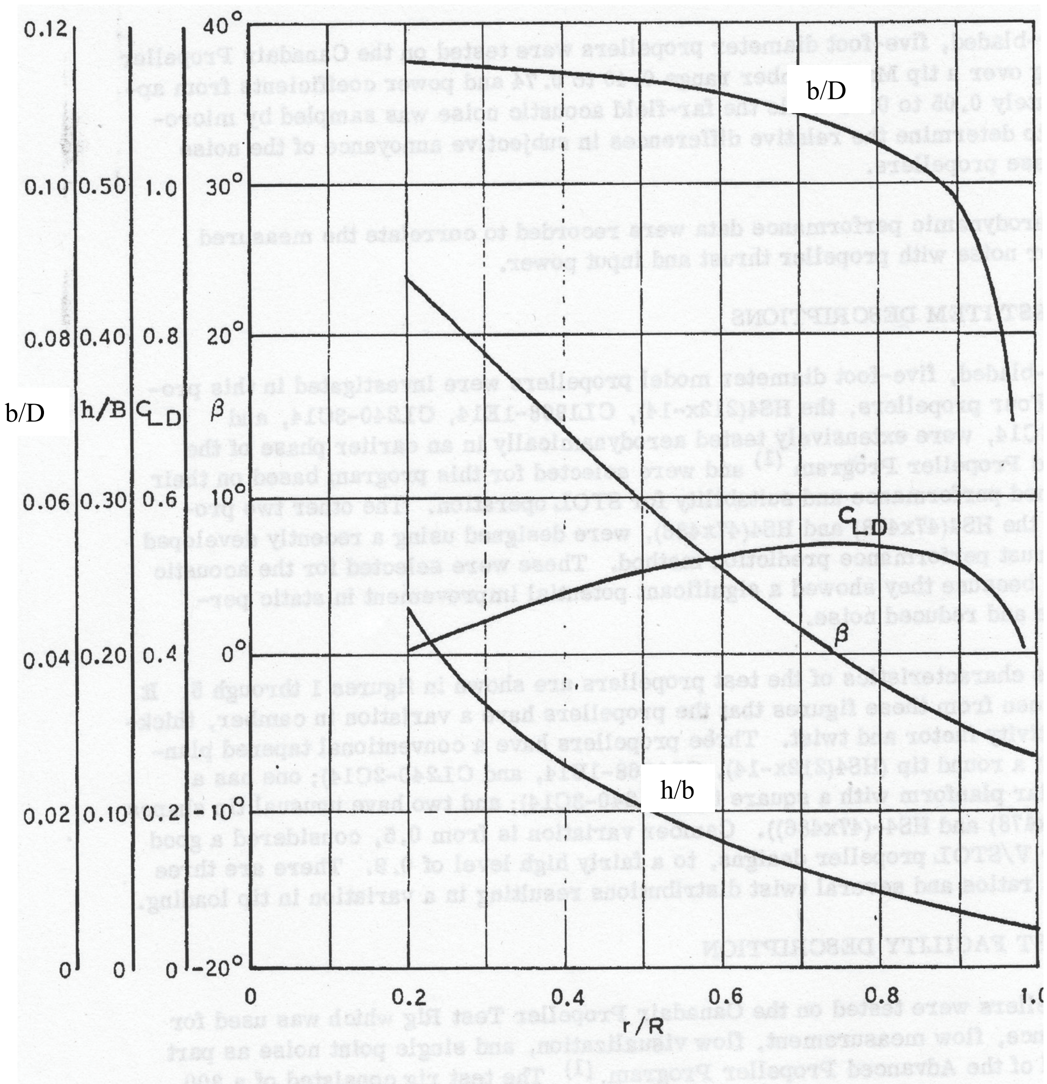

Figure K-1. Hamilton Standard 212X-14.
(This figure uses propeller nomenclature as shown the table below.)

Parameter	**Proprotor**	**Propeller**
Diameter	D	D
Radius	R	R
Blade chord	c	b
Blade number	b	N or B
Airfoil thickness	t	h
Blade width ratio	Rarely used	b/D
Airfoil thickness ratio	t/c	h/b
Blade pitch angle	θ	β_0
Blade radial station	r or x = r/R	r or x = r/R

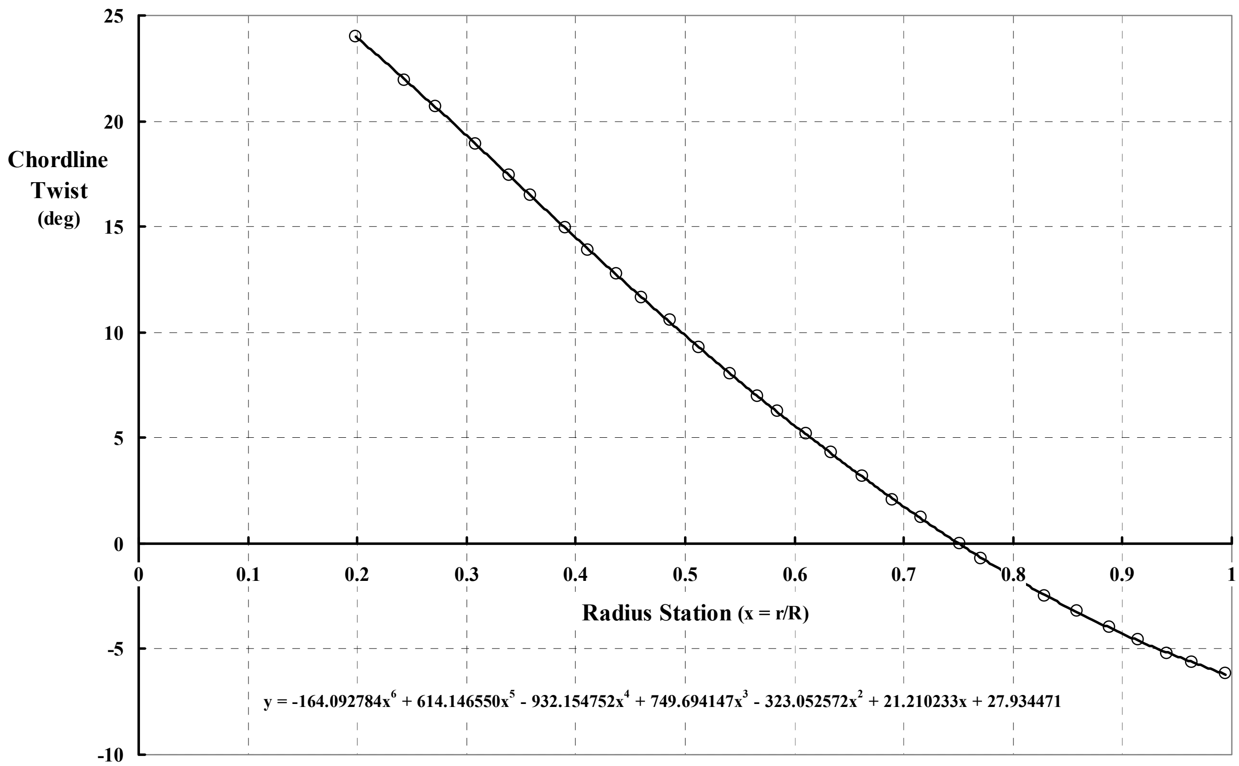

Figure K-2. Hamilton Standard 212X-14—twist vs. radius station.

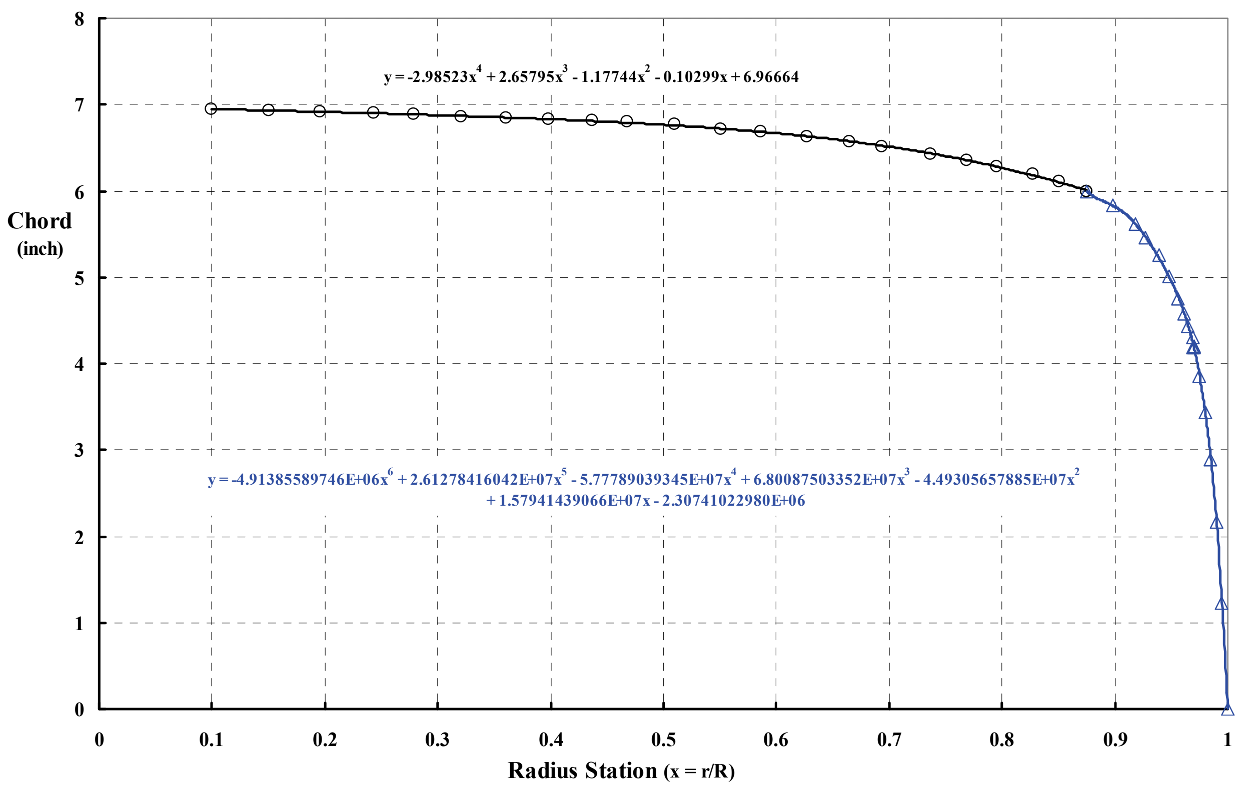

Figure K-3. Hamilton Standard 212X-14—chord vs. radius station.

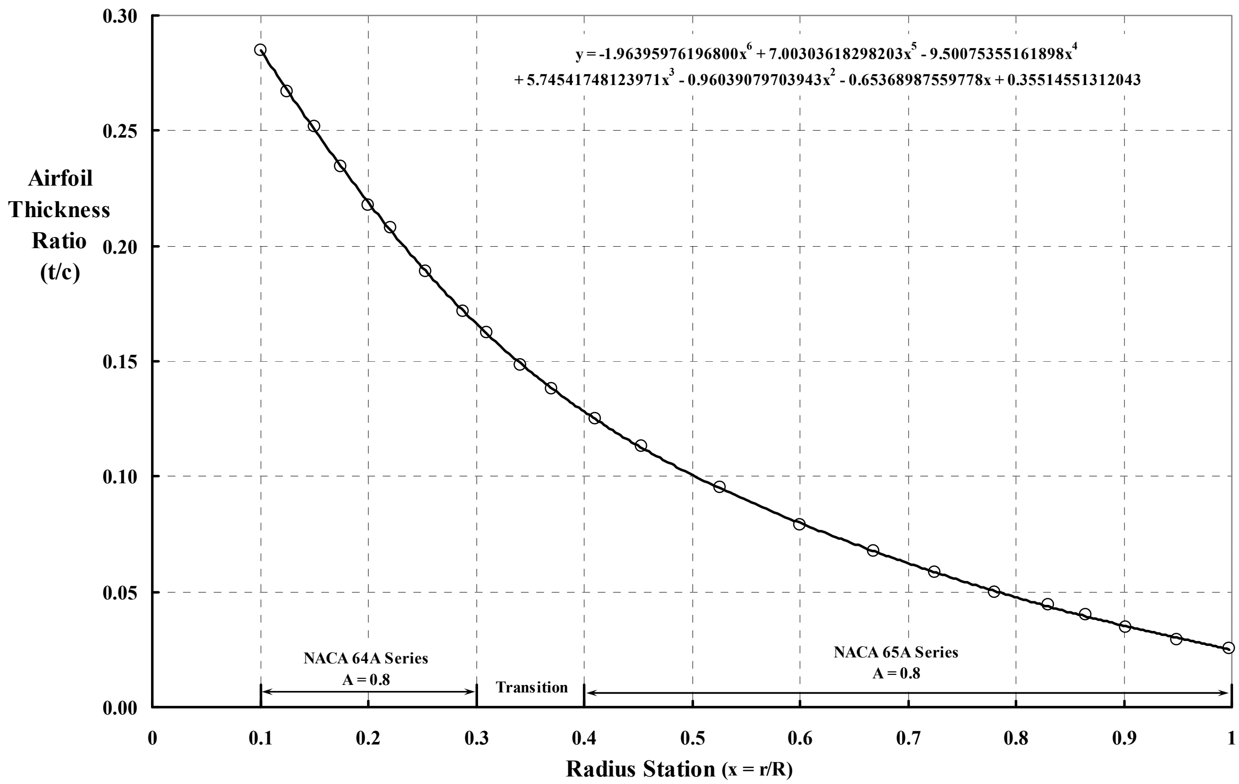

Figure K-4. Hamilton Standard 212X-14—airfoil thickness ratio vs. radius station.

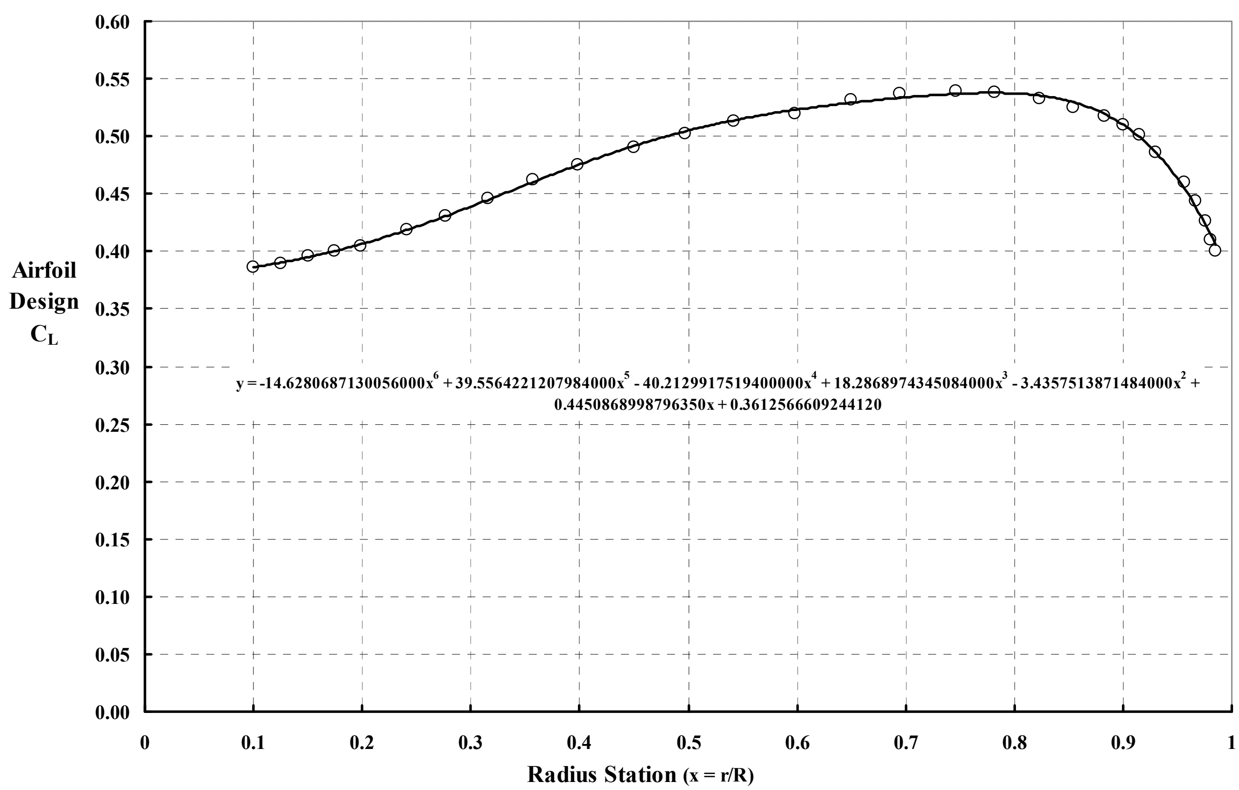

Figure K-5. Hamilton Standard 212X-14—airfoil design C_L vs. radius station.

3. Performance Data

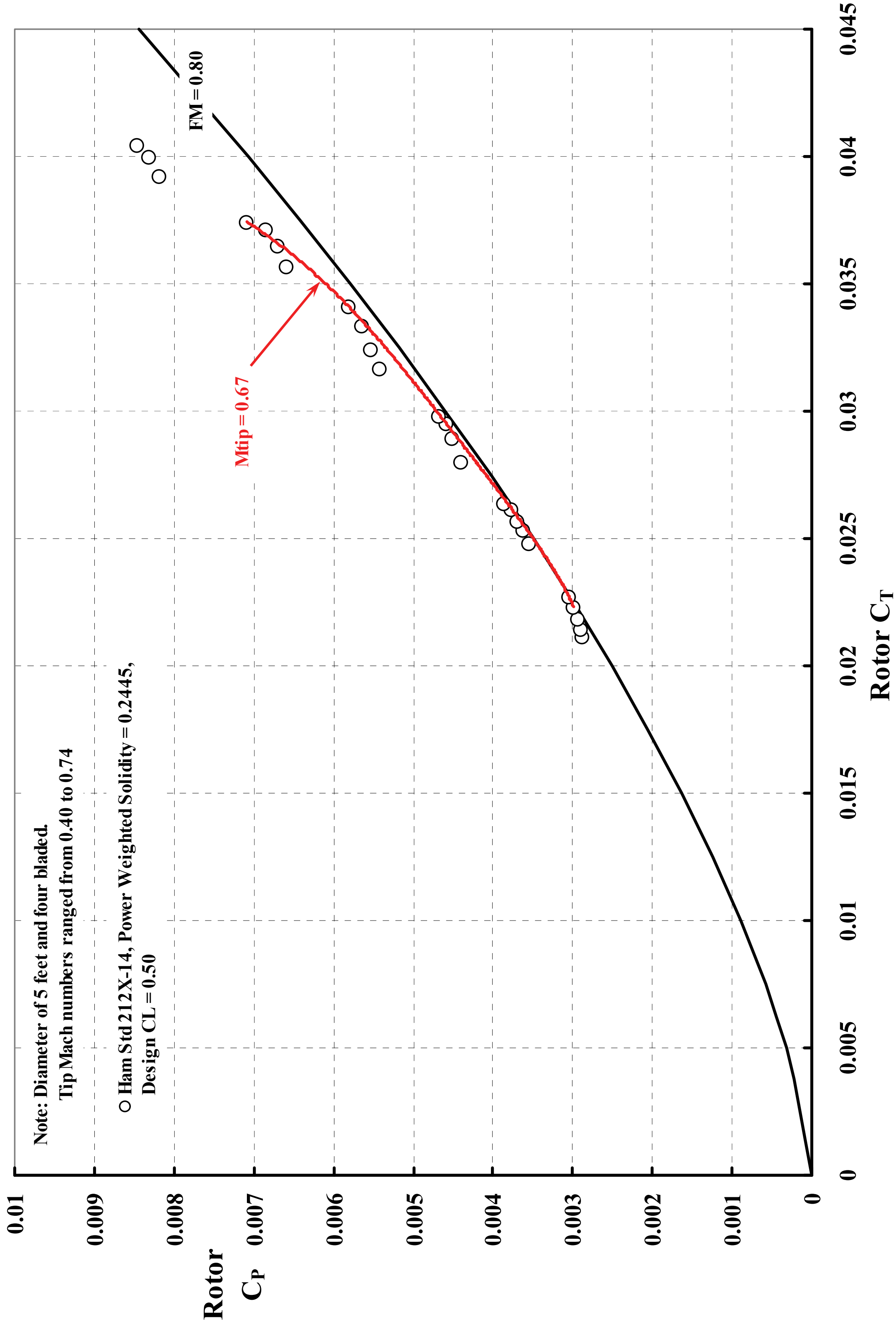

Figure K-6. Hamilton Standard 212X-14 test results at Canadair Ltd.—power vs. thrust coefficient.

