

AD-A159 193

COMPUTER PROGRAM FOR PERFORMANCE PREDICTION OF
TANDEM-ROTOR HELICOPTERS(U) NAVAL POSTGRADUATE SCHOOL
MONTEREY CA D L COTNER JUN 85

1/1

UNCLASSIFIED

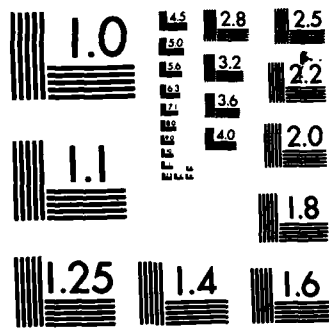
F/G 1/3

NL

END

FILMS

DTAC



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

AD-A159 193

NAVAL POSTGRADUATE SCHOOL
Monterey, California



THESIS

COMPUTER PROGRAM FOR PERFORMANCE
PREDICTION OF TANDEM-ROTOR HELICOPTERS

by

Dave L. Cotner

June 1985

Thesis Advisor:

D. M. Layton

Approved for public release; distribution is unlimited

DTIC
SELECTE
SEP 13 1985
S
D

DTIC FILE COPY

85 9 10 069

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

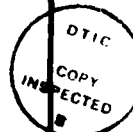
REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
	AD-A159193	
4. TITLE (and Subtitle)	5. TYPE OF REPORT & PERIOD COVERED	
Computer Program for Performance Prediction of Tandem-Rotor Helicopters	Master's Thesis Engineer's Thesis June 1985	
	6. PERFORMING ORG. REPORT NUMBER	
7. AUTHOR(s)	8. CONTRACT OR GRANT NUMBER(s)	
COTNER, Dave L.		
9. PERFORMING ORGANIZATION NAME AND ADDRESS	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS	
Naval Postgraduate School Monterey, California 93943-5100		
11. CONTROLLING OFFICE NAME AND ADDRESS	12. REPORT DATE	
Naval Postgraduate School Monterey, California 93943-5100	June 1985	
	13. NUMBER OF PAGES	
	41	
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)	15. SECURITY CLASS. (of this report)	
	UNCLASSIFIED	
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE	
16. DISTRIBUTION STATEMENT (of this Report)		
Approved for Public Release, Distribution Unlimited.		
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)		
Justification		
By		
Distribution/		
Availability Codes		
Dist Avail and/or Special		
A-1		
18. SUPPLEMENTARY NOTES		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number)		
Helicopter Computer Program Performance Prediction Power Required Tandem-Rotor Preliminary Design		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number)		
A computer program for the HP-41 series calculator is presented which predicts the rotor shaft horsepower required for tandem-rotor helicopters to a given set of helicopter parameters and flight conditions. Three simplified analytical methods of calculating the induced power for tandem-rotor helicopters were explored during the development of the program and their effect on the total shaft horsepower required was compared to actual test data.		

DD FORM 1473

EDITION OF 1 NOV 65 IS OBSOLETE
S/N 0102-LF-014-6601

UNCLASSIFIED

1 SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)



UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

These comparisons as well as size and complexity considerations were used in selecting the best method to be used. The program can be used in preliminary design analysis and as an educational tool where only an estimate of the actual shaft horsepower is required.

S. N 0102- LF- 014- 6601

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE(When Data Entered)

ABSTRACT

A computer program for the HP-41 series calculator is presented which predicts the rotor shaft horsepower required for tandem-rotor helicopters to a given set of helicopter parameters and flight conditions. Three simplified analytical methods of calculating the induced power for tandem-rotor helicopters were explored during the development of the program and their effect on the total shaft horsepower required was compared to actual test data. These comparisons as well as size and complexity considerations were used in selecting the best method to be used. The program can be used in preliminary design analysis and as an educational tool where only an estimate of the actual shaft horsepower is required.

Approved for public release; distribution is unlimited.

**Computer Program for
Performance Prediction of
Tandem-Rotor Helicopters**

by

**Dave L. Cotner
Lieutenant, United States Navy
B.S., Texas A&M University, 1978**

**Submitted in partial fulfillment of the
requirements for the degrees of**

MASTER OF SCIENCE IN AERONAUTICAL ENGINEERING

and

AERONAUTICAL ENGINEER

from the

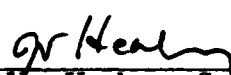
**NAVAL POSTGRADUATE SCHOOL
June 1985**

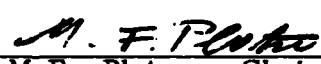
Author:


Dave L. Cotner

Approved by:


D.M. Layton, Thesis Advisor


J.V. Healey, Second Reader


M.F. Platz, Chairman,
Department of Aeronautics


John N. Dyer,
Dean of Science and Engineering

LIST OF FIGURES

2.1	Effective Rotor Disk Area	12
2.2	Tandem-rotor Geometry	13
2.3	Streamtube Mix of Two Rotors	15
2.4	Wake Separation Distance, h_{rr}	17
3.1	Comparison of Methods to Actual Power Required	20
3.2	H-46 SSL Power Required	22
3.3	H-47 SSL Power Required	23
3.4	H-46 at Altitude; Power Required	24

TABLE OF CONTENTS

I.	INTRODUCTION	7
	A. BACKGROUND	7
	B. GOALS	9
II.	APPROACH TO THE PROBLEM	10
	A. GENERAL	10
	B. EQUATIONS	10
III.	SOLUTION AND RESULTS	19
IV.	CONCLUSIONS AND RECOMMENDATIONS	25
	APPENDIX A: NOMENCLATURE	26
	APPENDIX B: HP-41 COMPUTER PROGRAM	28
	LIST OF REFERENCES	38
	BIBLIOGRAPHY	39
	INITIAL DISTRIBUTION LIST	40

some insight into a means of optimizing a design for a specific mission.

Computer programs for the HP-41 series hand-held calculator have been developed at the Naval Postgraduate School for performance predictions of single-rotor helicopters [Ref. 1]. These programs are used for single-rotor helicopter performance predictions in the Helicopter Performance and Preliminary Design Courses that are taught, but only a method of predicting the power required for tandem-rotor helicopters is presented.

A program was desired for tandem-rotor helicopters that would predict the approximate power required, for different helicopter configurations and flight conditions, as an addition to the previously developed programs for single-rotor helicopters. The program could be used in Preliminary design work and as an educational tool to examine how different helicopter configurations affect the power required. This could also be the first step in the addition of tandem-rotor helicopter design into the Helicopter Design Course, which covers single-rotor design only, and would allow for a comparison to be made between single-rotor and tandem-rotor designs to determine the best design to meet a specified mission requirement.