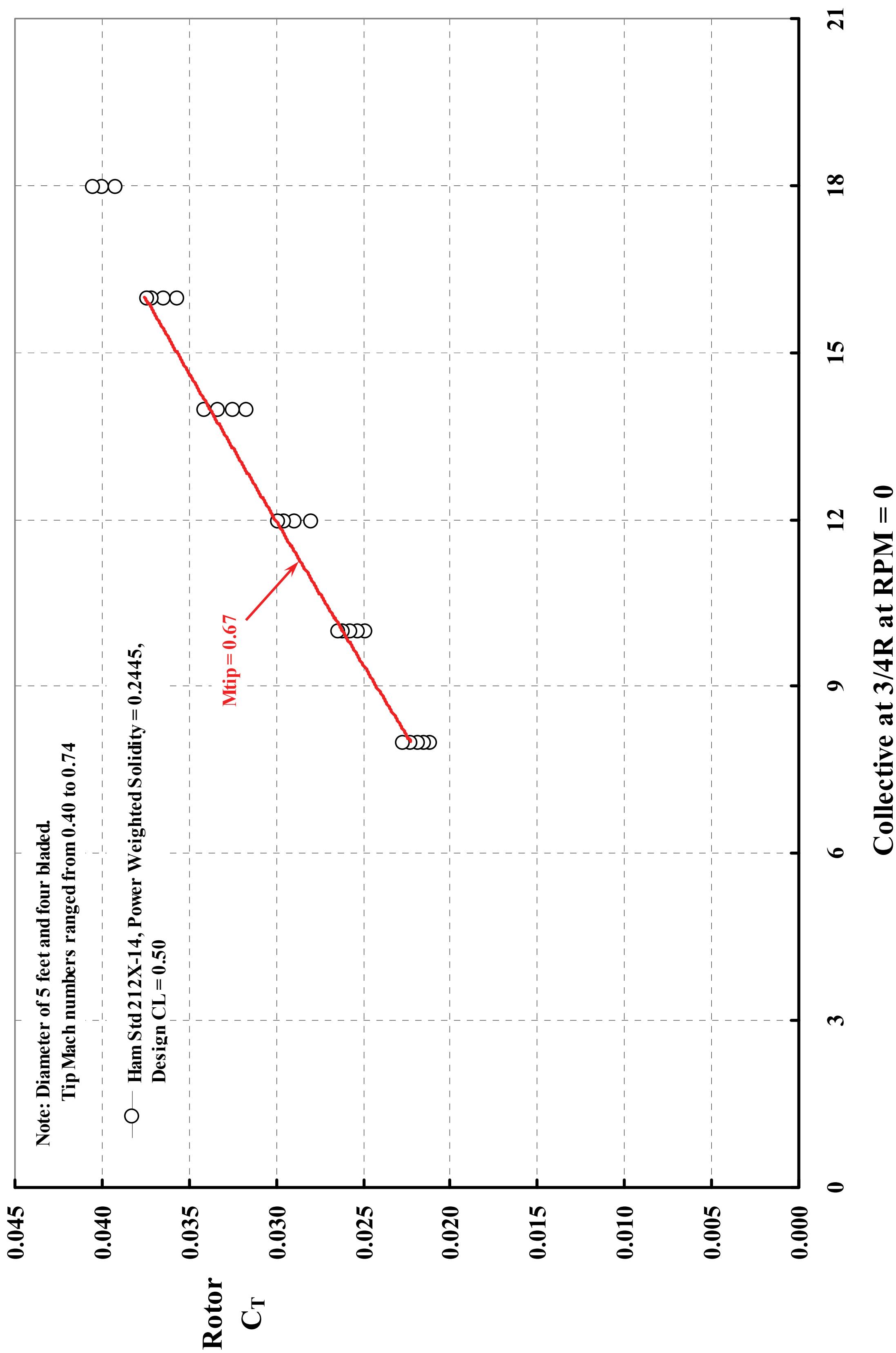

Figure K-7. Hamilton Standard 212X-14 test results at Canadair Ltd.—thrust coefficient vs. collective pitch.

Table K–1. Hamilton Standard 212X-14 Test Results at Canadair Ltd.

Vtip (fps)	Nominal Mtip	Beta (deg)	CT	CP	Ideal CP	F. M.	CT/CP	CT/σ_{power}
450	0.40	8.0	0.021183	0.002870	0.002180	0.7595	7.38	0.086651
550	0.49	8.0	0.021480	0.002903	0.002226	0.7667	7.40	0.087864
650	0.58	8.0	0.021867	0.002936	0.002286	0.7787	7.45	0.089448
750	0.67	8.0	0.022305	0.002985	0.002356	0.7890	7.47	0.091242
850	0.74	8.0	0.022731	0.003047	0.002423	0.7953	7.46	0.092983
450	0.40	10.0	0.024847	0.003548	0.002769	0.7806	7.00	0.101638
550	0.49	10.0	0.025337	0.003610	0.002852	0.7901	7.02	0.103643
650	0.58	10.0	0.025724	0.003688	0.002917	0.7911	6.98	0.105226
750	0.67	10.0	0.026188	0.003770	0.002997	0.7950	6.95	0.107126
850	0.74	10.0	0.026395	0.003864	0.003032	0.7847	6.83	0.107970
450	0.40	12.0	0.028020	0.004406	0.003317	0.7527	6.36	0.114620
550	0.49	12.0	0.028949	0.004513	0.003483	0.7718	6.41	0.118419
650	0.58	12.0	0.029530	0.004591	0.003588	0.7816	6.43	0.120794
750	0.67	12.0	0.029852	0.004669	0.003647	0.7811	6.39	0.122113
450	0.40	14.0	0.031697	0.005412	0.003990	0.7373	5.86	0.129659
550	0.49	14.0	0.032445	0.005523	0.004132	0.7482	5.87	0.132720
650	0.58	14.0	0.033361	0.005642	0.004309	0.7637	5.91	0.136467
750	0.67	14.0	0.034122	0.005815	0.004457	0.7665	5.87	0.139580
450	0.40	16.0	0.035670	0.006595	0.004764	0.7223	5.41	0.145913
550	0.49	16.0	0.036483	0.006702	0.004927	0.7353	5.44	0.149238
650	0.58	16.0	0.037180	0.006841	0.005069	0.7410	5.43	0.152087
750	0.67	16.0	0.037438	0.007084	0.005122	0.7231	5.29	0.153143
450	0.40	18.0	0.039244	0.008188	0.005497	0.6714	4.79	0.160531
550	0.49	18.0	0.039992	0.008307	0.005655	0.6807	4.81	0.163591
650	0.58	18.0	0.040482	0.008463	0.005759	0.6805	4.78	0.165597

Appendix L

5-Foot-Diameter Propeller, Hamilton Standard 47X-478 (Canadair Ltd. Test)

This appendix contains:

1. General discussion.
2. Propeller configuration (figs. L-1 to L-5).
3. Performance data of C_P versus C_T and C_T versus ¾ radius collective from the Canadair Ltd. test (figs. L-6 through L-7, and table L-1).

1. General Discussion

See Appendix K.

2. Propeller Configuration

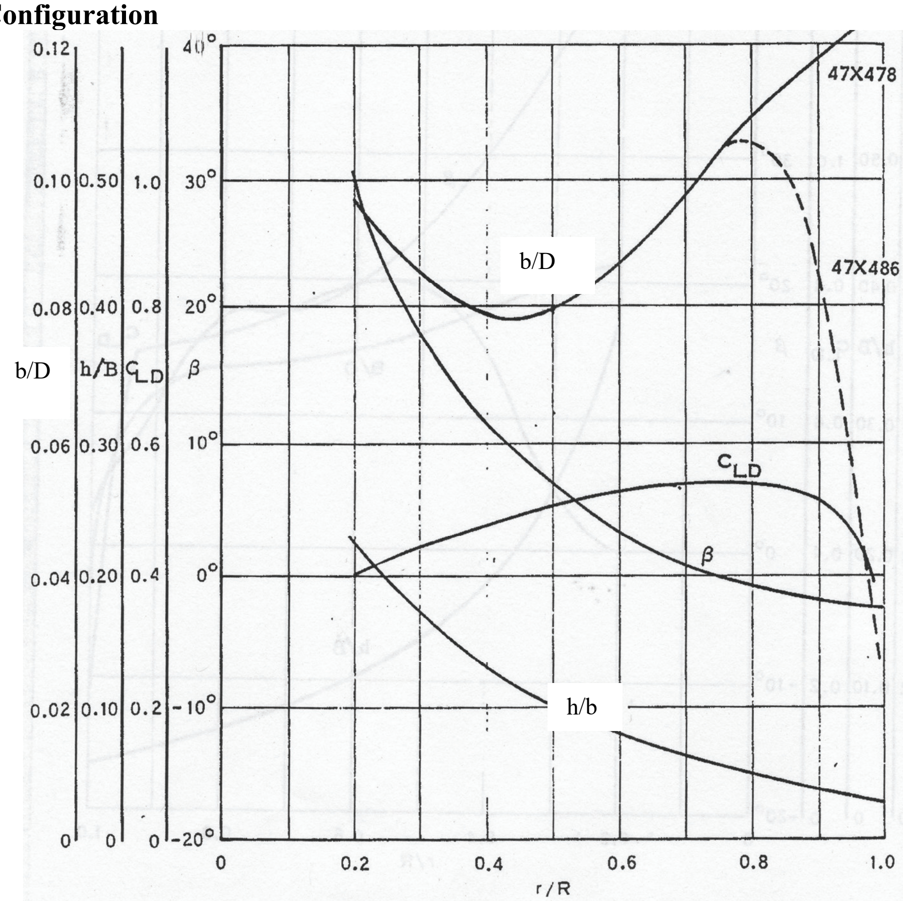

Figure L-1. Hamilton Standard 47X-478.
(This figure uses propeller nomenclature as shown the table below.)

Parameter	Proprotor	Propeller
Diameter	D	D
Radius	R	R
Blade chord	c	b
Blade number	b	N or B
Airfoil thickness	t	h
Blade width ratio	Rarely used	b/D
Airfoil thickness ratio	t/c	h/b
Blade pitch angle	θ	β_0
Blade radial station	r or x = r/R	r or x = r/R

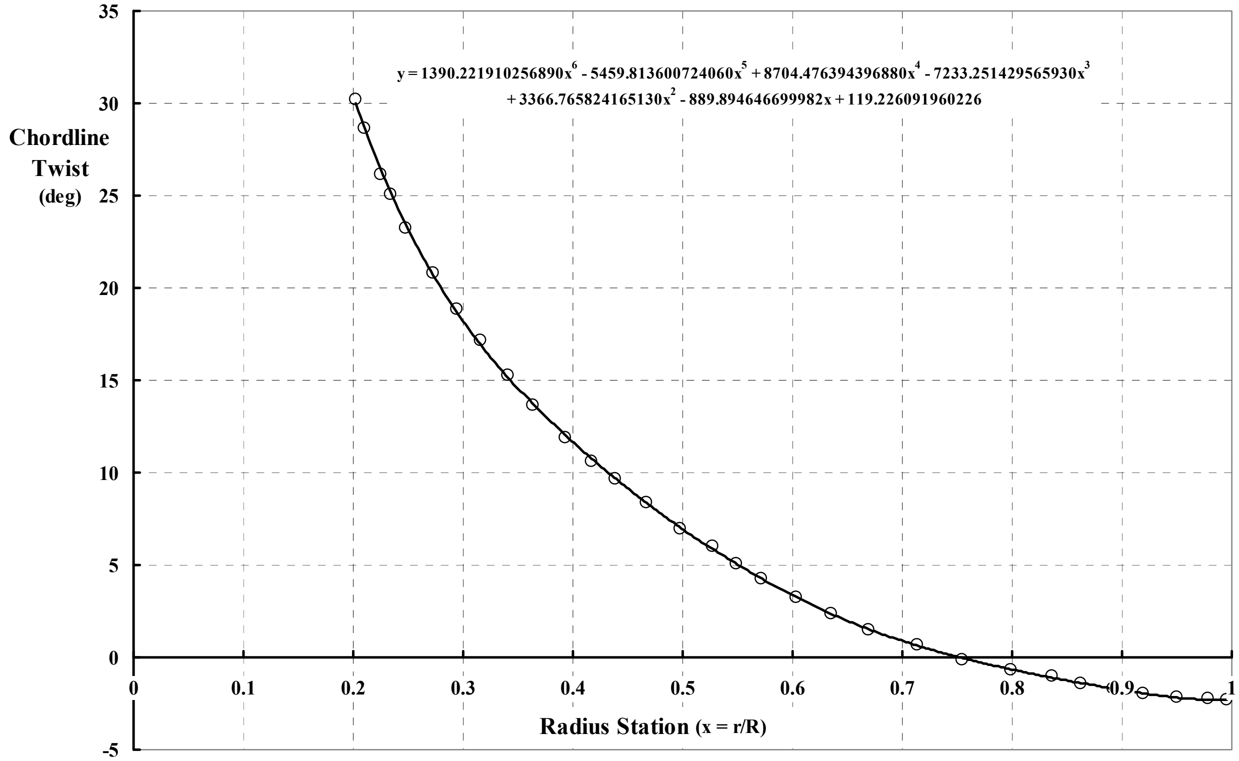

Figure L-2. Hamilton Standard 47X-478—twist vs. radius station.

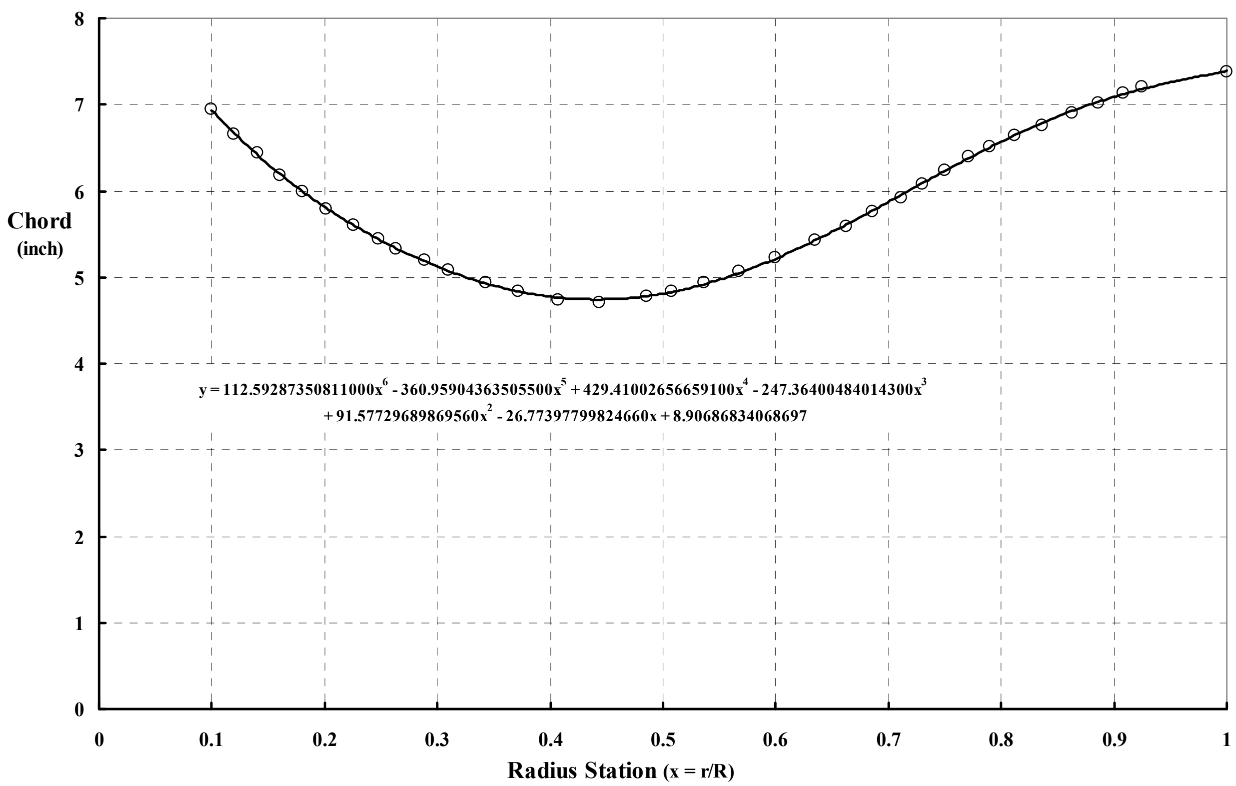

Figure L-3. Hamilton Standard 47X-478—chord vs. radius station.

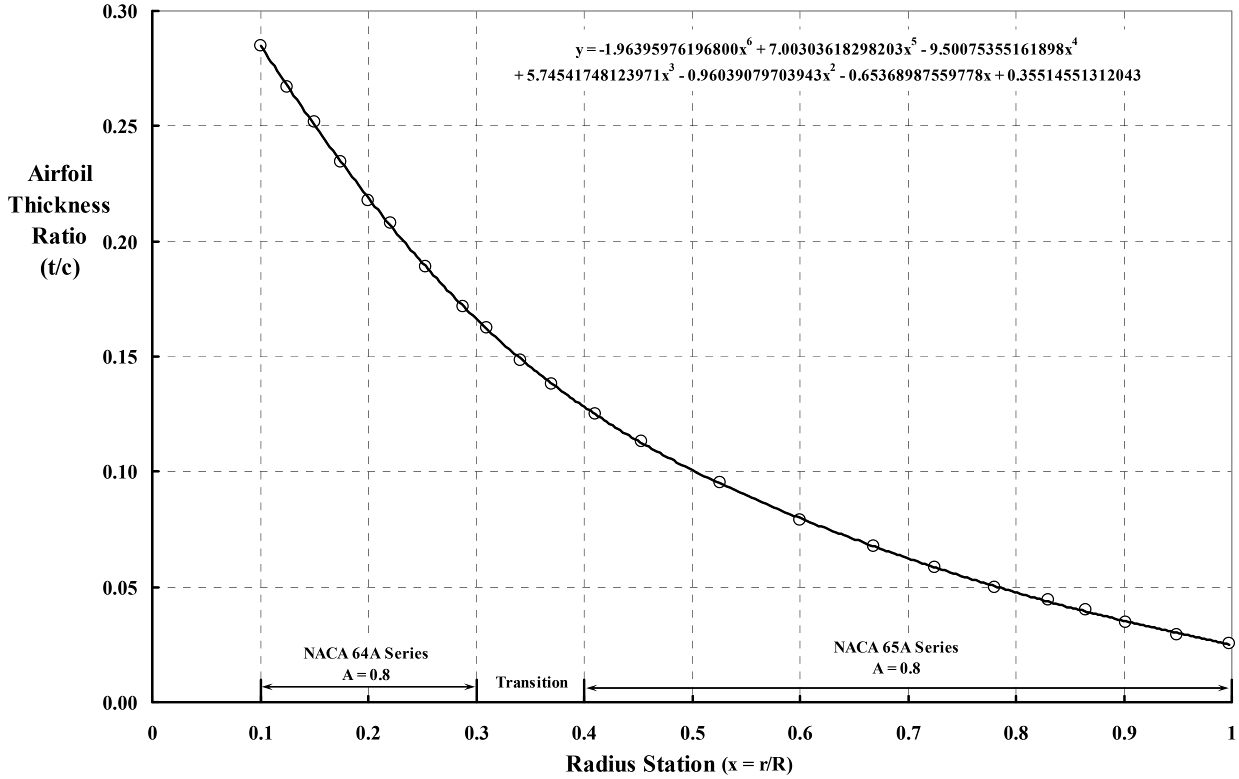

Figure L-4. Hamilton Standard 47X-478—airfoil thickness ratio vs. radius station.