A current program for use in single-rotor and tandem-rotor helicopter sizing and performance is HESCOMP [Ref. 2], however, this program is more suited for detailed design, requiring large amounts of input data for even a simple analysis.

I. INTRODUCTION

A. BACKGROUND

Tandem-Rotor helicopters and single-rotor helicopters are used in both the military and civilian communities. Tandem-Rotor helicopters have both advantages and disadvantages over single-rotor helicopters of the same gross weight and disk loading. Advantages include low shaft horsepower (shp) required to hover and elimination of required tail rotor power. Some disadvantages are higher power required in the minimum power range, decreased service ceiling and climb capability, and increased autorotational rate of descent. These differences in performance are primarily due to rotor-rotor interference, elimination of tail rotor power and a difference in download levels.

Performance prediction of helicopters for use in both the preliminary and Detailed Design process has been the subject of numerous articles and studies. Detailed design normally involves the use of large, detailed, time-consuming and costly computer programs. On the other hand, in Preliminary design work, performance evaluations using simplified analytical techniques based on a combined blade element and momentum theory provide a simple cost-effective means of investigating the influence of important design parameters on performance. The simplified techniques also give details concerning the power required breakdown and thus,

II. APPROACH TO THE PROBLEM

A. GENERAL

The major difference in Total Power required for ta-dem-rotor helicopters is due to the rotor-rotor interference effect, which causes an increase in the induced power required. The methods developed by D.M. Layton [Ref. 3] were the primary source for the equations for determining the total power required. Numerous other publications were also reviewed for alternate equations to determine the induced power and an induced power correction factor. From these, three methods were chosen for a comparison of the total power required to find the closest to actual test data of existing tandem-rotor helicopters.

The H-46 and the H-47 Chinook were chosen as comparison helicopters. The H-46 NATOPS was readily available with hover data for both in and out of ground effect. Additional test data were obtained for both the H-46 and the Chinook from the Boeing Vertol Company.

B. EQUATIONS

The analytical methods for prediction of power required can be simplified by making assumptions to the flow through the rotor disks. Errors in the results are introduced by these assumptions but are insignificant compared to the simplification obtained. The assumptions are listed as follows [Ref. 3: pp. 27-28]:

B. GOALS

The goal of this project was to produce a self-prompting, alpha-numeric computer program for the HP-41 series calculator that determines the shaft horsepower required, for the given parameters and flight conditions, to within 10% of the actual values. This could then be used in the preliminary design process for tandem-rotor helicopters and for parametric studies. The program should be consistent and compatible with the programs of [Ref. 1] using the Standard Data Set with certain exceptions and additions. Instructions, equations and examples should also be provided.

1. Air is a frictionless, incompressible fluid.
2. The rotor acts as a disc with an infinite number of blades.
3. Flow through the disc is steady and uniform.
4. The rotor imparts no rotation to the air as it passes through.
5. Flow above and below the rotor is streamlined and of constant energy, although the energy is different above and below.
6. Energy is added at the rotor in the form of a pressure increase.

The total power required for tandem-rotor helicopters was determined using the same equations for thrust coefficient, tiploss, profile power, parasite power and climb power used for single-rotor helicopters. The three methods used in determining the induced power and induced power correction factor are described below.

The first method was taken from [Ref. 3] and [Ref. 4]. The induced power equation is:

$$P_i = T \cdot v_{ih} \cdot K \cdot K_u \quad (2.1)$$

where

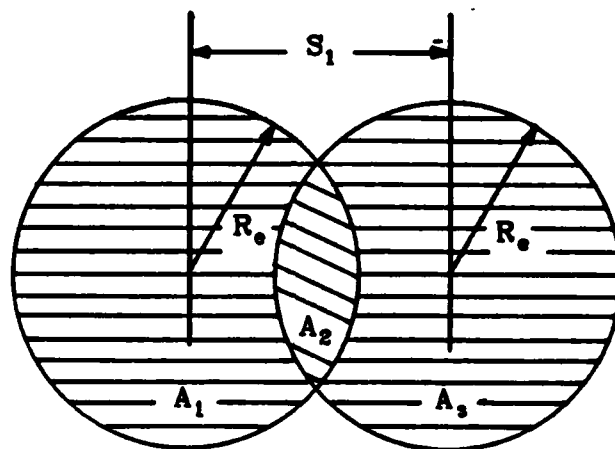
$$v_{ih} = \left(\frac{T}{2\rho A_e} \right)^{1/2} \quad (2.2)$$

The factor K is a hover induced power correction factor due to overlap and is an approximation from numerous tests. Its value is determined as a function of the rotor shaft spacing ratio, S_R , by the equation

$$K = 1.46 - .253 \cdot S_R \quad (2.3)$$

A_e is the effective area and is equal to the projected area of the two rotor disks with the radii reduced by a factor to account for tip losses. The equation for A_e was derived from Figure 2.1 to be

$$A_e = 2R_e^2 \left[\pi - \frac{\pi}{180} \cos^{-1} \left(\frac{S_1}{2R_e} \right) \right] + S_1 \sqrt{R_e^2 - \frac{1}{4}S_1^2} \quad (2.4)$$



$$A_e = A_1 + A_2 + A_3$$

Figure 2.1 Effective Rotor Disk Area.

The forward flight correction factor, K_u , is computed from

$$K_u^4 + \left(\frac{A_r}{A_e} \right)^2 \left(\frac{V_f}{V_{ih}} \right)^2 \cdot K_u^2 = 1 \quad (2.5)$$

which is derived in [Ref. 5] from momentum theory. Solving for

K_u

$$K_u = \left\{ \left[\frac{1}{4} \left(\frac{A_r}{A_e} \right)^2 \left(\frac{V_f}{V_{ih}} \right)^2 + 1 \right]^{1/2} - \frac{1}{2} \left(\frac{A_r}{A_e} \right)^2 \left(\frac{V_f}{V_{ih}} \right)^2 \right\}^{1/2} \quad (2.6)$$