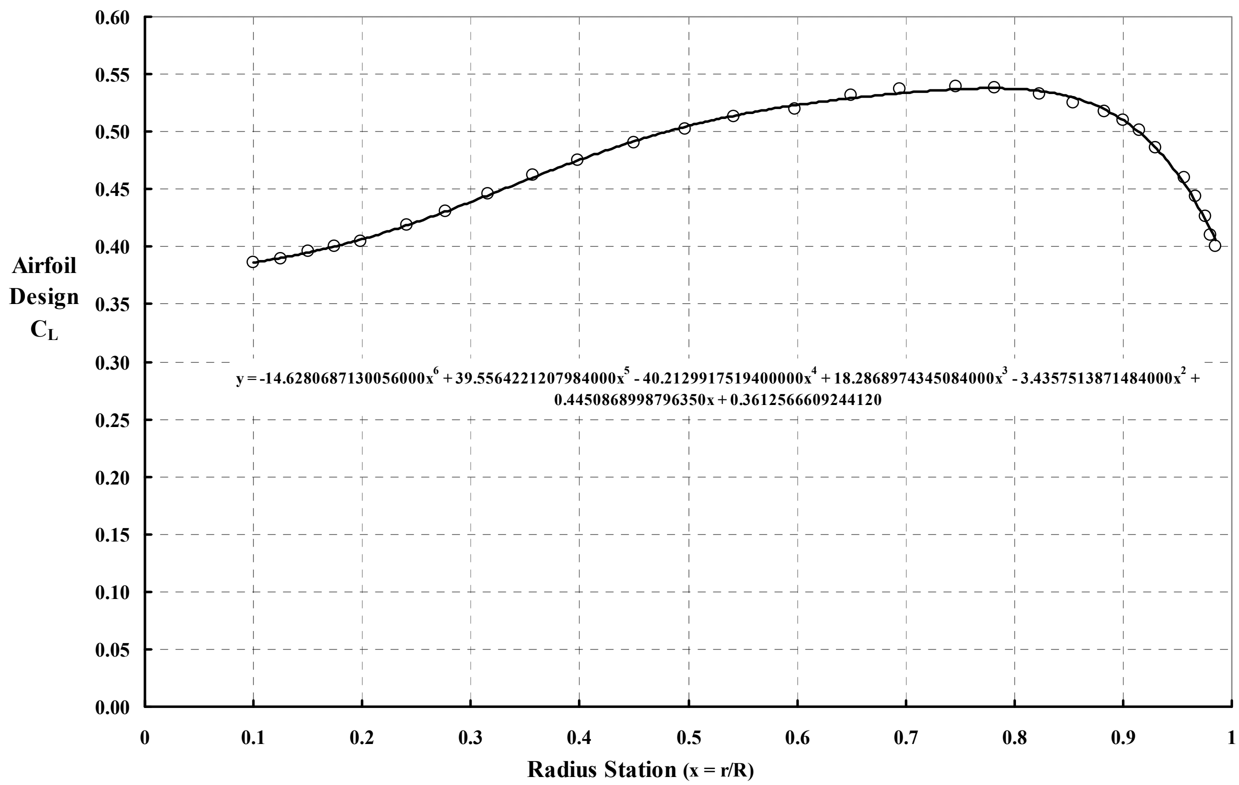

Figure L-5. Hamilton Standard 47X-478—airfoil design C_L vs. radius station.

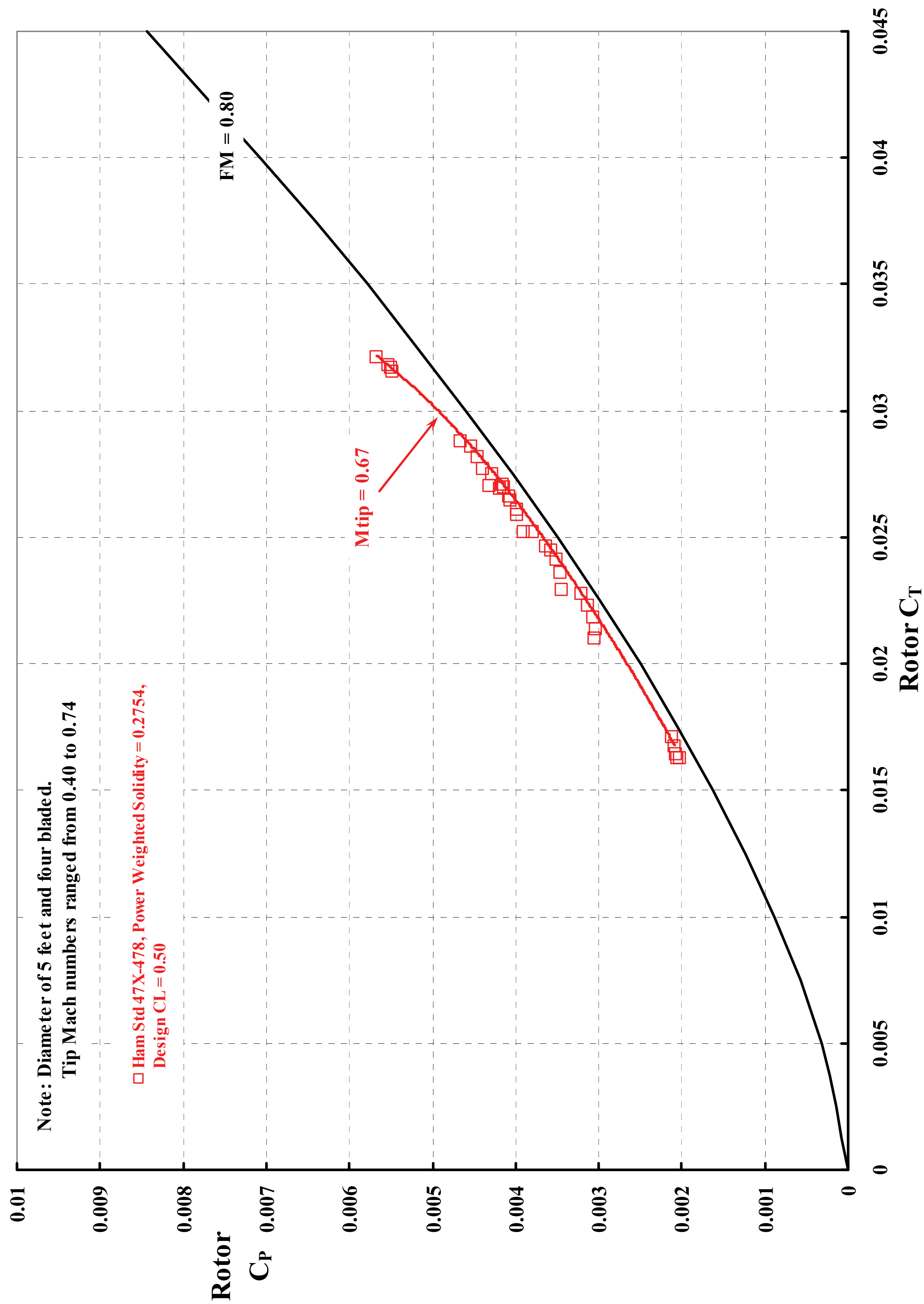

Figure L-6. Hamilton Standard 47X-478 test results at Canadair Ltd.—power vs. thrust coefficient.

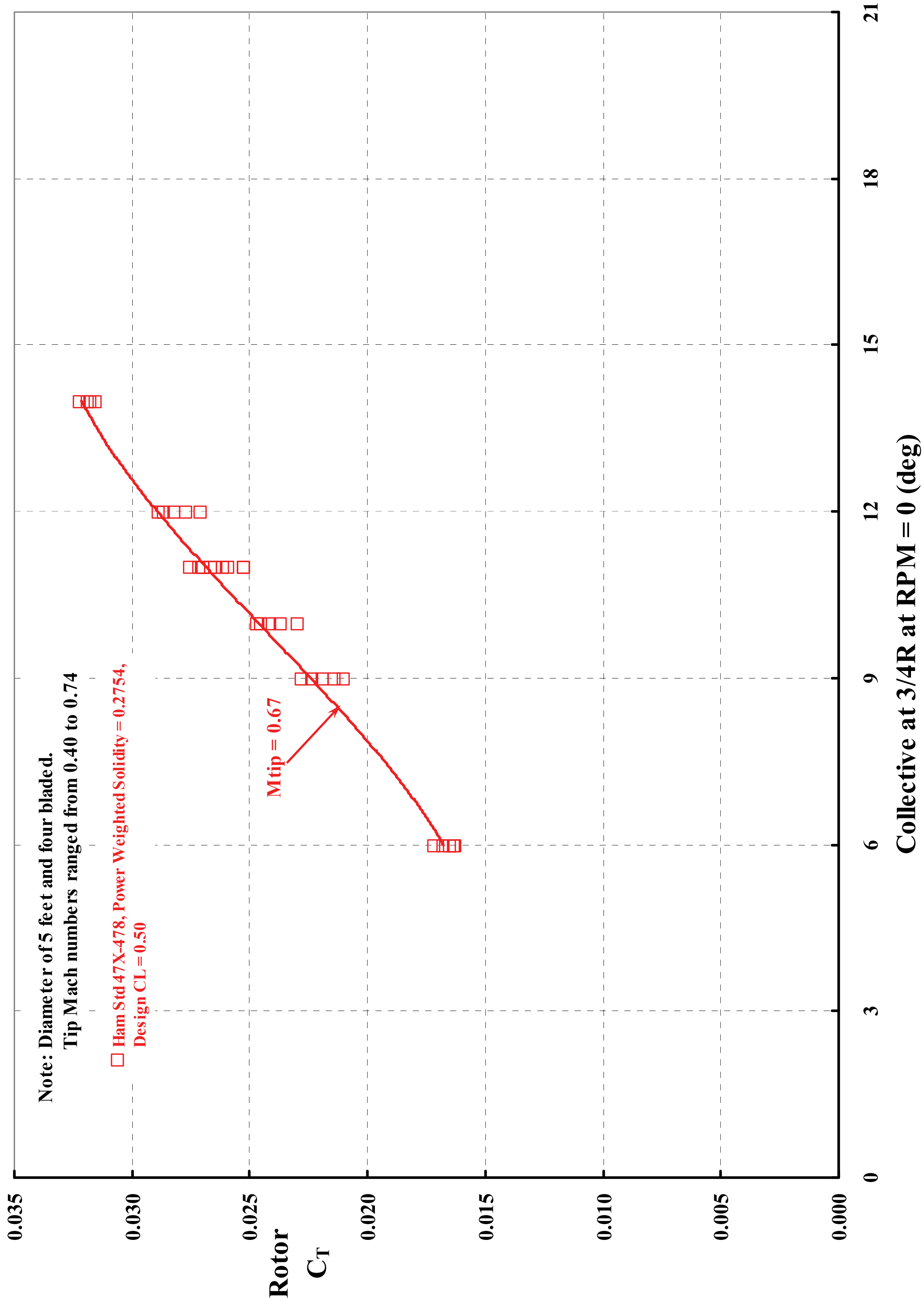

Figure L-7. Hamilton Standard 47X-478 test results at Canadair Ltd.—thrust coefficient vs. collective pitch.

Table L-1. Hamilton Standard 47X-478 Test Results at Canadair Ltd.

V tip (fps)	Nominal Mtip	Beta (deg)	CT	CP	Ideal CP	F. M.	CT/CP	CT/σ_{power}
50	0.40	6.0	0.016306	0.002024	0.001472	0.7273	8.05	0.0592
550	0.49	6.0	0.016293	0.002057	0.001471	0.7148	7.92	0.0592
650	0.58	6.0	0.016487	0.002074	0.001497	0.7218	7.95	0.0599
750	0.67	6.0	0.016784	0.002090	0.001538	0.7356	8.03	0.0609
850	0.74	6.0	0.017145	0.002119	0.001587	0.7492	8.09	0.0622
450	0.40	9.0	0.021028	0.003043	0.002156	0.7086	6.91	0.0763
550	0.49	9.0	0.021428	0.003035	0.002218	0.7309	7.06	0.0778
650	0.58	9.0	0.021879	0.003067	0.002288	0.7460	7.13	0.0794
750	0.67	9.0	0.022357	0.003121	0.002364	0.7574	7.16	0.0812
850	0.74	9.0	0.022821	0.003211	0.002438	0.7591	7.11	0.0829
450	0.40	10.0	0.022963	0.003437	0.002461	0.7159	6.68	0.0834
550	0.49	10.0	0.023660	0.003458	0.002573	0.7443	6.84	0.0859
650	0.58	10.0	0.024137	0.003511	0.002652	0.7552	6.87	0.0876
750	0.67	10.0	0.024550	0.003564	0.002720	0.7631	6.89	0.0891
850	0.74	10.0	0.024692	0.003630	0.002744	0.7558	6.80	0.0896
450	0.40	11.0	0.025247	0.003905	0.002837	0.7263	6.46	0.0917
550	0.49	11.0	0.025917	0.003975	0.002950	0.7422	6.52	0.0941
650	0.58	11.0	0.026498	0.004057	0.003050	0.7518	6.53	0.0962
750	0.67	11.0	0.027143	0.004152	0.003162	0.7617	6.54	0.0985
850	0.74	11.0	0.027543	0.004287	0.003232	0.7539	6.42	0.1000
450	0.40	11.0	0.025234	0.003794	0.002834	0.7470	6.65	0.0916
550	0.49	11.0	0.026137	0.003979	0.002988	0.7509	6.57	0.0949
650	0.58	11.0	0.026640	0.004082	0.003075	0.7532	6.53	0.0967
750	0.67	11.0	0.027001	0.004143	0.003137	0.7572	6.52	0.0980
850	0.74	11.0	0.026975	0.004193	0.003133	0.7472	6.43	0.0979
450	0.40	12.0	0.027091	0.004308	0.003153	0.7320	6.29	0.0984
550	0.49	12.0	0.027723	0.004386	0.003264	0.7443	6.32	0.1007
650	0.58	12.0	0.028201	0.004455	0.003349	0.7516	6.33	0.1024
750	0.67	12.0	0.028626	0.004533	0.003425	0.7555	6.31	0.1039
850	0.74	12.0	0.028859	0.004653	0.003467	0.7451	6.20	0.1048
450	0.40	14.0	0.031761	0.005498	0.004003	0.7279	5.78	0.1153
550	0.49	14.0	0.031568	0.005478	0.003966	0.7240	5.76	0.1146
650	0.58	14.0	0.031852	0.005527	0.004020	0.7272	5.76	0.1156
750	0.67	14.0	0.032187	0.005671	0.004083	0.7200	5.68	0.1169

Appendix M

5-Foot-Diameter Propeller, Hamilton Standard 47X-486 (Canadair Ltd. Test)

This appendix contains:

1. General discussion.
2. Propeller configuration (figs. M-1 to M-5).
3. Performance data of C_P versus C_T and C_T versus 3/4 radius collective from the Canadair Ltd. test (figs. M-6 through M-7, and table M-1).

1. General Discussion

See Appendix K.

2. Propeller Configuration

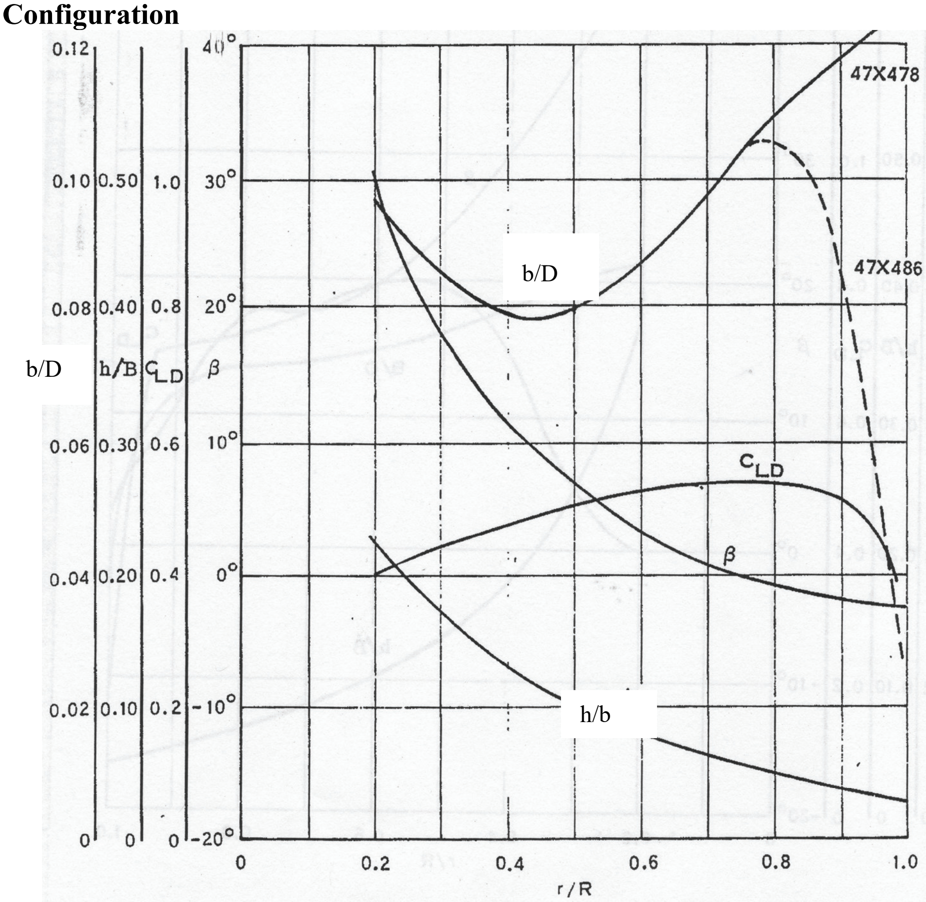

Figure M-1. Hamilton Standard 47X-486.
(This figure uses propeller nomenclature as shown the table below.)

Parameter	Proprotor	Propeller
Diameter	D	D
Radius	R	R
Blade chord	c	b
Blade number	b	N or B
Airfoil thickness	t	h
Blade width ratio	Rarely used	b/D
Airfoil thickness ratio	t/c	h/b
Blade pitch angle	θ	β_0
Blade radial station	r or x = r/R	r or x = r/R

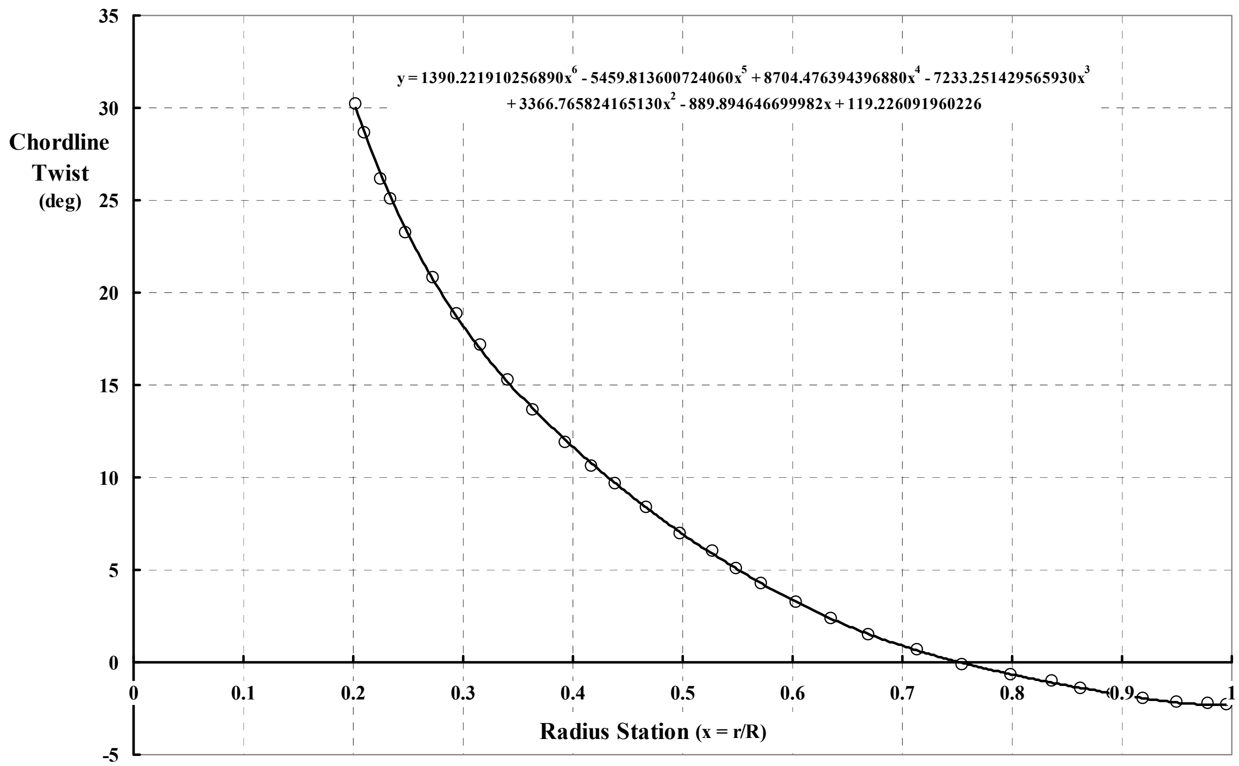

Figure M-2. Hamilton Standard 47X-486—twist vs. radius station.