The angle that the forward rotor wake is skewed, γ , before it strikes the aft rotor is calculated by

$$\gamma = \tan^{-1} \frac{1.5v_{ifr}}{V_f} = \frac{1.5T_{fr}}{2\rho A_{fr} V_f^2} \quad (2.10)$$

and uses the approximation

$$v_{ifr} = \frac{T}{2\rho A_{fr} V_f} \quad (2.11)$$

which is valid at velocities where $V_f/V_{ih} > 2$. The induced power correction factor, K_u , is multiplied by the induced power for a single-rotor helicopter with the same gross weight and disk loading, including tip losses, to give the induced power equation

$$P_i = K_u \cdot P_{i_{single}} \quad (2.12)$$

$$P_i = K_u \cdot T \cdot v_{ih} \left\{ \left[\frac{1}{4} \left(\frac{V_f}{v_{ih}} \right)^4 + 1 \right]^{1/2} - \frac{1}{2} \left(\frac{V_f}{v_{ih}} \right)^2 \right\}^{1/2} \quad (2.13)$$

where

$$v_{ih} = \left(\frac{T}{4\rho\pi R^2} \right)^{1/2} \quad (2.14)$$

The third method is actually two in that the correction factor was determined in two ways. The first, K_{indo} , is developed theoretically in [Ref. 7] and is based on momentum theory by assuming the downwash of the forward rotor mixing with the rear rotor has reached its downstream value of $2v_{ifr}$.

$$k_{indo} = 2 \left[\frac{1}{4} + \left(\frac{\pi R^2}{4} \right) A_{refree} + A_{remix} \right] \quad (2.15)$$

The vertical area A_v is shown in Figure 2.2 and is equal to

$$A_v = \pi R^2 + 2R \cdot g \quad (2.7)$$

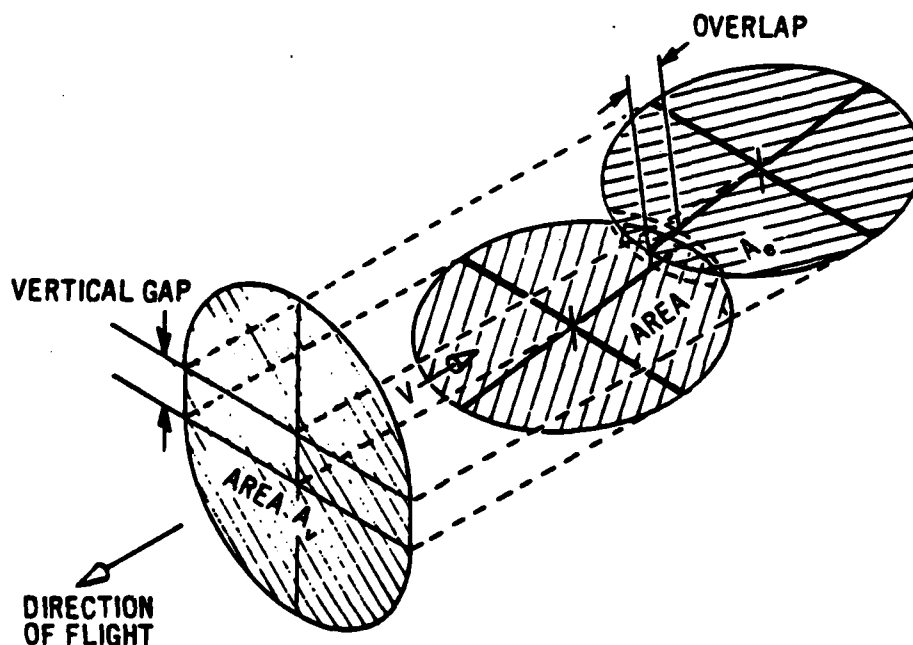


Figure 2.2 Tandem-rotor Geometry.

The second method uses the correction factor K_u derived in [Ref. 6] and presented in [Ref. 3] and [Ref. 4].

$$K_u = 1 + \frac{d_f}{2} \quad (2.8)$$

The factor d_f is the amount of forward rotor downwash velocity that is added to the rear rotor downwash and is equal to

$$d_f = \frac{\sqrt{1 + S_R^2 + S_R \cos \gamma}}{\sqrt{1 + S_R^2(1 + S_R^2 \sin^2 \gamma)}} \quad (2.9)$$

A curve fit to this data provided the following equation for K_{ind} .

$$K_{ind} = \frac{2.08 - 5.5h_{rr} + 69.9h_{rr}^2 + 4.8h_{rr}^3}{1 - 2.93h_{rr} + 34.14h_{rr}^2 + 21.5h_{rr}^3} \quad (2.19)$$

The value of the parameter h_{rr}/R used for both correction factors was determined from the equations developed in [Ref. 9], modified slightly. These equations are listed below and their relationships are shown in Figure 2.4. The helicopter pitch attitude, θ_t , was assumed to be zero in this project.

$$\frac{h_{rr}}{R} = - \frac{\sqrt{g^2 + S_1^2}}{R} \sin \gamma \quad (2.20)$$

$$\gamma = \theta_t - \varepsilon - \gamma_o \quad (2.21)$$

$$\gamma_o = \tan^{-1} \left(\frac{g}{S_1} \right) \quad (2.22)$$

$$\varepsilon = \tan^{-1} \left(\frac{K_d v_{ifr}}{V_t} \right) \quad (2.23)$$

$$v_{ifr} = v_{ih} \left\{ \left[\frac{1}{4} \left(\frac{V_t}{v_{ih}} \right)^4 + 1 \right]^{1/2} - \frac{1}{2} \left(\frac{V_t}{v_{ih}} \right)^2 \right\}^{1/2} \quad (2.24)$$

$$v_{ih} = \left(\frac{T}{4\rho\pi R^2} \right)^{1/2} \quad (2.25)$$

$$K_d = \frac{.043}{.043 + \mu} \quad (2.26)$$

The areas derived from Figure 2.3 in terms of the elevation of the rear rotor hub above the centerline of the forward rotor streamtube, h_{rr} , are

$$A_{re mix} = \left(\frac{\pi}{90}\right) R^2 \cos^{-1}\left(\frac{h_{rr}}{2R}\right) - h_{rr} \sqrt{R^2 - \frac{1}{4} h_{rr}^2} \quad (2.16)$$

$$A_{refree} = \pi R^2 - A_{re mix} \quad (2.17)$$

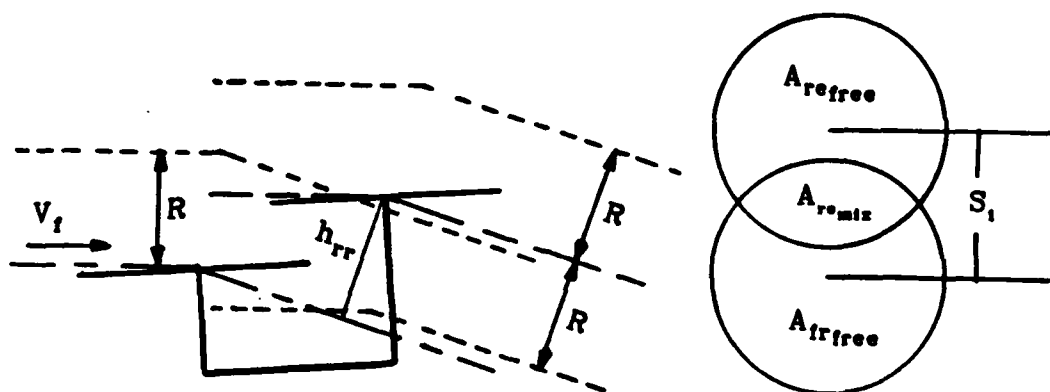


Figure 2.3 Streamtube Mix of Two Rotors.

Substituting into equation 2.15 and including tip losses

$$K_{indo} = \left[1 + \left(\frac{1}{90}\right) \cos^{-1}\left(\frac{h_{rr}}{2R}\right) - \left(\frac{h_{rr}}{\pi R}\right) \sqrt{1 - \frac{1}{4} \left(\frac{h_{rr}}{R}\right)^2} \right] \cdot \frac{1}{B} \quad (2.18)$$

The second, K_{ind} , was determined empirically from wind tunnel data given in [Ref. 9: Figure 5-13] where the correction factor K_{ind} is plotted versus the rotor wake separation ratio h_{rr}/R .

In order that the comparisons of power predicted by each of these equations could be made more quickly, for a number of different flight conditions, the equations were programmed on the IBM 3033.

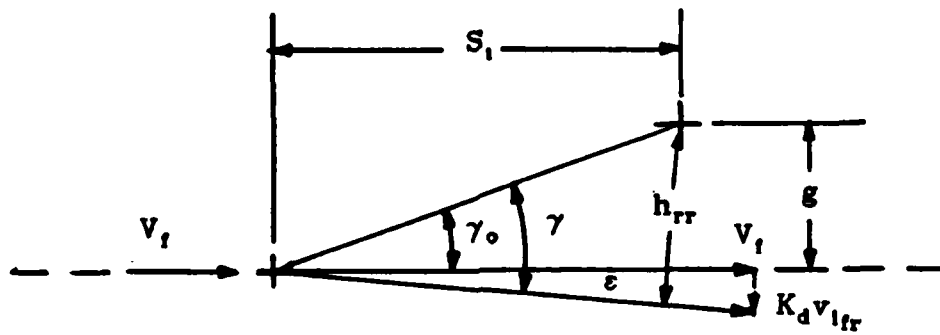


Figure 2.4 Wake Separation Distance, h_{rr} .

The induced power correction factors were multiplied by the ideal induced power of one rotor producing one half T to give the equations

$$P_i = 2P_{id} \cdot K_{indo} \quad (2.27)$$

$$P_i = 2P_{id} \cdot K_{ind} \quad (2.28)$$

P_{id} was calculated by

$$P_{id} = \frac{1}{2} T \cdot v_{ih} \quad (2.29)$$

where v_{ih} is the same as v_{ifr} in equation 2.24

The induced power correction factor due to Ground Effect for tandem-rotor helicopters is the same as for single-rotor helicopters. The value for a given wheel height is normally larger for the tandem-rotor helicopter because the aft rotor is normally higher than the main rotor for a single-rotor helicopter.