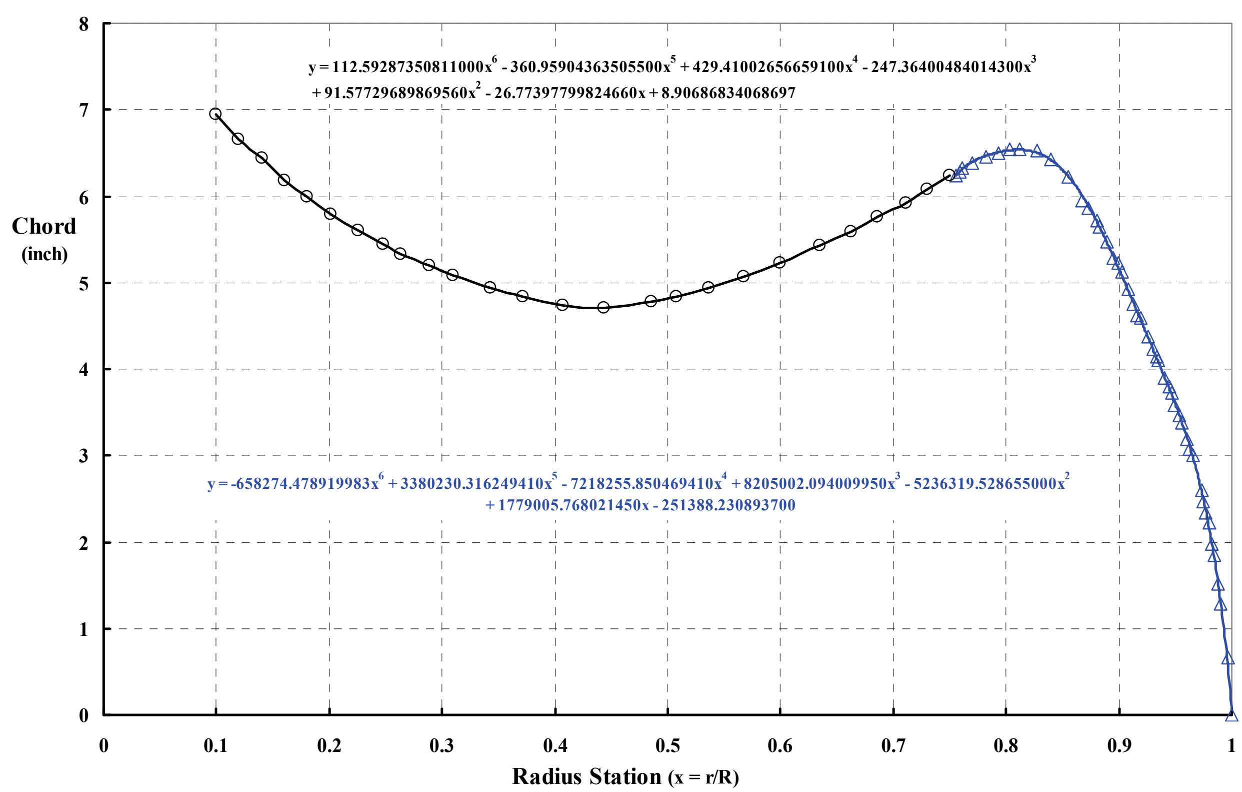

Figure M-3. Hamilton Standard 47X-486—chord vs. radius station.

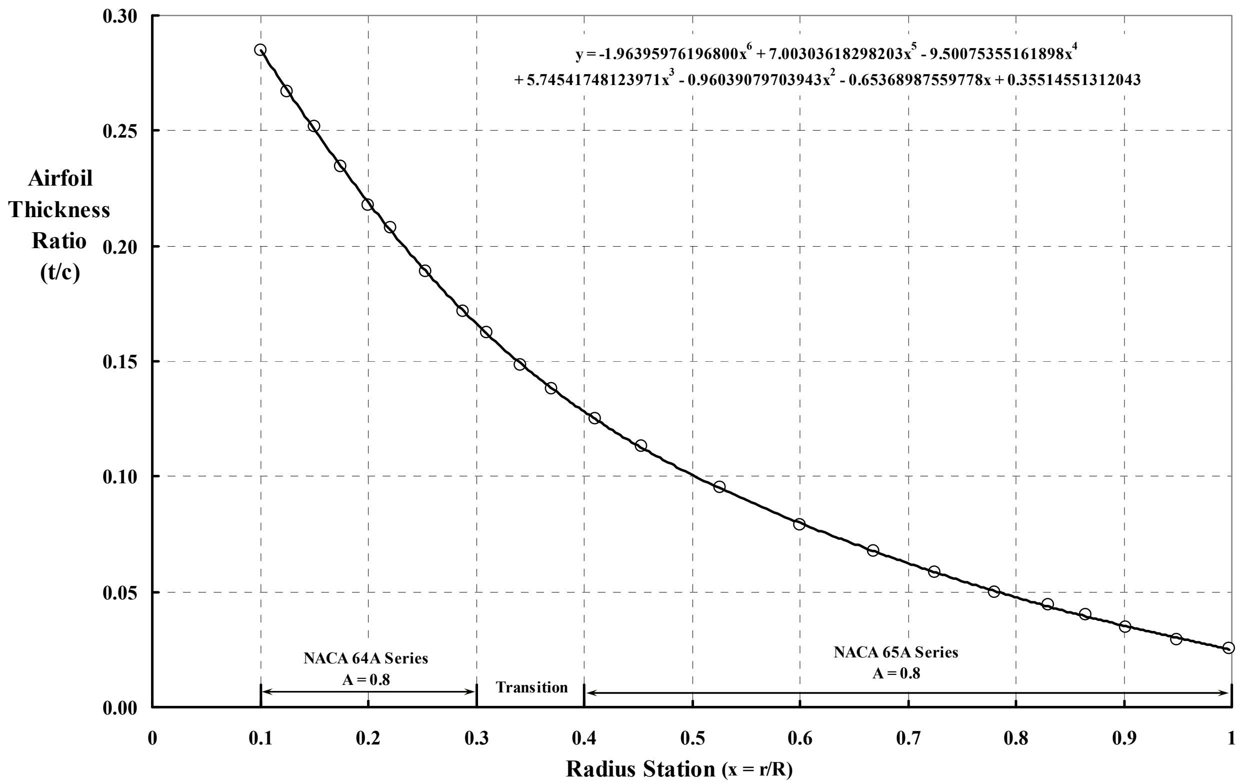

Figure M-4. Hamilton Standard 47X-486—airfoil thickness ratio vs. radius station.

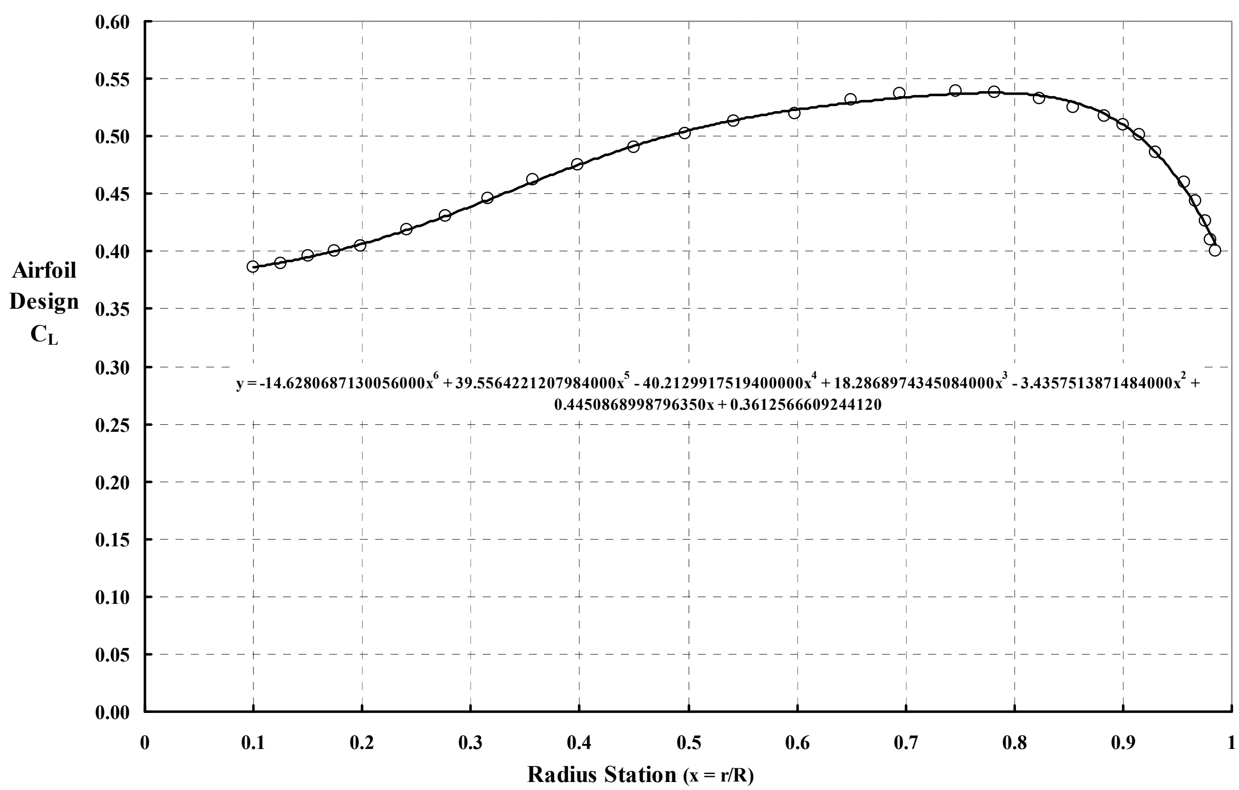

Figure M-5. Hamilton Standard 47X-486—airfoil design C_L vs. radius station.

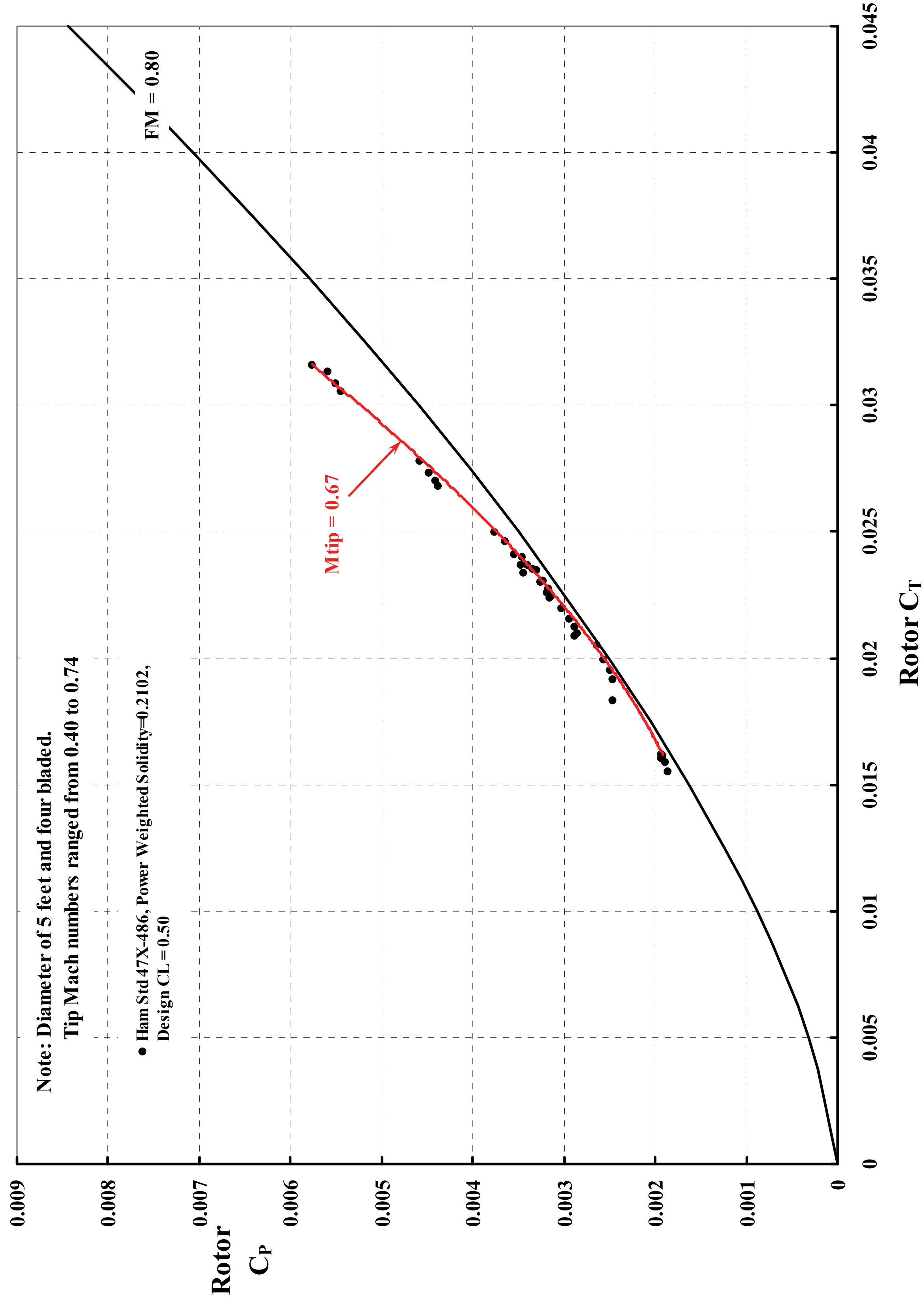

Figure M-6. Hamilton Standard 47X-486 test results at Canadair Ltd.—power vs. thrust coefficient.

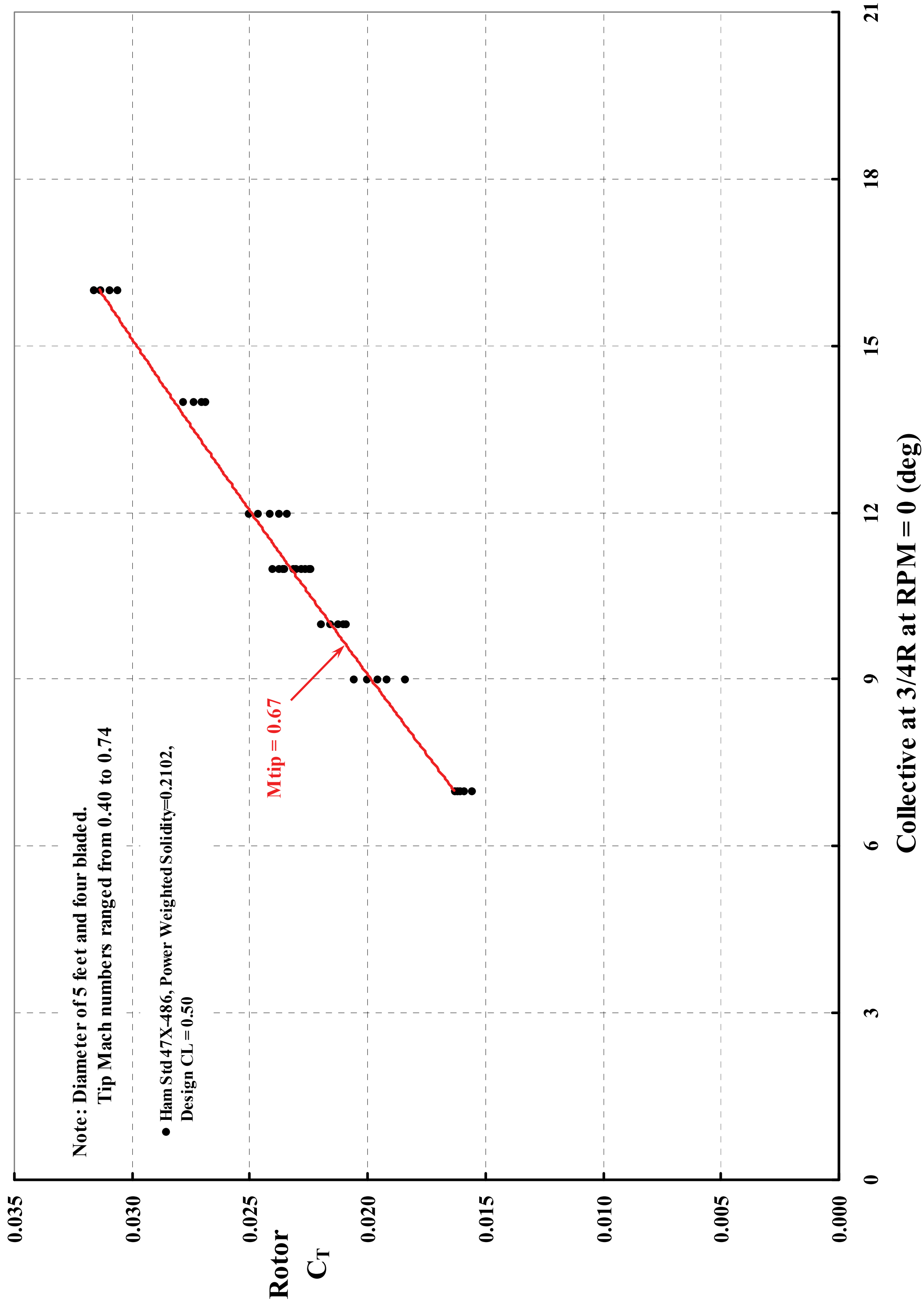

Figure M-7. Hamilton Standard 47X-486 test results at Canadair Ltd.—thrust coefficient vs. collective pitch.

Table M-1. Hamilton Standard 47X-486 Test Results at Canadair Ltd.

V tip (fps)	Nominal Mtip	Beta (deg)	CT	CP	Ideal CP	FM	CT/CP	CT/σ_{power}
450	0.40	7.0	0.015532	0.001864	0.001369	0.7342	8.33	0.0739
550	0.49	7.0	0.016074	0.001926	0.001441	0.7482	8.35	0.0765
650	0.58	7.0	0.016255	0.001930	0.001465	0.7593	8.42	0.0773
750	0.67	7.0	0.016177	0.001909	0.001455	0.7620	8.47	0.0769
850	0.74	7.0	0.015894	0.001885	0.001417	0.7517	8.43	0.0756
450	0.40	9.0	0.018370	0.002456	0.001761	0.7170	7.48	0.0874
550	0.49	9.0	0.019183	0.002468	0.001879	0.7613	7.77	0.0912
650	0.58	9.0	0.019544	0.002497	0.001932	0.7738	7.83	0.0930
750	0.67	9.0	0.019983	0.002566	0.001997	0.7783	7.79	0.0950
850	0.74	9.0	0.020564	0.002636	0.002085	0.7909	7.80	0.0978
450	0.40	10.0	0.020899	0.002879	0.002136	0.7422	7.26	0.0994
550	0.49	10.0	0.021002	0.002858	0.002152	0.7530	7.35	0.0999
650	0.58	10.0	0.021260	0.002879	0.002192	0.7615	7.39	0.1011
750	0.67	10.0	0.021583	0.002940	0.002242	0.7626	7.34	0.1027
850	0.74	10.0	0.021983	0.003026	0.002305	0.7615	7.26	0.1046
450	0.40	11.0	0.022408	0.003158	0.002372	0.7511	7.10	0.1066
550	0.49	11.0	0.022641	0.003187	0.002409	0.7560	7.11	0.1077
650	0.58	11.0	0.023028	0.003256	0.002471	0.7588	7.07	0.1095
750	0.67	11.0	0.023557	0.003338	0.002557	0.7658	7.06	0.1120
850	0.74	11.0	0.024021	0.003458	0.002633	0.7614	6.95	0.1143
450	0.40	11.0	0.022486	0.003133	0.002384	0.7610	7.18	0.1070
550	0.49	11.0	0.022782	0.003166	0.002432	0.7680	7.20	0.1084
650	0.58	11.0	0.023118	0.003228	0.002485	0.7701	7.16	0.1100
750	0.67	11.0	0.023492	0.003302	0.002546	0.7712	7.12	0.1117
850	0.74	11.0	0.023737	0.003400	0.002586	0.7606	6.98	0.1129
450	0.40	12.0	0.023428	0.003437	0.002536	0.7377	6.82	0.1114
550	0.49	12.0	0.023737	0.003466	0.002586	0.7461	6.85	0.1129
650	0.58	12.0	0.024137	0.003548	0.002652	0.7474	6.80	0.1148
750	0.67	12.0	0.024640	0.003638	0.002735	0.7517	6.77	0.1172
850	0.74	12.0	0.025014	0.003753	0.002797	0.7454	6.66	0.1190

V tip (fps)	Nominal Mtip	Beta (deg)	CT	CP	Ideal CP	FM	CT/CP	CT/σ_{power}
450	0.40	14.0	0.026846	0.004382	0.003110	0.7099	6.13	0.1277
550	0.49	14.0	0.027053	0.004406	0.003146	0.7141	6.14	0.1287
650	0.58	14.0	0.027362	0.004472	0.003200	0.7157	6.12	0.1301
750	0.67	14.0	0.027827	0.004583	0.003282	0.7162	6.07	0.1324
450	0.40	16.0	0.030574	0.005437	0.003780	0.6953	5.62	0.1454
550	0.49	16.0	0.030923	0.005494	0.003845	0.6998	5.63	0.1471
650	0.58	16.0	0.031348	0.005589	0.003925	0.7022	5.61	0.1491
750	0.67	16.0	0.031607	0.005757	0.003973	0.6901	5.49	0.1503

Appendix N

5-Foot-Diameter Propeller, Canadair Ltd. 1968-1E14 (Canadair Ltd. Test)

This appendix contains:

1. General discussion.
2. Propeller configuration (figs. N-1 to N-5).
3. Performance data of C_P versus C_T and C_T versus 3/4 radius collective from the Canadair Ltd. test (figs. N-6 through N-7, and table N-1).