H-46 POWER REQUIRED

W=21,000 LBS STANDARD SEA LEVEL

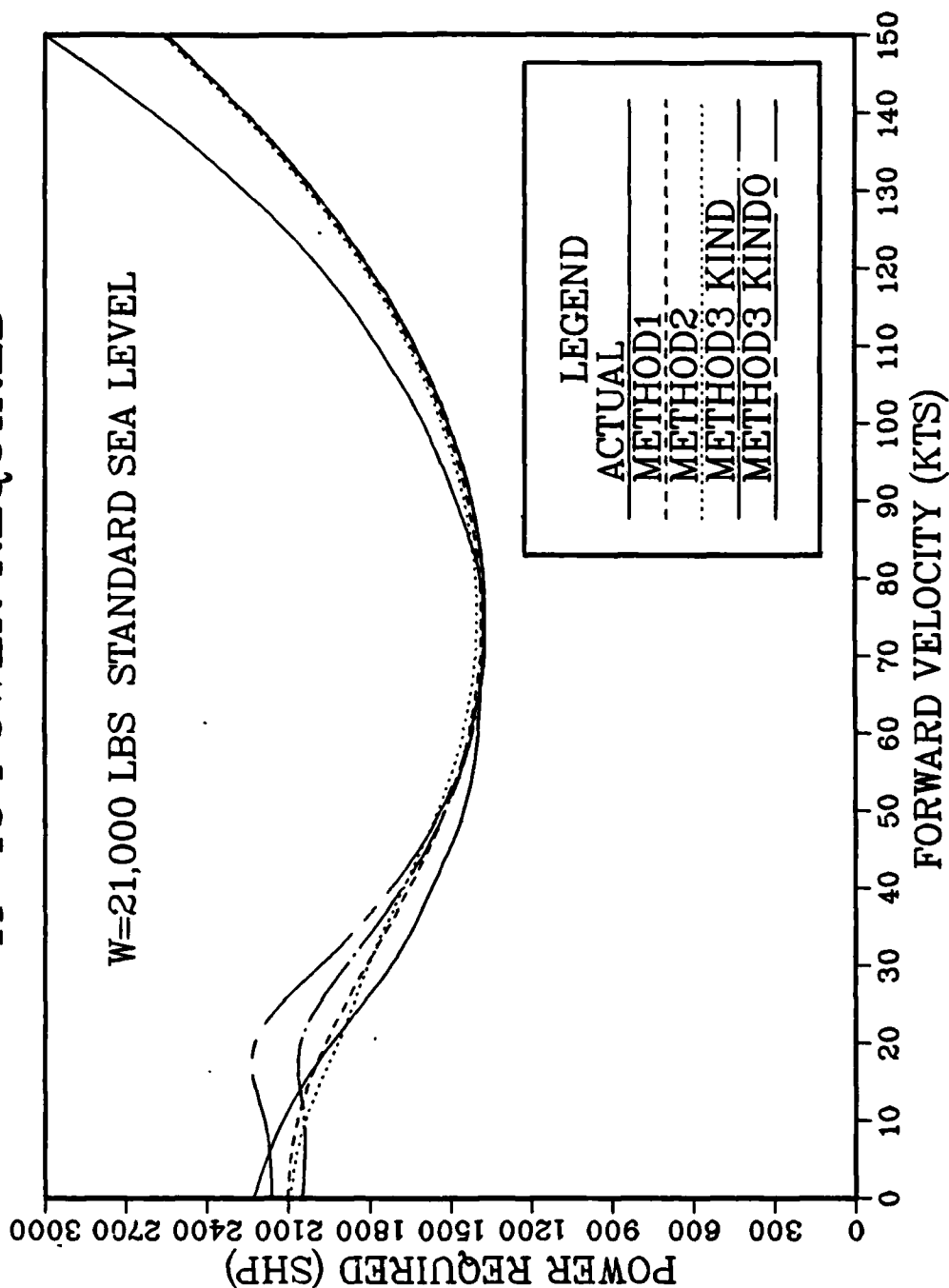


Figure 3.1 Comparison of Methods to Actual Power Required.

III. SOLUTION AND RESULTS

The actual power required data was entered into the IBM 3033 program and the percentage error of each of the methods was calculated. The three methods gave results within a few percent of each other for most weights and flight conditions tested. These results are shown in Figure 3.1 for the H-46 at a weight of 21,000 lbs and standard sea level (ssl) conditions.

The first method was used for both hover and forward flight calculations whereas the second and third methods were derived for forward flight use. The second method gave closest results at most velocities above the minimum power velocities but the first method's results were normally within 1% of these values. The third method sometimes gave the closest results but no trends could be established for either K_{ind} or K_{indo} correction factors.

To get results that are the closest possible using these methods, a combination of methods should be used. This would require a large and complex program since the switching points between methods would be weight and altitude dependent.

Considering all the above information, the first method was selected for use in the HP-41 program. This allows one method to be used from hover to V_{max} and at all weights and flight conditions while minimizing the size and complexity of the program and still meeting the desired goals. The HP-41 program developed is a self-prompting, alpha-numeric computer program that determines the

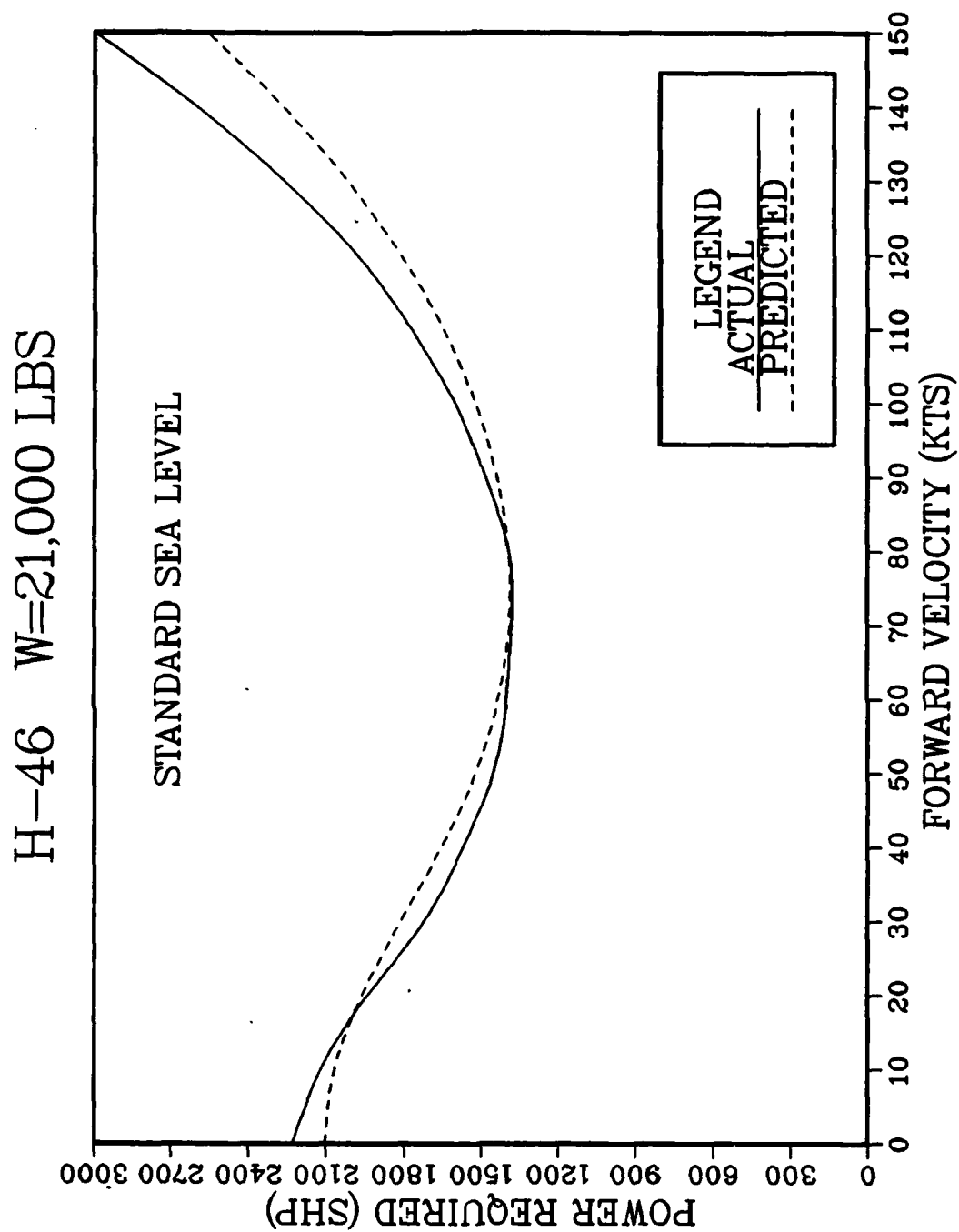


Figure 3.2 H-46 SSL Power Required.

steady state power requirements for tandem-rotor helicopters. Basic geometric and flight parameters are inputs to the program and the total rotor shaft horsepower required is the output. Appendix B is the program documentation which is presented in the same format as the programs of [Ref. 1]. The documentation includes an introduction to the program, additional programs required, the equations used, a list of the standard storage registers utilized with a separate list of non-standard and additional storage registers, a detailed step-by-step example problem and a complete program listing.

Differences in the power required predicted by the HP-41 program and actual test data can be seen in Figures 3.2, 3.3 and 3.4. Figures 3.2 and 3.3 are plots of the H-46 and H-47 at normal operating weights and standard sea level conditions. Figure 3.4 shows the H-46 at maximum gross weight and an altitude of 4000 ft and 95 degrees Fahrenheit. Compressibility and blade stall effects at high velocities and altitudes result in additional power required. These high speed effects were not taken into account in the program and with the exception of these high velocities and altitudes, the predicted power required was within the desired 10% of the actual values for all weights and flight conditions tested.

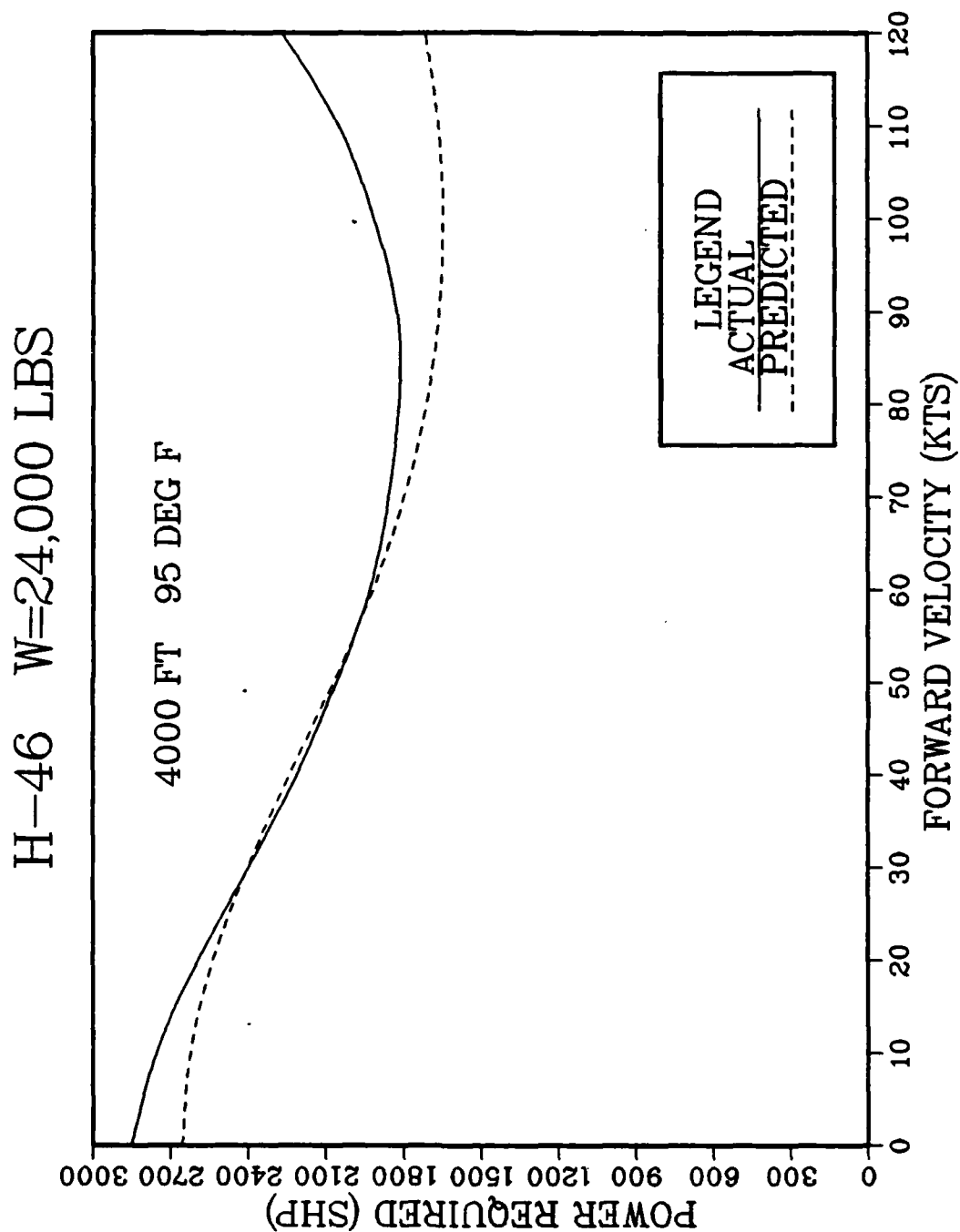


Figure 3.4 H-46 at Altitude: Power Required.