1. General Discussion

See Appendix K.

2. Propeller Configuration

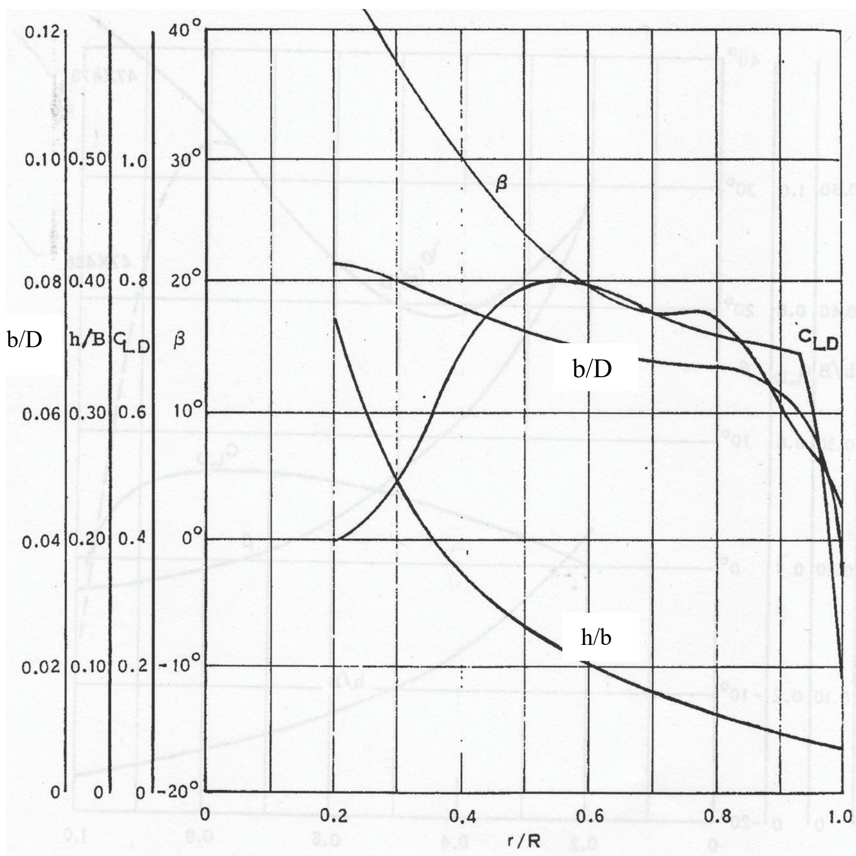

Figure N-1. Canadair Ltd. 1968-1E14.
(This figure uses propeller nomenclature as shown the table below.)

Parameter	Proprotor	Propeller
Diameter	D	D
Radius	R	R
Blade chord	c	b
Blade number	b	N or B
Airfoil thickness	t	h
Blade width ratio	Rarely used	b/D
Airfoil thickness ratio	t/c	h/b
Blade pitch angle	θ	β_0
Blade radial station	r or x = r/R	r or x = r/R

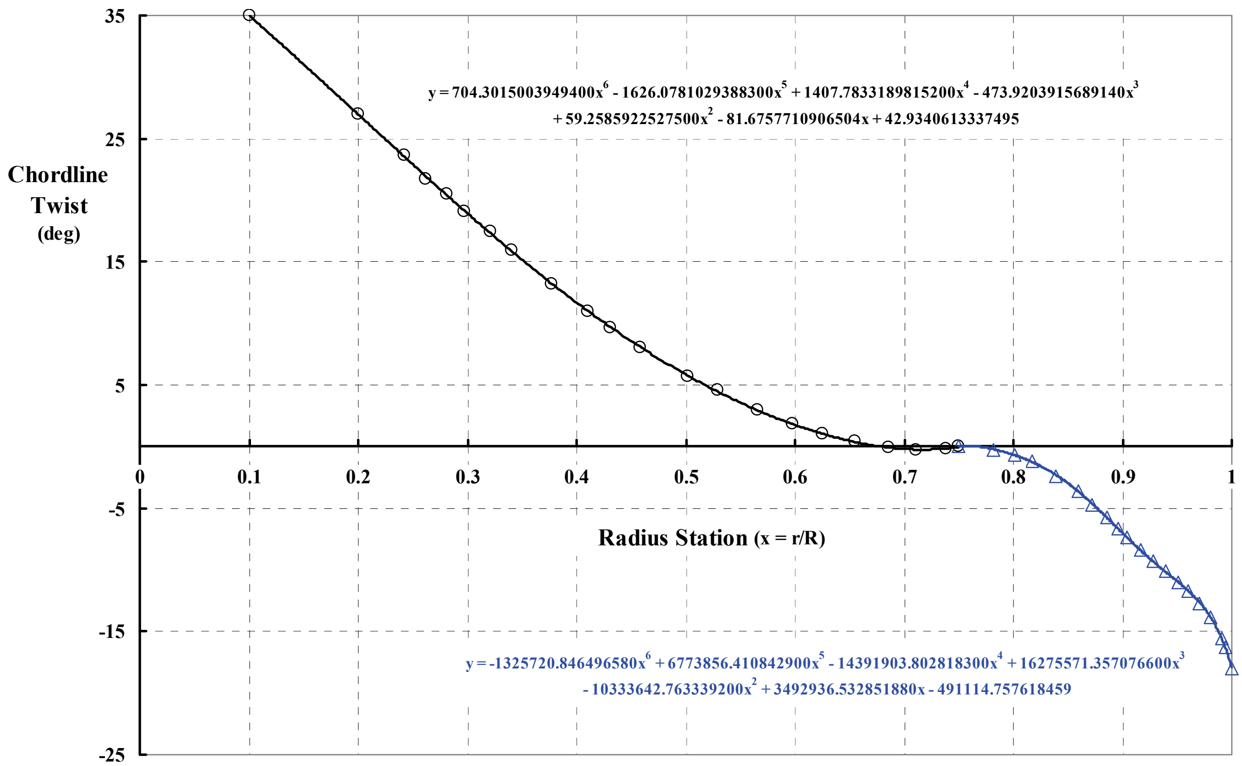

Figure N-2. Canadair Ltd. 1968-1E146—twist vs. radius station.

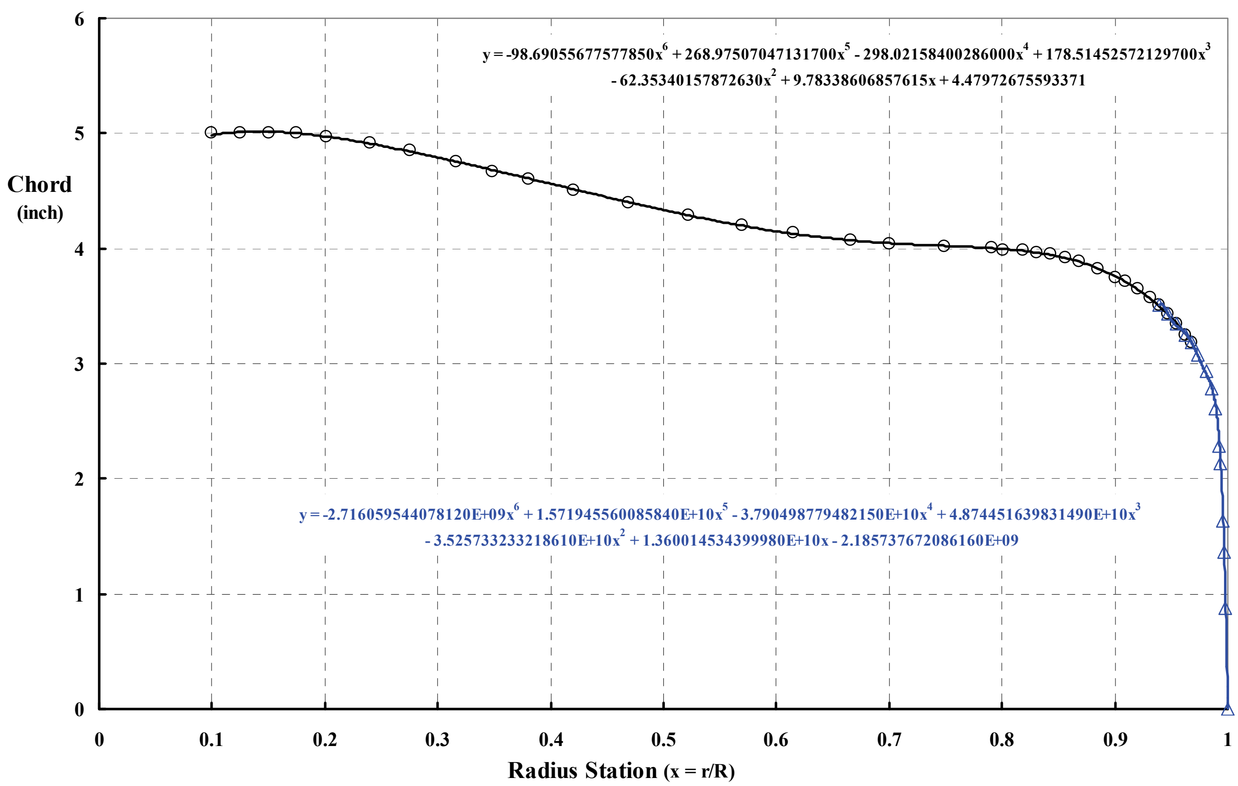

Figure N-3. Canadair Ltd. 1968-1E14—chord vs. radius station.

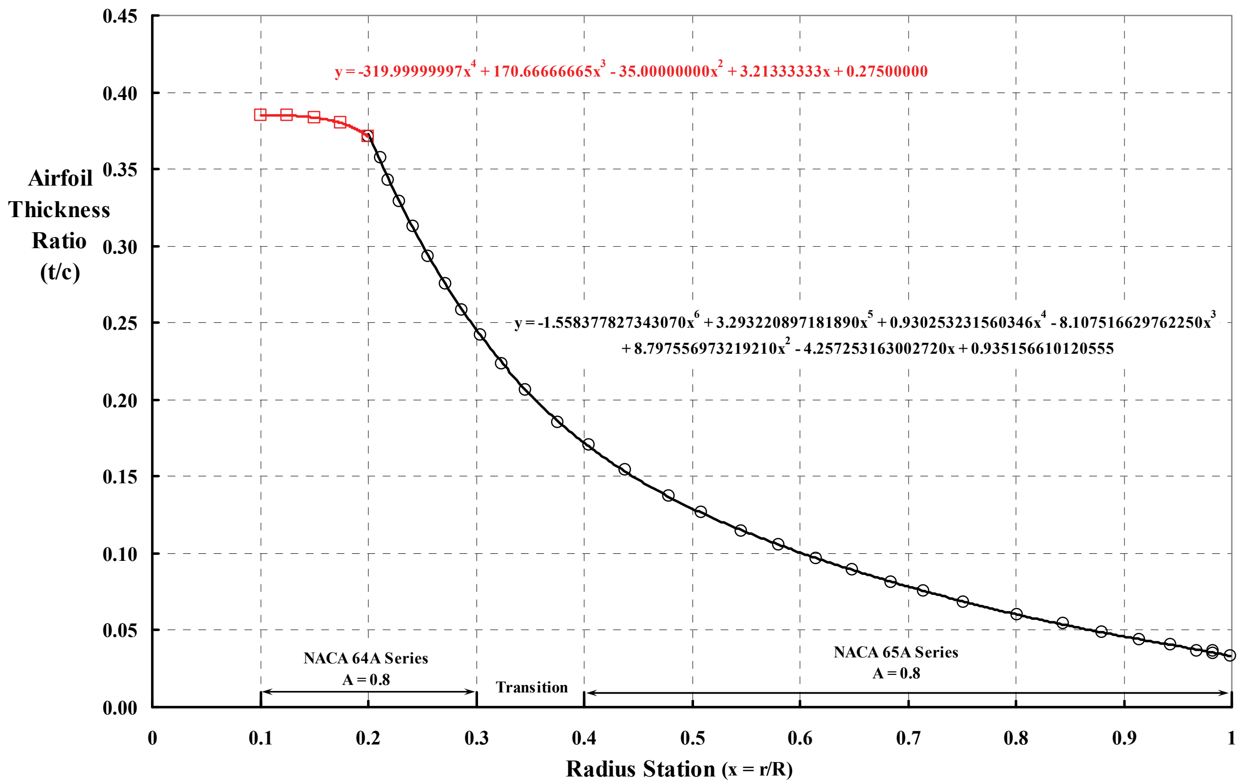

Figure N-4. Canadair Ltd. 1968-1E14—airfoil thickness ratio vs. radius station.

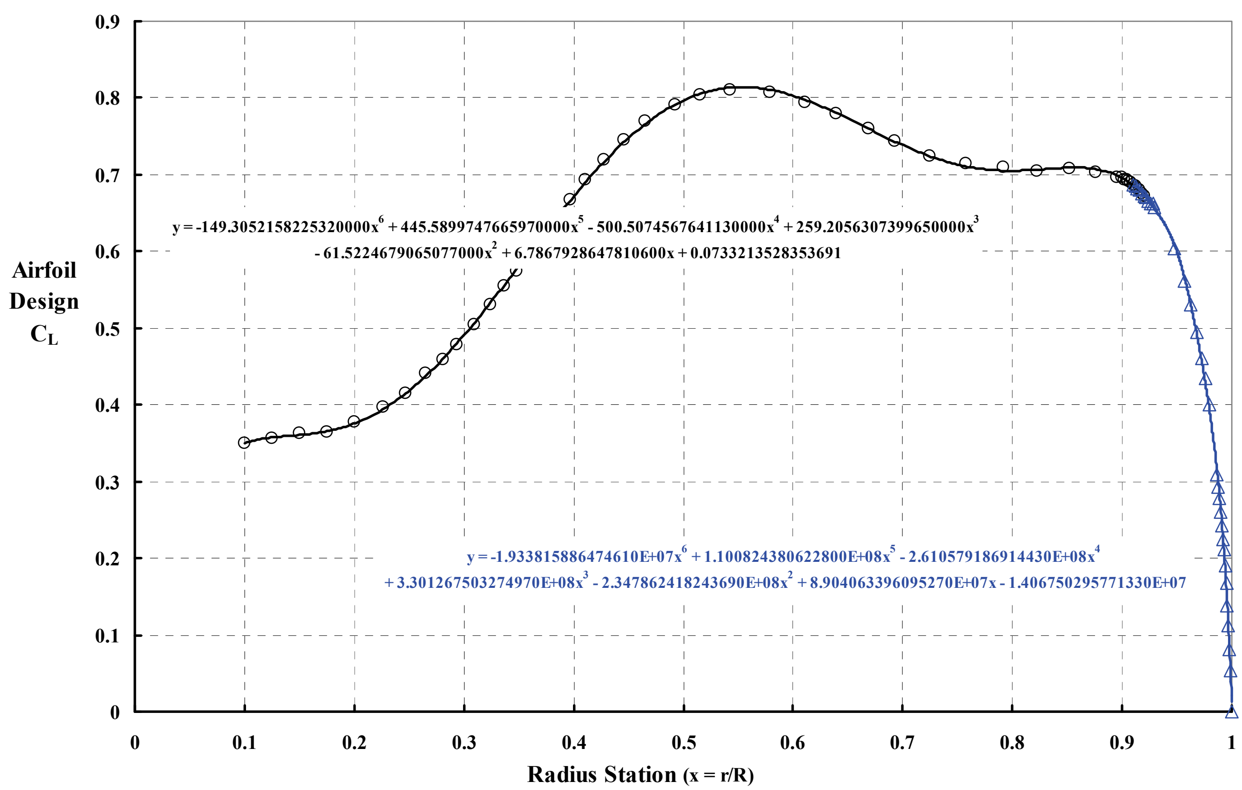

Figure N-5. Canadair Ltd. 1968-1E14—airfoil design C_L vs. radius station.

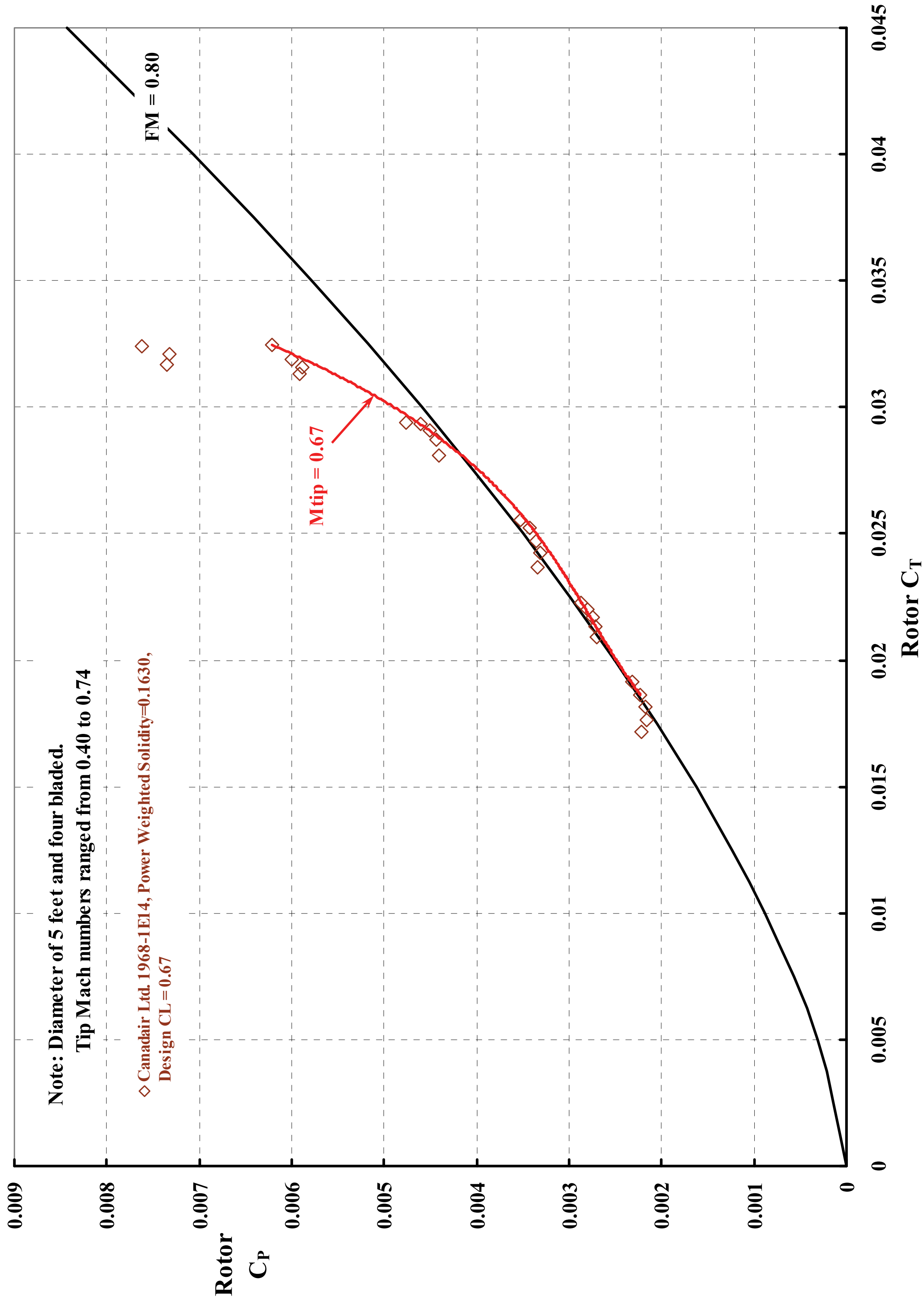

Figure N-6. Canadair Ltd. 1968-1E14 test results at Canadair Ltd.—power vs. thrust coefficient.