H-47 W=44,000 LBS

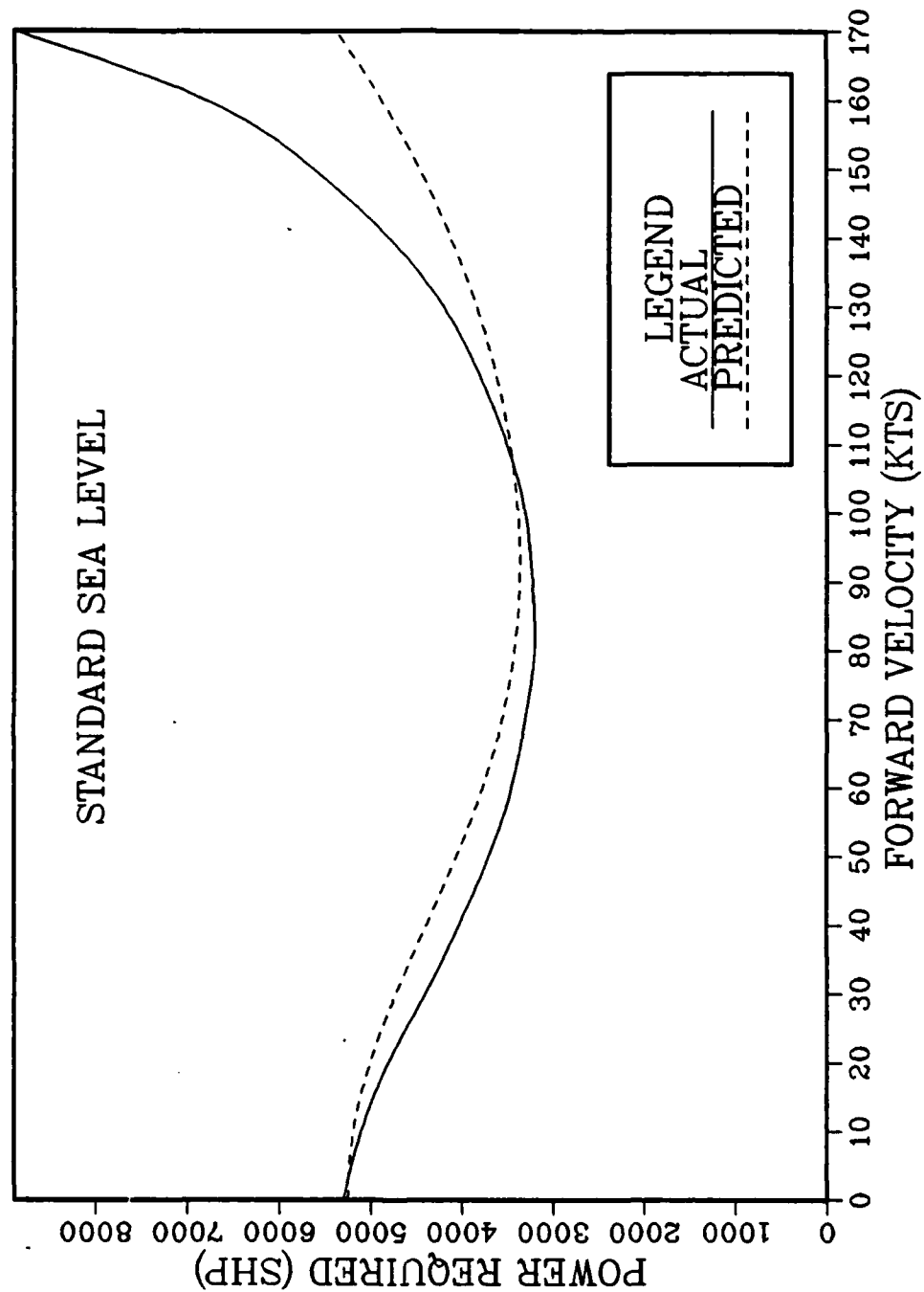


Figure 3.3 H-47 SSL Power Required.

APPENDIX A
NOMENCLATURE

TERM	DEFINITION	UNITS
A_e	- effective rotor disc area of tandem rotors	ft ²
A_{fr}	- rotor disc area of forward rotor	ft ²
A_{refree}	- area of the nonmixed part of the rear-rotor airstream	ft ²
A_{remix}	- area where the two streamtubes mix together	ft ²
A_v	- vertical area equal to single rotor plus vertical gap area	ft ²
d_f	- induced power interference parameter	dimensionless
g	- vertical gap between rotor hubs	ft
h_{rr}	- elevation of rear rotor hub above the centerline of the forward rotor streamtube, or, the rotor wake separation distance	ft
K	- hover induced power correction factor due to overlap	dimensionless
K_d	- local downwash velocity correction factor	dimensionless
K_{ind}	- tandem-rotor induced power correction factor	dimensionless
K_{indo}	- tandem-rotor induced power correction factor	dimensionless
K_u	- forward flight induced power correction factor	dimensionless
OGE	- out-of-ground effect	

IV. CONCLUSIONS AND RECOMMENDATIONS

Three methods of calculating the induced power required for tandem-rotor helicopters were used to predict the total power required for various weights and flight conditions. These values were then compared to the actual test data and a method was selected for use in an HP-41 program. A HP-41 program was then developed that predicts the rotor shaft horsepower required within 10% of the actual values for given helicopter parameters and flight conditions, except where high speed effects are significant. The documentation and program are consistent with the existing programs of [Ref. 1] developed for single-rotor helicopters and it uses the standard data set with some exceptions and additions. The program gives a rough estimate of the actual power required and its main use is as an educational tool.

A more exact and detailed analysis of any design should be done with a larger main frame type computer program, such as HESCOMP.

The HP-41 High Speed Program [Ref. 1: pp. 35-40] computes the additional power required for single-rotor helicopters due to blade stall and compressibility. This program could be modified to include tandem-rotor helicopters. With the addition of high speed effects, the total power required should be recomputed using the three methods and compared to the actual data. Additional test data for other tandem-rotor helicopters should also be obtained for further comparisons of actual and predicted values.

APPENDIX B

HP-41 COMPUTER PROGRAM

TANPWR

Tandem-Rotor Helicopter Power Required

Introduction: This program determines the steady state power requirements for a tandem-rotor helicopter. Basic geometric and flight parameters of the helicopter are inputs to the program and the total rotor shaft horsepower required is the output. Other results can be viewed by recalling the appropriate storage registers. High speed effects are not included in this program. The Standard Data Set is utilized with the tandem-rotor parameters using the registers for tail-rotor parameters. These non-standard registers and the additional storage registers are listed. The HP-41 should be in degrees mode with size 060.

Additional Programs Required: None

Equations:

PGM

$$h/D = (\text{WHEEL HT} + \text{RTR HT})/2R$$
$$\{(h/D) - 1.55\} < 0 ? (\text{In Ground Effect})$$

P_i	- total tandem-rotor induced power	ft-lb/sec
P_{id}	- ideal induced power of one rotor producing one half T	ft-lb/sec
$P_{i, \text{single}}$	- induced power of a single-rotor helicopter with the same gross weight and disc loading	ft-lb/sec
R	- rotor radius	ft
R_e	- effective rotor radius	ft
S_1	- distance between rotor shafts	ft
S_R	- ratio of the distance between rotor shafts and rotor radius	dimensionless
T	- total thrust	lb
T_{fr}	- thrust of forward rotor	lb
V_f	- forward velocity, or, free stream velocity	ft/sec
V_{if}	- rotor-induced velocity in forward flight OGE	ft/sec
V_{ifr}	- rotor-induced velocity of forward rotor	ft/sec
V_{ih}	- tandem-rotor induced velocity in hover OGE	ft/sec
ρ	- density of air	lb sec ² /ft ⁴
γ	- forward rotor wake skew angle	radians
γ	- forward rotor wake separation angle	degrees
γ_o	- aft rotor hub elevation angle	degrees
ϵ	- forward rotor downwash angle	degrees
μ	- rotor advance ratio	dimensionless
θ_i	- fuselage pitch attitude	degrees