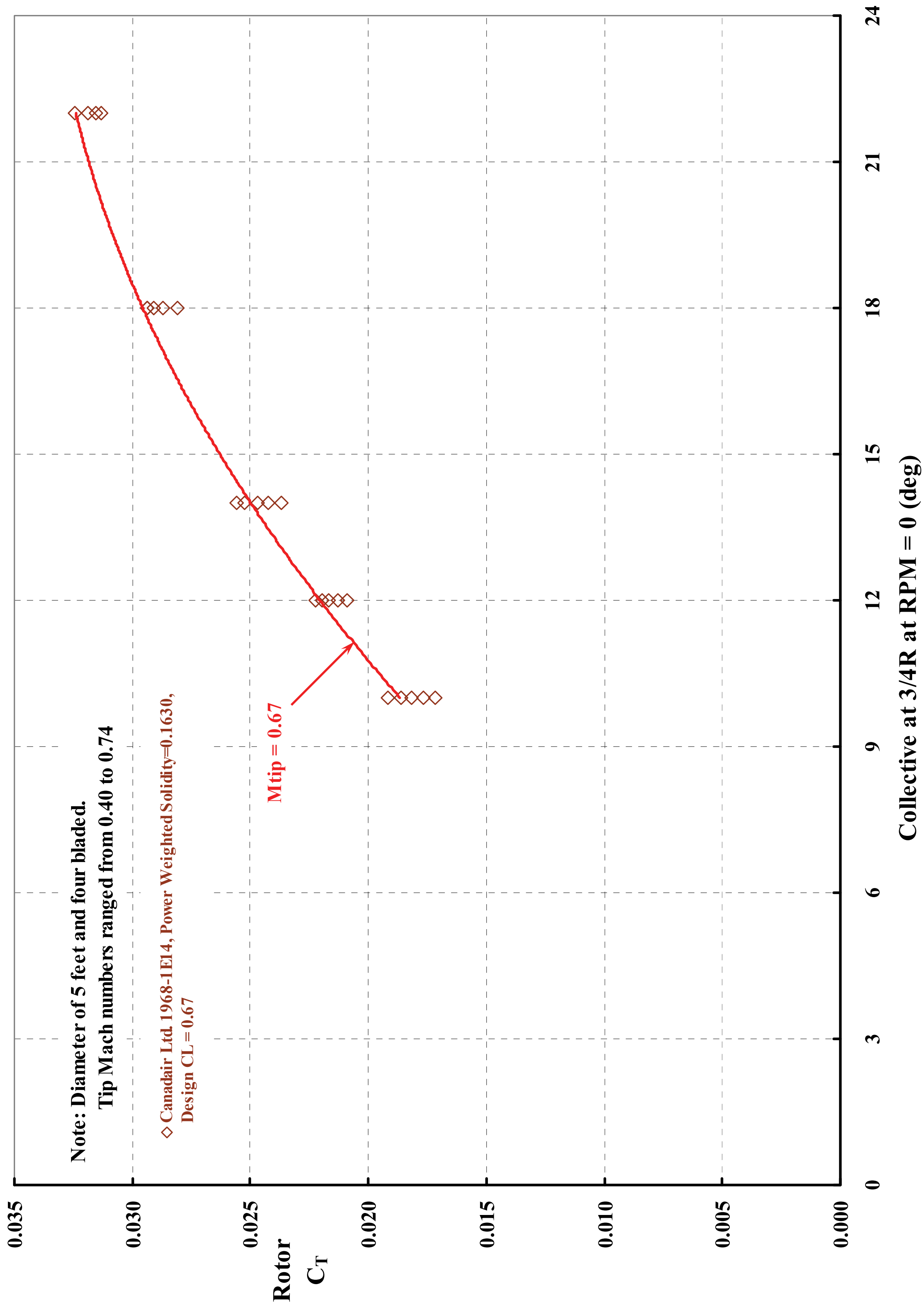

Figure N-7. Canadair Ltd. 1968-1E14 test results at Canadair Ltd.—thrust coefficient vs. collective pitch.

Table N-1. Canadair Ltd. 1968-1E14 Test Results at Canadair Ltd.

Vtip (fps)	Nominal Mtip	Beta (deg)	CT	CP	Ideal CP	F. M.	CT/CP	CT/σ_{power}
450	0.40	10.0	0.017145	0.002213	0.001587	0.7172	7.75	0.105200
550	0.49	10.0	0.017648	0.002168	0.001658	0.7646	8.14	0.108287
650	0.58	10.0	0.018151	0.002180	0.001729	0.7930	8.32	0.111374
750	0.67	10.0	0.018616	0.002230	0.001796	0.8055	8.35	0.114224
850	0.74	10.0	0.019145	0.002316	0.001873	0.8087	8.27	0.117469
450	0.40	12.0	0.020912	0.002706	0.002138	0.7902	7.73	0.128314
550	0.49	12.0	0.021312	0.002723	0.002200	0.8081	7.83	0.130768
650	0.58	12.0	0.021673	0.002747	0.002256	0.8213	7.89	0.132984
750	0.67	12.0	0.021983	0.002805	0.002305	0.8217	7.84	0.134884
850	0.74	12.0	0.022241	0.002870	0.002345	0.8171	7.75	0.136467
450	0.40	14.0	0.023660	0.003347	0.002573	0.7689	7.07	0.145174
550	0.49	14.0	0.024227	0.003314	0.002667	0.8047	7.31	0.148657
650	0.58	14.0	0.024705	0.003355	0.002746	0.8184	7.36	0.151586
750	0.67	14.0	0.025234	0.003421	0.002834	0.8286	7.38	0.154831
850	0.74	14.0	0.025556	0.003527	0.002889	0.8190	7.25	0.156810
450	0.40	18.0	0.028110	0.004402	0.003333	0.7571	6.39	0.172483
550	0.49	18.0	0.028717	0.004439	0.003441	0.7752	6.47	0.176204
650	0.58	18.0	0.029104	0.004505	0.003511	0.7794	6.46	0.178579
750	0.67	18.0	0.029349	0.004607	0.003555	0.7716	6.37	0.180083
850	0.74	18.0	0.029388	0.004763	0.003562	0.7478	6.17	0.180320
450	0.40	22.0	0.031323	0.005909	0.003920	0.6634	5.30	0.192194
550	0.49	22.0	0.031555	0.005893	0.003964	0.6726	5.35	0.193618
650	0.58	22.0	0.031903	0.005999	0.004029	0.6716	5.32	0.195756
750	0.67	22.0	0.032458	0.006217	0.004135	0.6651	5.22	0.199159
450	0.40	25.0	0.032123	0.007322	0.004071	0.5560	4.39	0.197101
550	0.49	25.0	0.031671	0.007355	0.003985	0.5419	4.31	0.194331
650	0.58	25.0	0.032393	0.007617	0.004123	0.5412	4.25	0.198764

Appendix O

5-Foot-Diameter Propeller, Canadair Ltd. 240-3C14
(Canadair Ltd. Test)

This appendix contains:

1. General discussion.
2. Propeller configuration (figs. O-1 to O-5).
3. Performance data of C_P versus C_T and C_T versus 3/4 radius collective from the Canadair Ltd. test (figs. O-6 through O-7, and table O-1).

1. General Discussion

See Appendix K.

2. Propeller Configuration

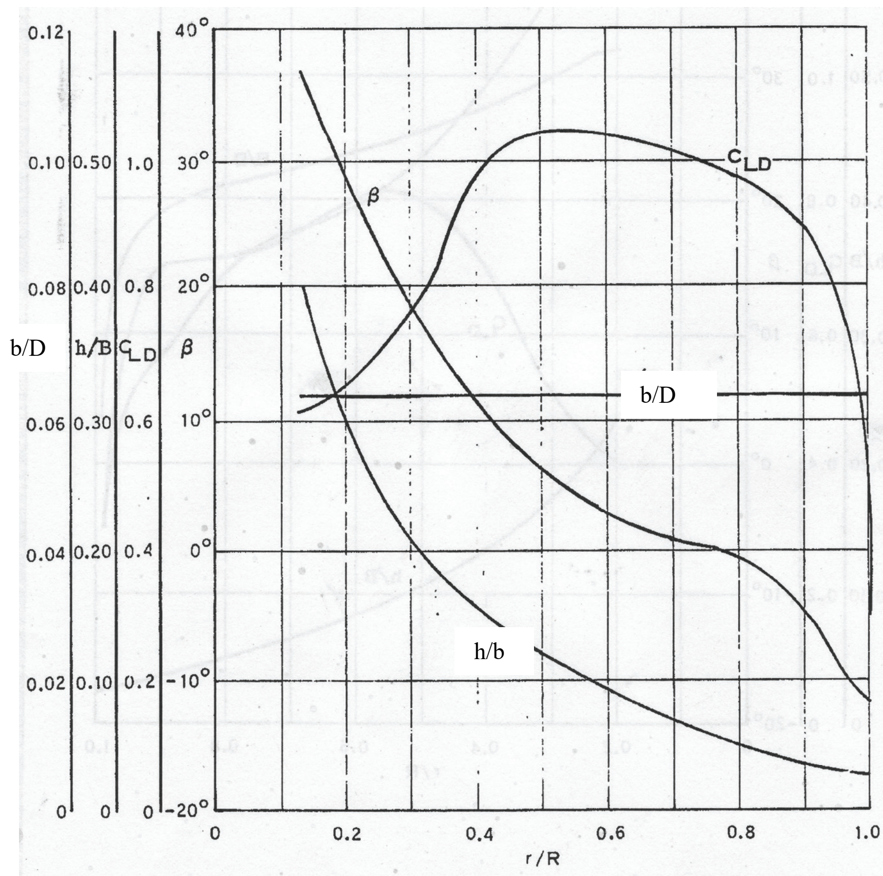

Figure O-1. Canadair Ltd. 240-3C14.
(This figure uses propeller nomenclature as shown the table below.)

Parameter	Proprotor	Propeller
Diameter	D	D
Radius	R	R
Blade chord	c	b
Blade number	b	N or B
Airfoil thickness	t	h
Blade width ratio	Rarely used	b/D
Airfoil thickness ratio	t/c	h/b
Blade pitch angle	θ	β_0
Blade radial station	r or x = r/R	r or x = r/R

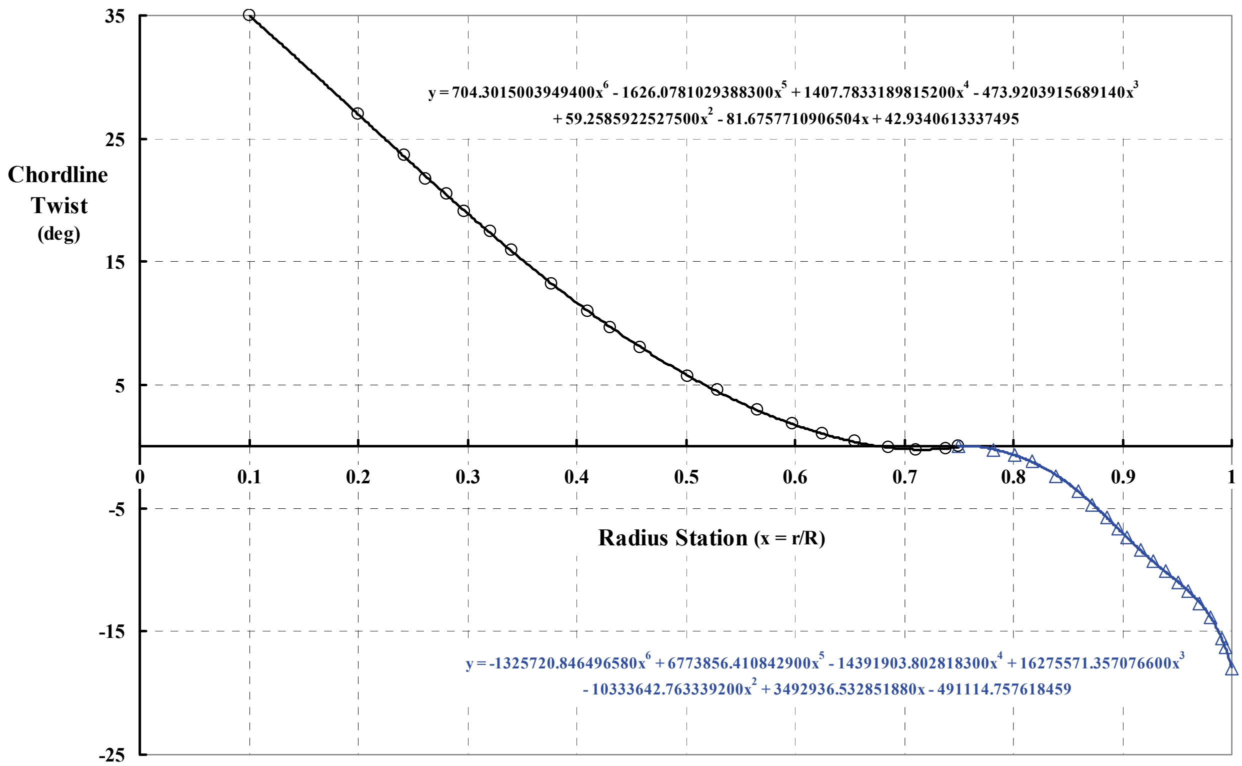

Figure O-2. Canadair Ltd. 240-3C14—twist vs. radius station.

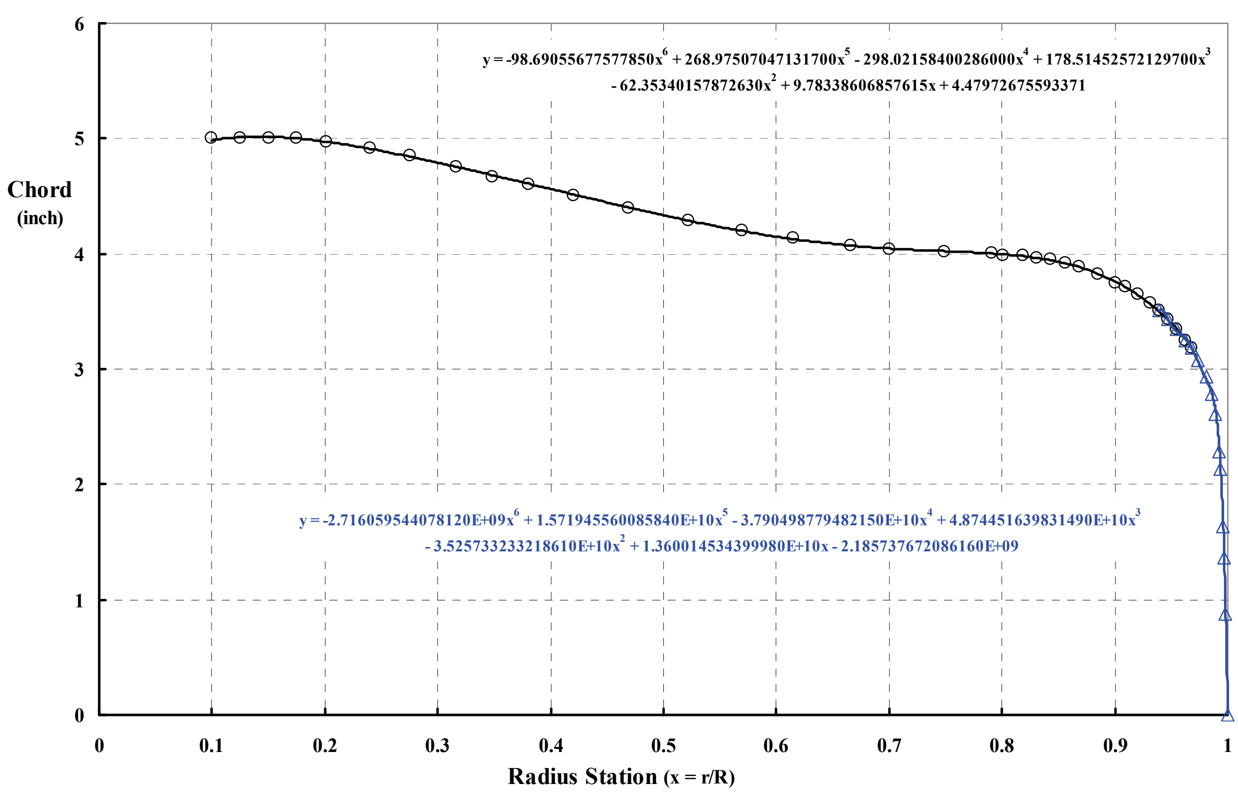

Figure O-3. Canadair Ltd. 240-3C14—chord vs. radius station.

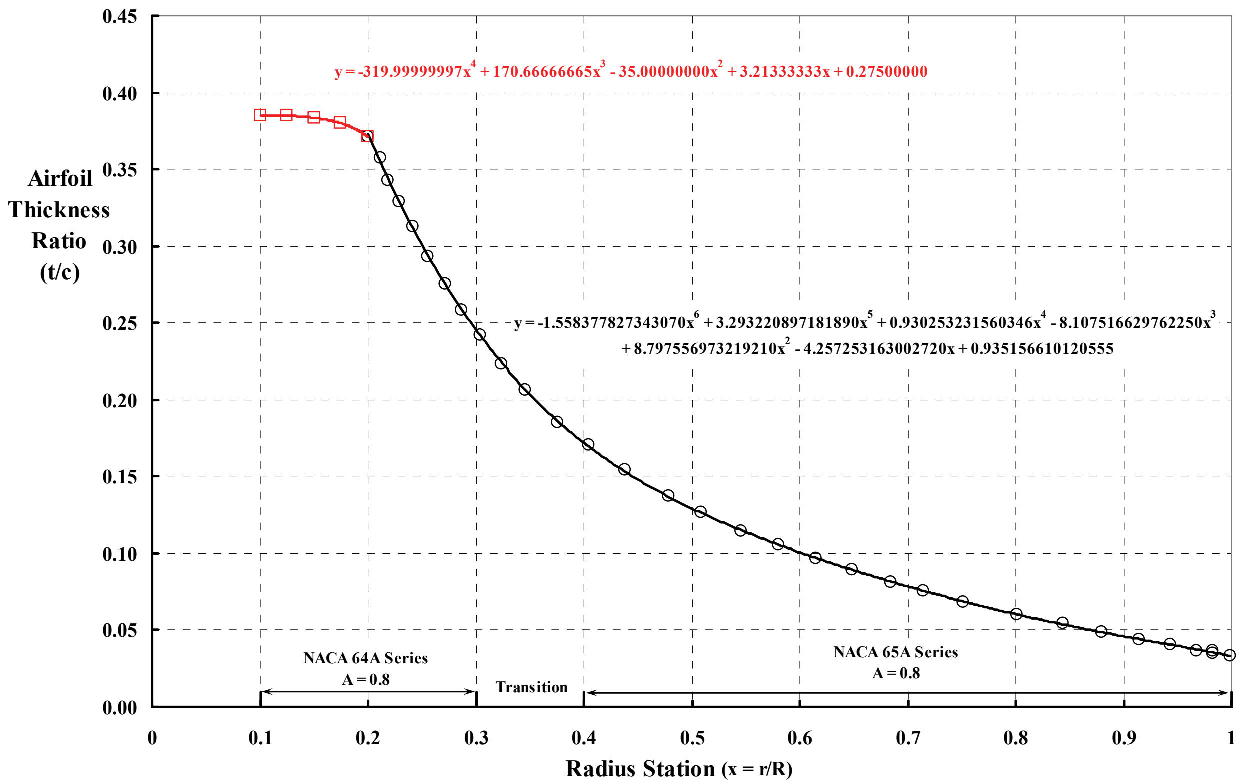

Figure O-4. Canadair Ltd. 240-3C14—airfoil thickness ratio vs. radius station.

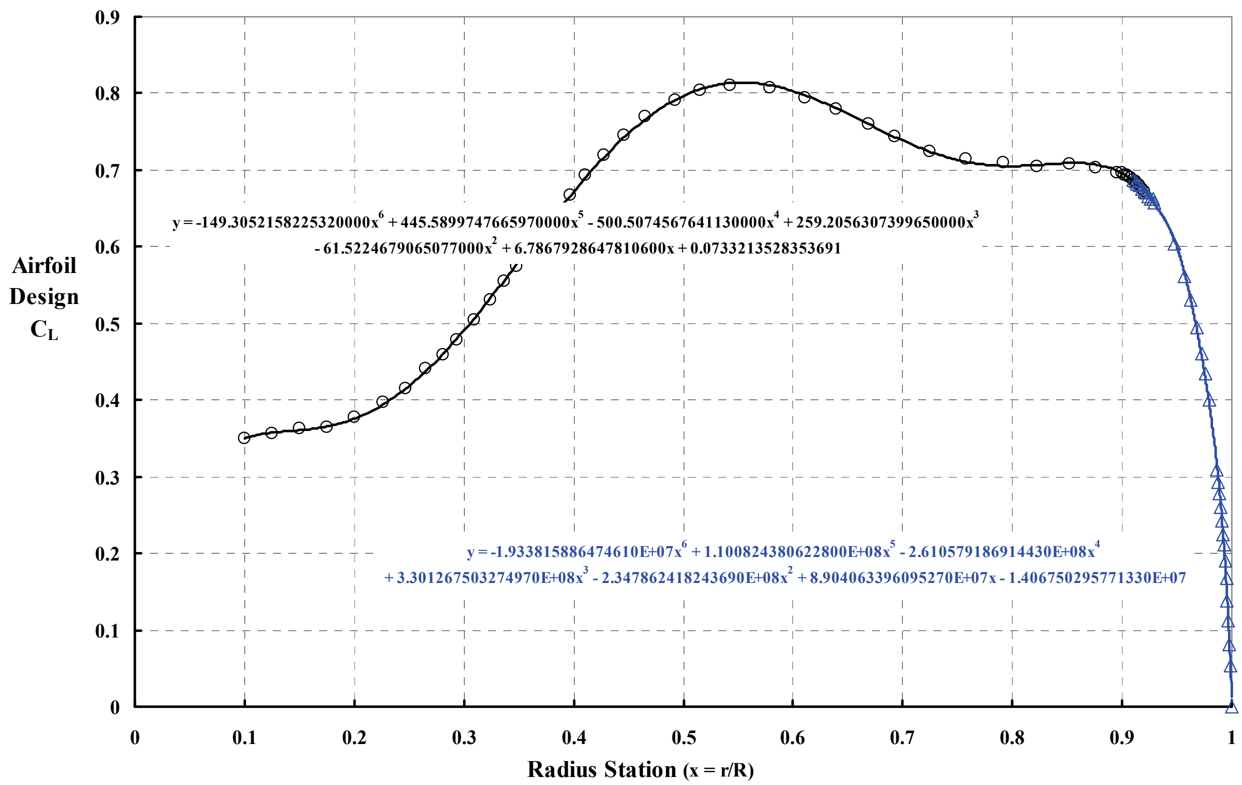

Figure O-5. Canadair Ltd. 240-3C14—airfoil design C_L vs. radius station.

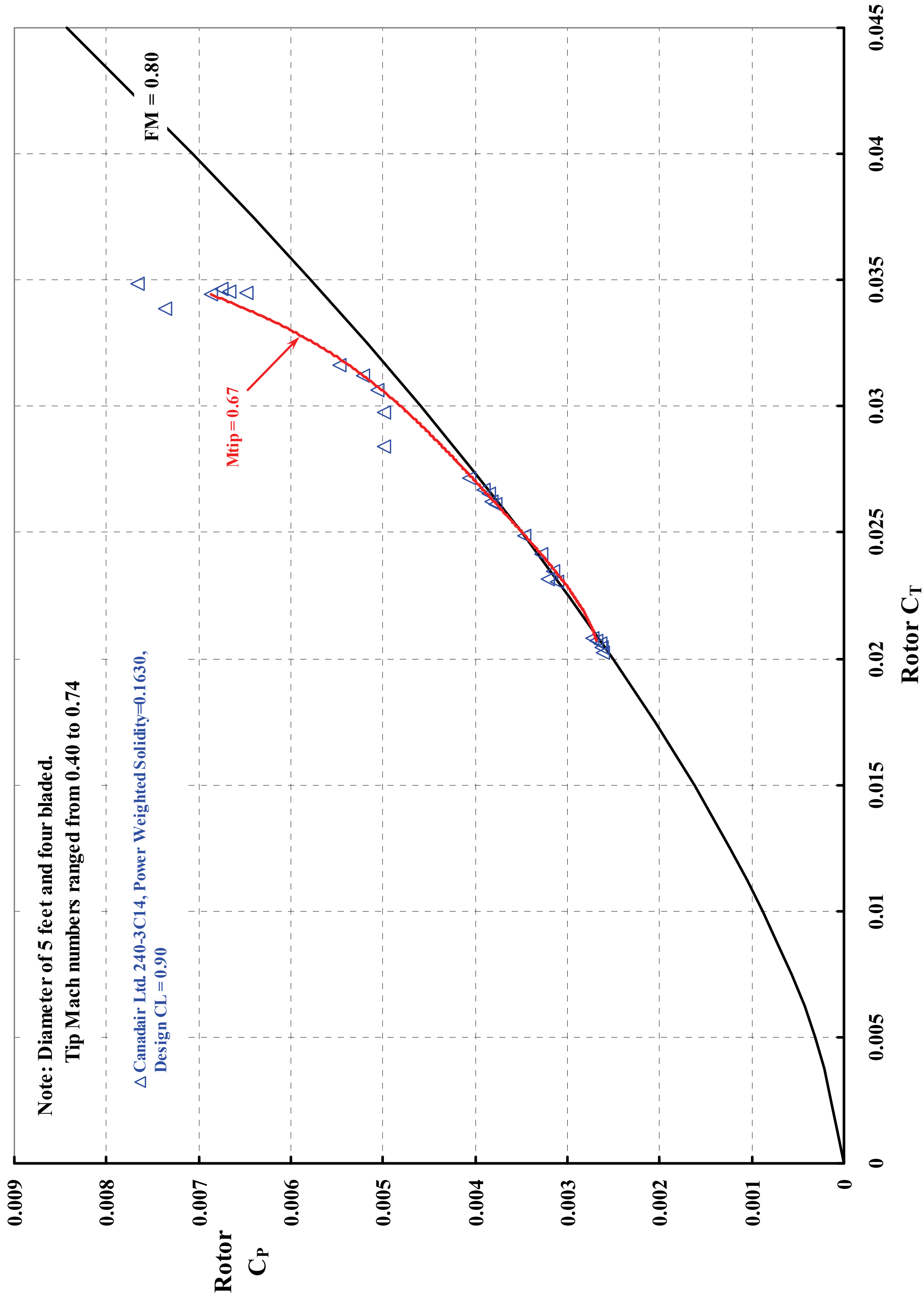

Figure O-6. Canadair Ltd. 240-3C14 test results at Canadair Ltd.—power vs. thrust coefficient.

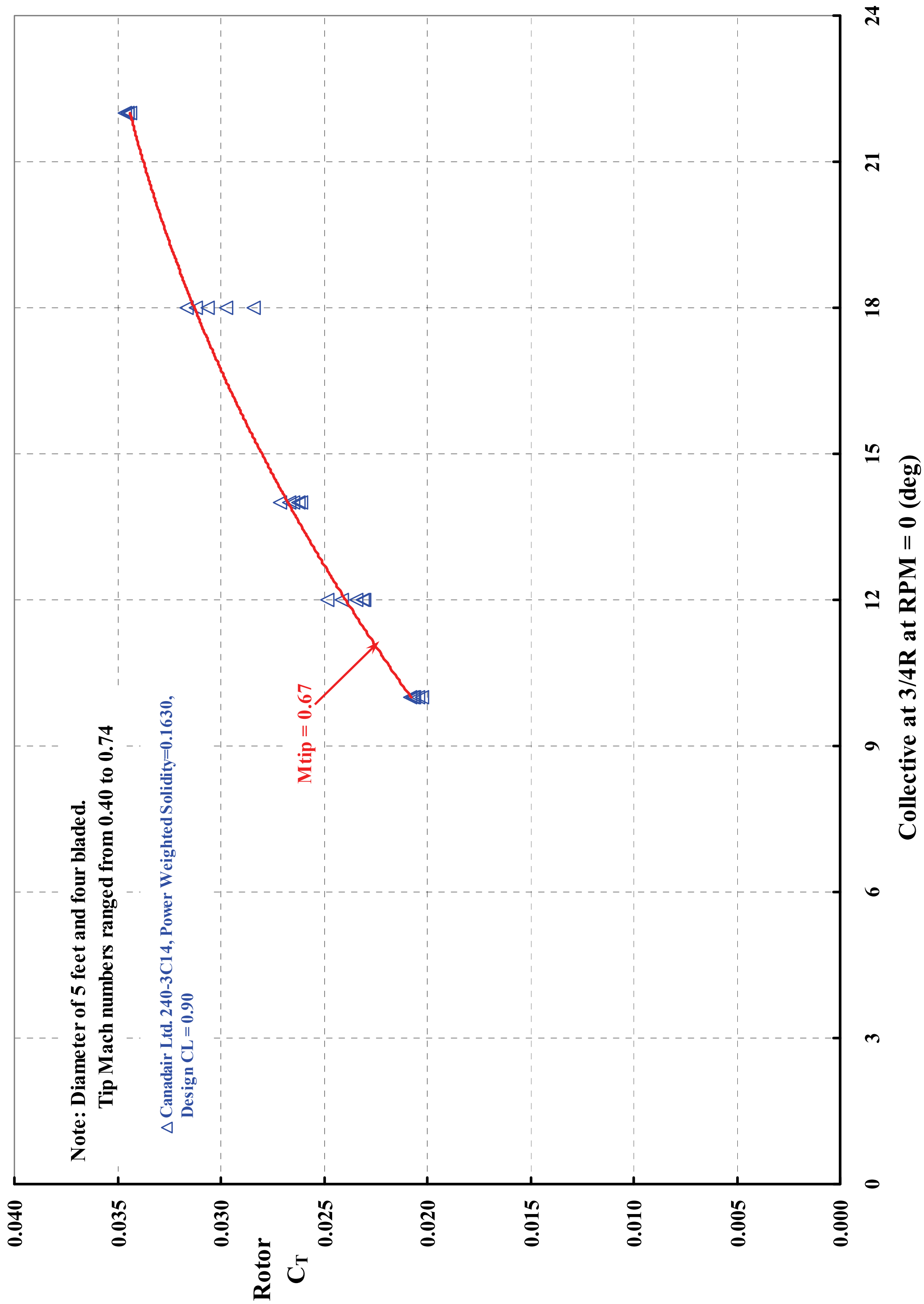

Figure O-7. Canadair Ltd. 240-3C14 test results at Canadair Ltd.—thrust coefficient vs. collective pitch.

Table O-1. Canadair Ltd. 240-3C14 Test Results at Canadair Ltd.

Vtip (fps)	Nominal Mtip	Beta (deg)	CT	CP	Ideal CP	FM	CT/CP	CT/σ_{power}
450	0.40	10.0	0.020241	0.002616	0.002036	0.7785	7.74	0.124198
550	0.49	10.0	0.020435	0.002624	0.002066	0.7872	7.79	0.125385
650	0.58	10.0	0.020615	0.002640	0.002093	0.7927	7.81	0.126493
750	0.67	10.0	0.020705	0.002686	0.002107	0.7845	7.71	0.127047
850	0.74	10.0	0.020809	0.002731	0.002123	0.7773	7.62	0.127681
450	0.40	12.0	0.023144	0.003207	0.002490	0.7763	7.22	0.142008
550	0.49	12.0	0.023066	0.003117	0.002477	0.7948	7.40	0.141533
650	0.58	12.0	0.023440	0.003162	0.002538	0.8026	7.41	0.143829
750	0.67	12.0	0.024124	0.003281	0.002649	0.8075	7.35	0.148024
850	0.74	12.0	0.024847	0.003466	0.002769	0.7991	7.17	0.152457
450	0.40	14.0	0.026511	0.003856	0.003052	0.7916	6.88	0.162668
550	0.49	14.0	0.026124	0.003782	0.002986	0.7894	6.91	0.160293
650	0.58	14.0	0.026214	0.003819	0.003001	0.7859	6.86	0.160847
750	0.67	14.0	0.026691	0.003913	0.003083	0.7879	6.82	0.163776
850	0.74	14.0	0.027143	0.004061	0.003162	0.7786	6.68	0.166547
450	0.40	18.0	0.028394	0.004993	0.003383	0.6775	5.69	0.174225
550	0.49	18.0	0.029736	0.004989	0.003626	0.7267	5.96	0.182457
650	0.58	18.0	0.030665	0.005063	0.003797	0.7499	6.06	0.188157
750	0.67	18.0	0.031232	0.005219	0.003903	0.7478	5.98	0.191640
850	0.74	18.0	0.031632	0.005470	0.003978	0.7273	5.78	0.194093
450	0.40	22.0	0.034509	0.006484	0.004533	0.6991	5.32	0.211745
550	0.49	22.0	0.034522	0.006665	0.004536	0.6805	5.18	0.211825
650	0.58	22.0	0.034638	0.006755	0.004558	0.6748	5.13	0.212537
750	0.67	22.0	0.034419	0.006870	0.004515	0.6572	5.01	0.211191
450	0.40	25.0	0.033864	0.007371	0.004407	0.5978	4.59	0.207788
550	0.49	25.0	0.034845	0.007658	0.004599	0.6005	4.55	0.213804

Appendix P

5-Foot-Diameter Propeller, Canadair Ltd. 240-2C14 (Canadair Ltd. Test)

This appendix contains:

1. General discussion.
2. Propeller configuration (figs. P-1 to P-5).
3. Performance data of C_P versus C_T and C_T versus 3/4 radius collective from the Canadair Ltd. test (figs. P-6 through P-7, and table P-1).

1. General Discussion

See Appendix K.

2. Propeller Configuration

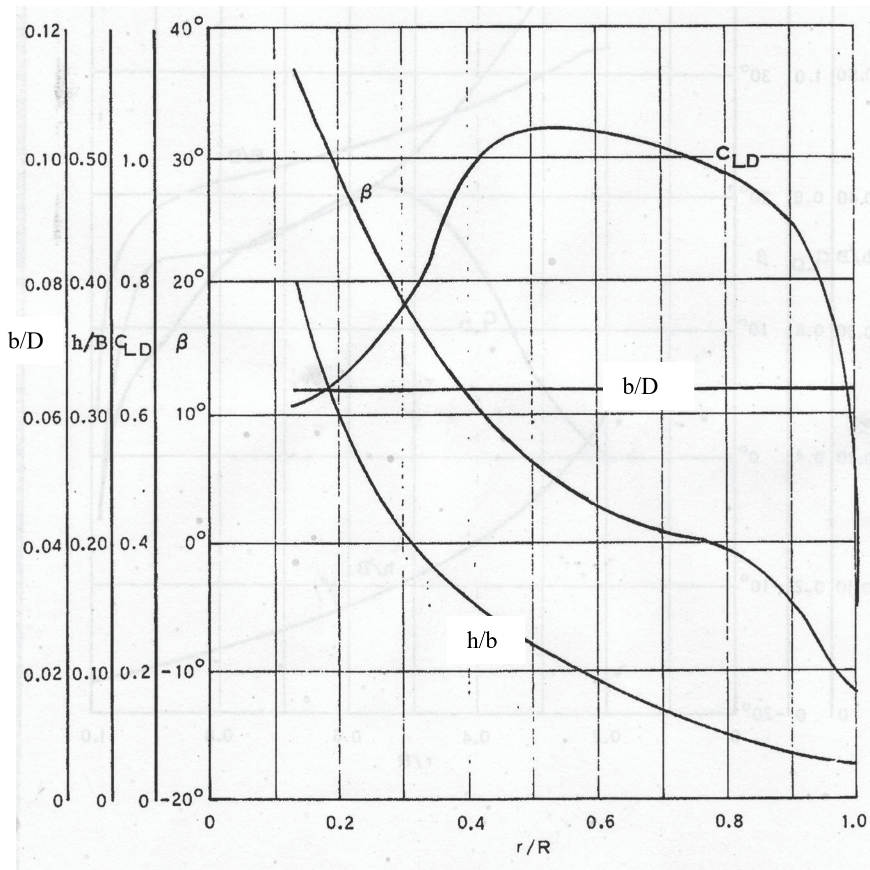

Figure P-1. Canadair Ltd. 240-2C14.
(This figure uses propeller nomenclature as shown the table below.)

Parameter	**Proprotor**	**Propeller**
Diameter	D	D
Radius	R	R
Blade chord	c	b
Blade number	b	N or B
Airfoil thickness	t	h
Blade width ratio	Rarely used	b/D
Airfoil thickness ratio	t/c	h/b
Blade pitch angle	θ	β_0
Blade radial station	r or $x = r/R$	r or $x = r/R$

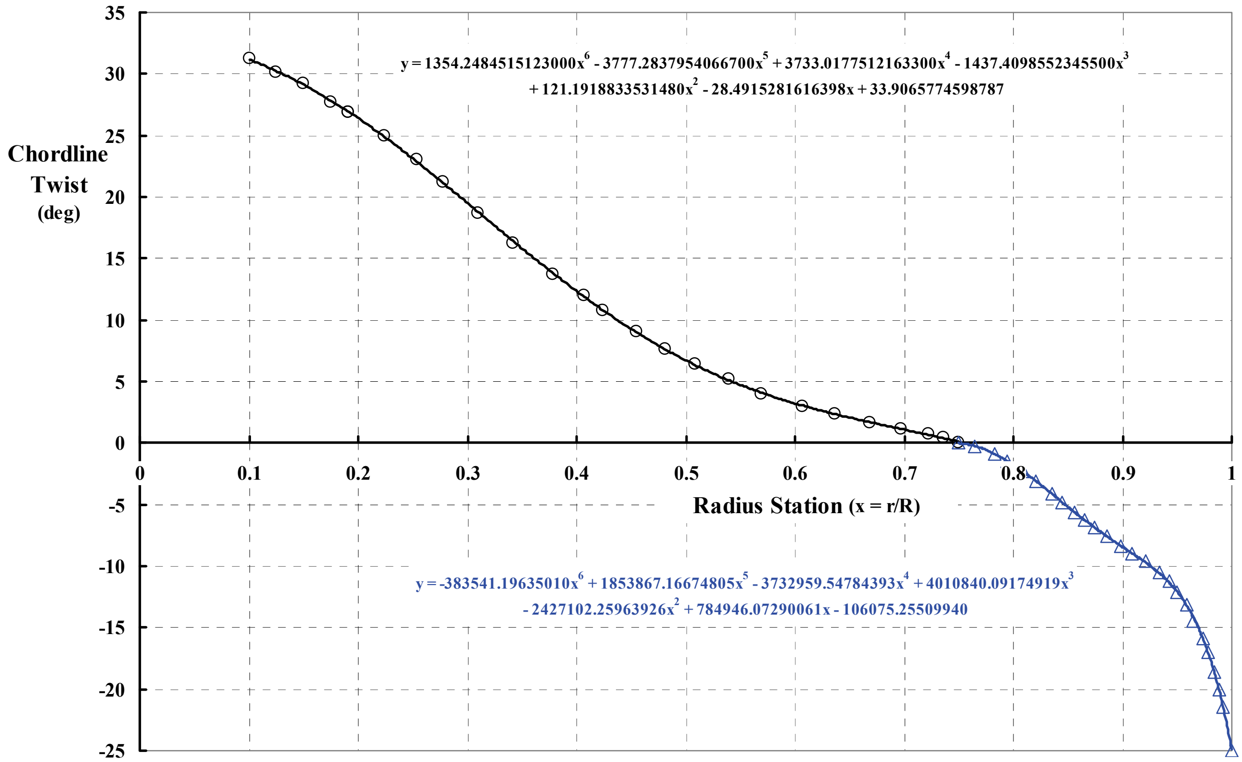

Figure P-2. Canadair Ltd. 240-2C14—twist vs. radius station.

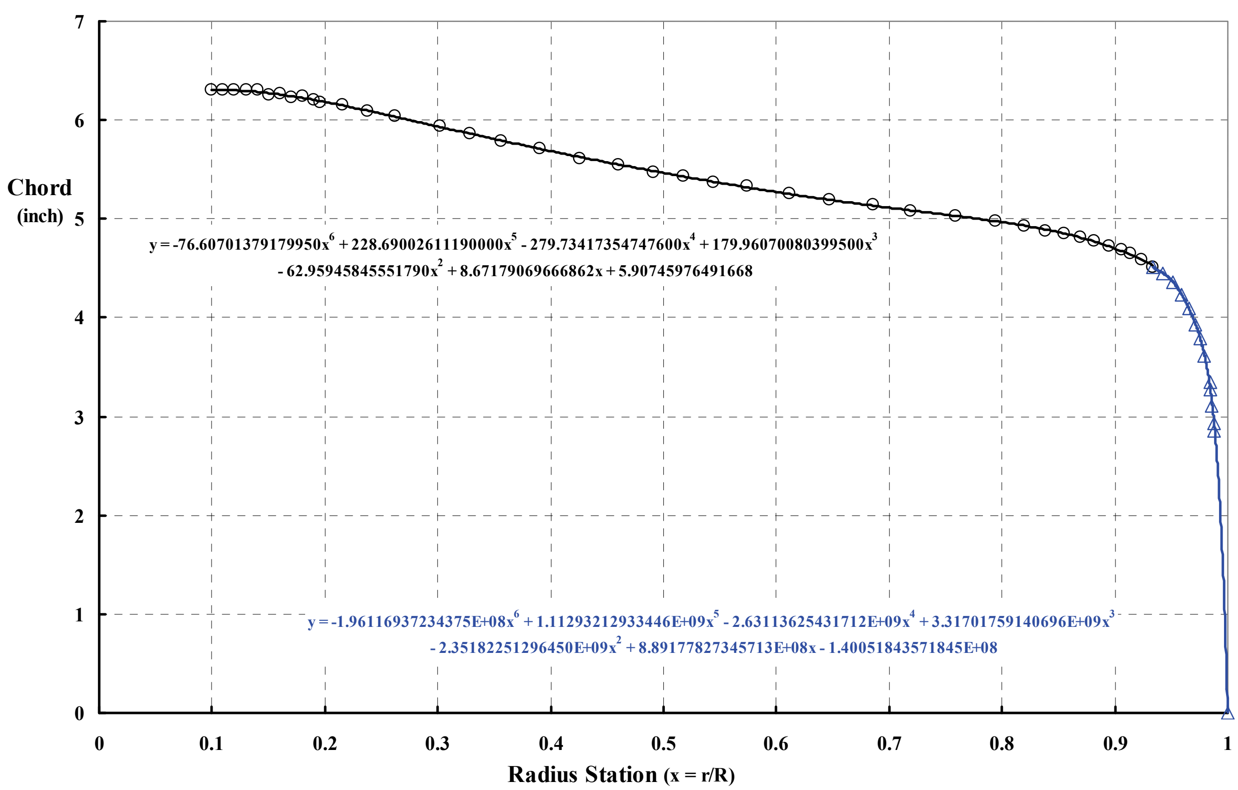

Figure P-3. Canadair Ltd. 240-2C14—chord vs. radius station.

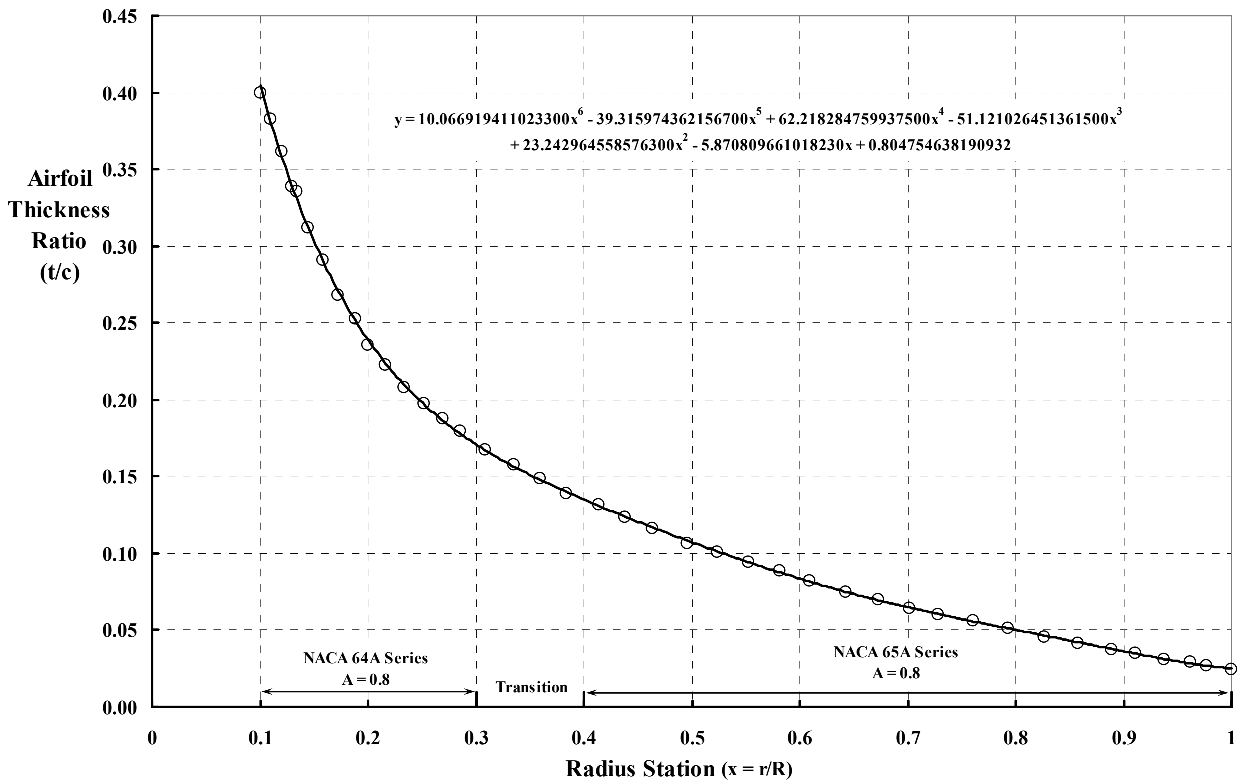

Figure P-4. Canadair Ltd. 240-2C14—airfoil thickness ratio vs. radius station.

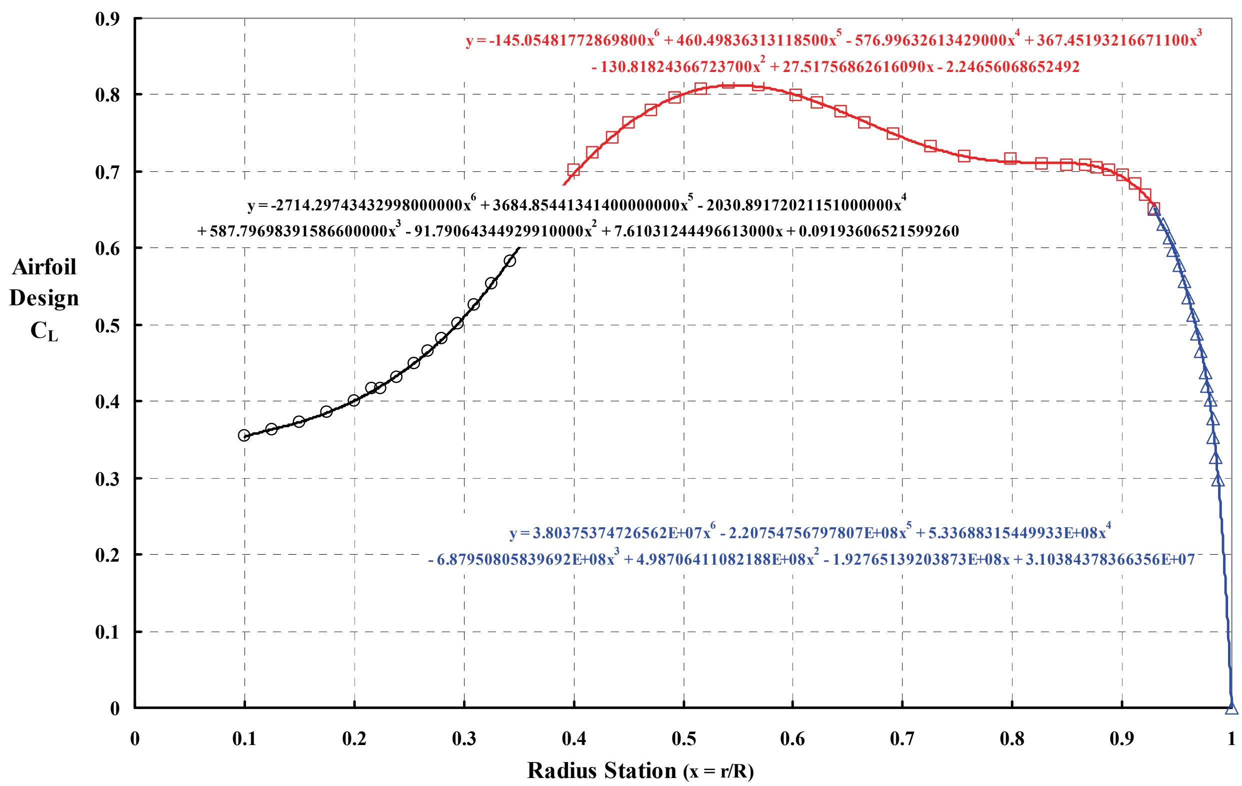

Figure P-5. Canadair Ltd. 240-2C14—airfoil design C_L vs. radius station.

3. Performance Data

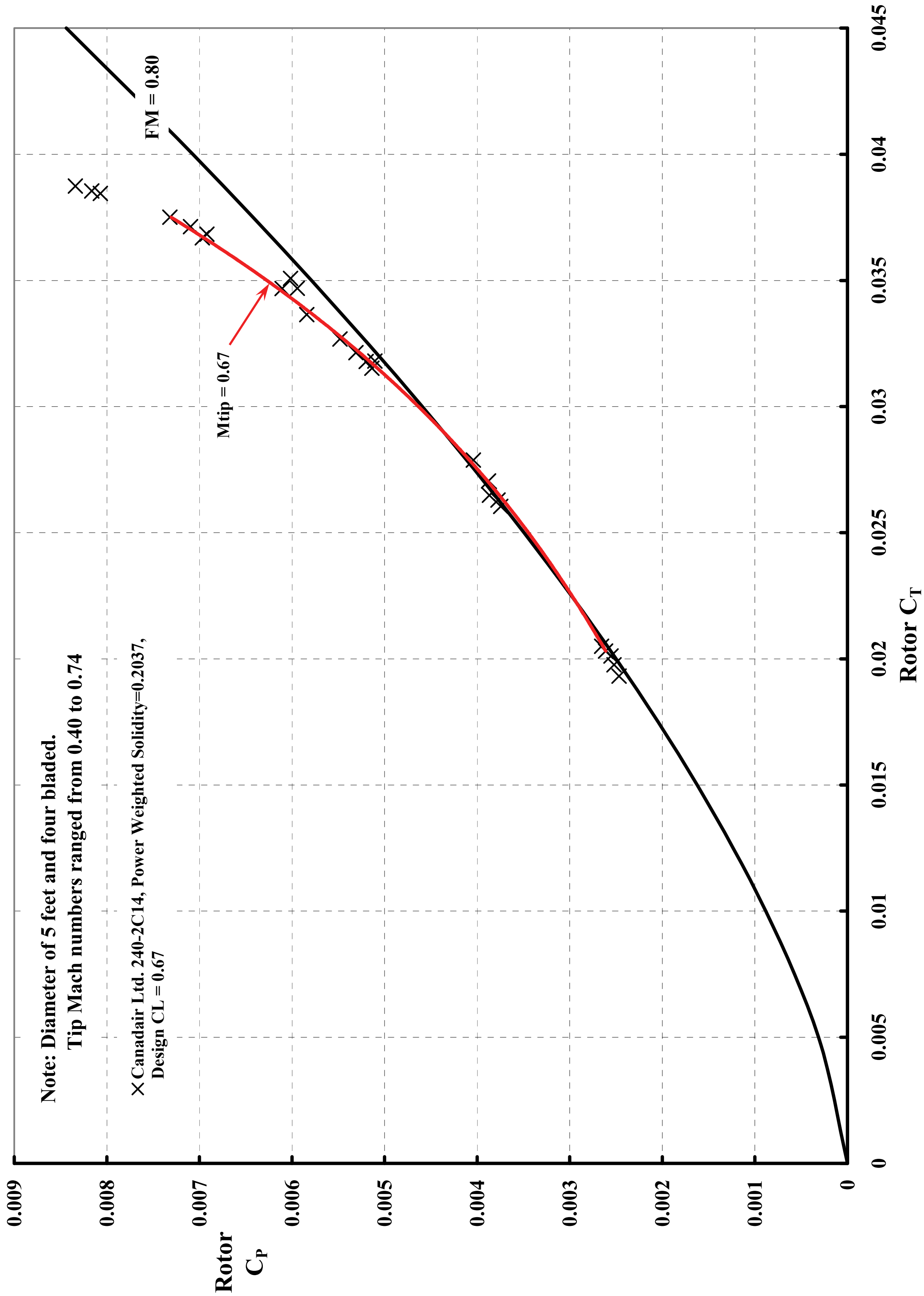

Figure P-6. Canadair Ltd. 240-2C14 test results at Canadair Ltd.—power vs. thrust coefficient.

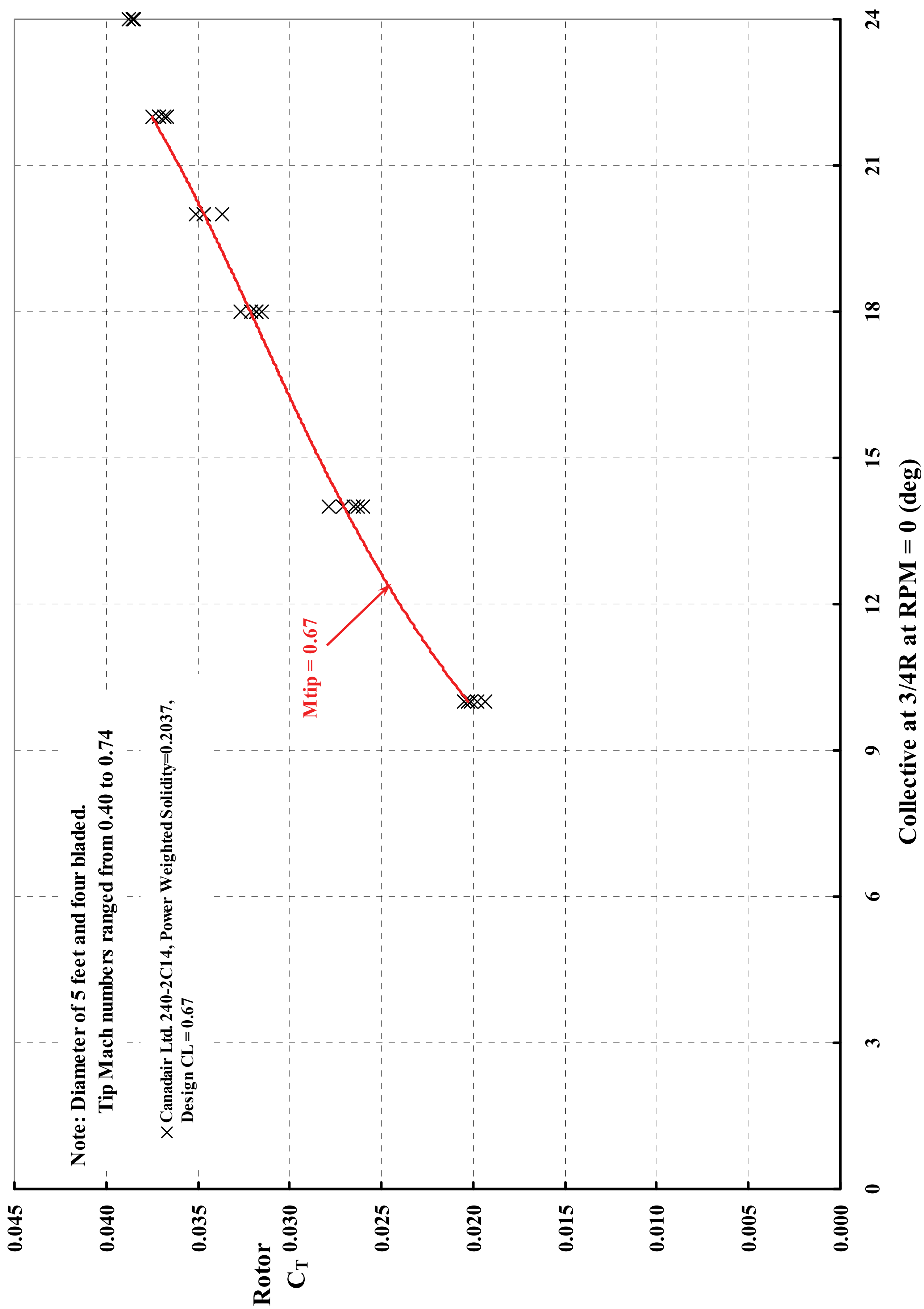

Figure P-7. Canadair Ltd. 240-2C14 test results at Canadair Ltd.—thrust coefficient vs. collective pitch.

Table P-1. Canadair Ltd. 240-2C14 Test Results at Canadair Ltd.

Vtip (fps)	Nominal Mtip	Beta (deg)	CT	CP	Ideal CP	FM	CT/CP	CT/σ_{power}
450	0.40	10.0	0.019312	0.002468	0.001898	0.7690	7.83	0.094799
550	0.49	10.0	0.019764	0.002521	0.001965	0.7792	7.84	0.097015
650	0.58	10.0	0.020112	0.002554	0.002017	0.7896	7.87	0.098725
750	0.67	10.0	0.020306	0.002612	0.002046	0.7834	7.77	0.099675
850	0.74	10.0	0.020499	0.002657	0.002075	0.7811	7.72	0.100625
450	0.40	14.0	0.026485	0.003868	0.003048	0.7879	6.85	0.130008
550	0.49	14.0	0.026046	0.003745	0.002972	0.7937	6.95	0.127855
650	0.58	14.0	0.026291	0.003774	0.003014	0.7988	6.97	0.129058
750	0.67	14.0	0.027053	0.003876	0.003146	0.8116	6.98	0.132794
850	0.74	14.0	0.027878	0.004041	0.003291	0.8146	6.90	0.136847
450	0.40	18.0	0.031800	0.005104	0.004010	0.7856	6.23	0.156098
550	0.49	18.0	0.031516	0.005137	0.003956	0.7701	6.14	0.154705
650	0.58	18.0	0.031787	0.005199	0.004007	0.7708	6.11	0.156035
750	0.67	18.0	0.032135	0.005310	0.004073	0.7672	6.05	0.157744
850	0.74	18.0	0.032677	0.005482	0.004177	0.7619	5.96	0.160404
450	0.40	20.0	0.033645	0.005839	0.004364	0.7473	5.76	0.165154
550	0.49	20.0	0.034690	0.005942	0.004569	0.7689	5.84	0.170283
650	0.58	20.0	0.035077	0.006016	0.004645	0.7722	5.83	0.172183
750	0.67	20.0	0.034677	0.006106	0.004566	0.7478	5.68	0.170220
	0.74							
450	0.40	22.0	0.036831	0.006919	0.004998	0.7224	5.32	0.180795
550	0.49	22.0	0.036689	0.006969	0.004969	0.7131	5.26	0.180098
650	0.58	22.0	0.037128	0.007096	0.005059	0.7129	5.23	0.182251
750	0.67	22.0	0.037502	0.007318	0.005135	0.7018	5.12	0.184088
450	0.40	24.0	0.038444	0.008069	0.005330	0.6605	4.76	0.188711
550	0.49	24.0	0.038547	0.008164	0.005351	0.6555	4.72	0.189217
650	0.58	24.0	0.038741	0.008340	0.005392	0.6465	4.65	0.190167

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