VI

$$v_i = (T/2\rho A_e)^{1/2}$$

KU

$$K_u = \left\{ \left[\frac{1}{4} \left(\frac{A_y}{A_e} \right)^4 \left(\frac{V_f}{v_{ib}} \right)^4 + 1 \right]^{1/2} - \frac{1}{2} \left(\frac{A_y}{A_e} \right)^2 \left(\frac{V_f}{v_{ib}} \right)^2 \right\}^{1/2}$$

PI

$$P_i = (P_i/P_{i_{0GE}})(Tv_i/550) \cdot K \cdot K_u$$

PO

$$P_o = (C_{d_o} \cdot b \cdot c \cdot R \cdot V_T^3 \rho / 2200)(1 + 4.3\mu^2)$$

PP

$$P_p = V_f^3 F_f \rho / 1100$$

PC

$$P_c = (T \cdot V_v + \rho F_f V_v^3) / 1100$$

PT

$$P_T = P_i + P_o + P_p + P_c = P_T < AC >$$

GE

$$P_i/P_{i_{\text{logE}}} = .5147 + 1.3432(h/D) - 1.4569(h/D)^2 \\ + .7080(h/D)^3 - .1276(h/D)^4$$

VT

$$V_T = RV \cdot R$$

ICAO

$$P_{\text{alt}}/P_{\text{sl}} = (1 - 6.87535 \times 10^{-6} \cdot H)^{5.2561} = \delta$$

$$\rho_{\text{alt}}/\rho_{\text{sl}} = (1 - 6.87535 \times 10^{-6} \cdot H)^{4.2561} = \sigma$$

TEMP

$$\theta = [\text{Temp} (^{\circ}\text{F}) + 459.68]/518.68$$

$$\sigma = \delta/\theta$$

RHO

$$\rho_{\text{alt}} = \sigma \cdot .0023769$$

T

$$T = 1.055 \cdot W$$

CT

$$C_T = T/\rho \pi R^2 V_T^2$$

TL

$$B = 1 - (2C_T)^{1/2}/b$$

AREA

$$S_R = S_i/R$$

$$R_e = B \cdot R$$

$$A_e = 2R_e^2 \left[\pi - \frac{\pi}{180} \cos^{-1} \left(\frac{S_i}{2R_e} \right) \right] + S_i \sqrt{R_e^2 - \frac{1}{4}S_i^2}$$

K

$$K = 1.46 - .253 \cdot S_R$$

AV

$$A_v = \pi R^2 - 2R \cdot g$$

TANPWR

Standard Storage Registers Utilized:

Storage Register	Stored Quantity
00	R - main rotor radius (ft)
01	c - main rotor equivalent chord (ft)
02	RV - main rotor rotational velocity (ft/sec)
03	C_{d_0} - main rotor profile drag coefficient
04	b - number of main rotor blades
11	W - helicopter weight (lbs)
12	F_f - forward equivalent flat plate area (sq ft)
13	F_v - vertical equivalent flat plate area (sq ft)
14	RTR HT - main rotor height above wheels (ft)
18	V_f - forward velocity of aircraft (ft/sec)
19	V_v - vertical velocity of aircraft (ft/sec)
20	PA/DA - pressure or density altitude (ft)
21	TEMP<F> - temp deg F converted and stored in deg R
22	ρ - ambient density (slugs/cubic ft)
25	WHEEL HT - height of wheels above the ground (ft)
26	h/D - ratio of rotor height to diameter
27	V_T - main rotor tip velocity (ft/sec)
29	C_T - main rotor coefficient of thrust
31	v_i - main rotor induced velocity (ft/sec)
33	B - main rotor tip loss factor
35	P_i - main rotor induced power (SHP)

36	P_o - main rotor profile power (SHP)
37	P_p - main rotor parasite power (SHP)
38	P_c - main rotor climb power (SHP)
39	$P_T<MR>$ - main rotor total power (SHP)
44	$P_T<AC>$ - aircraft total power required (SHP)
45	$P_i/P_{i_{0GE}}$ - ground effect induced power ratio

TANPWR

			SIZE 060
INSTRUCTIONS	INPUT	FUNCTION	DISPLAY
1. Initialize the program		XEQ TANPWR	NEED DATA?
2. Answer 1 for yes, 0 for no	1	R/S	RV=?
3. Input rotor rotational velocity (rad/sec)	28	R/S	b=?
4. Input number of blades per rotor	3	R/S	c=?
5. Input rotor chord (ft)	1.6	R/S	CdO=?
6. Input rotor drag coefficient	.009	R/S	R=?
7. Input rotor radius (ft)	26	R/S	S1=?
8. Input rotor shaft spacing (ft)	33	R/S	G=?
9. Input vertical gap (ft)	4	R/S	FF=?
10. Input forward flat plate area (sq ft)	44	R/S	FV=?
11. Input vertical flat plate area (sq ft)	100	R/S	RTR HT=?
12. Input rotor height above wheels (ft)	16	R/S	W=?
13. Input weight (lbs)	20000	R/S	WHEEL HT=?
14. Input wheel height above ground (ft)	100	R/S	PA?
15. Do you know pressure altitude?			
a. Answer 1 for yes	1	R/S	PA=?
Input pressure altitude (ft)	0	R/S	TEMP<F>=?

TANPWR

Non-standard and Additional Storage Registers:

Storage Register	Stored Quantity
05	S_1 - rotor shaft spacing (ft)
06	S_R - rotor shaft spacing ratio
07	g - vertical gap between rotors (ft)
15	solidity
23	A_e - effective rotor area (sq ft)
24	A_v - vertical gap area (sq ft)
30	T - rotor thrust (lbs force)
41	R_e - effective blade radius (ft)
42	K - tandem-rotor interference factor due to overlap
43	K_u - forward flight induced power correction factor
40	σ - density ratio
47	δ - pressure ratio
50	scratch
51	scratch

TANPWR

01*LBL "TANPWR"	46 "RTR HT=?"	91 *
02 FIX 2	47 PROMPT	92 +
03 CF 04	48 STO 14	93 .5147
04 CF 05	49*LBL "PGM"	94 +
05 "NEED DATA?"	50 RCL 11	95 STO 45
06 PROMPT	51 "W=?"	96*LBL "VT"
07 X=0?	52 PROMPT	97 RCL 00
08 GTD "PGM"	53 STO 11	98 RCL 02
09 RCL 02	54 RCL 25	99 *
10 "RV=?"	55 "WHEEL HT=?"	100 STO 27
11 PROMPT	56 PROMPT	101*LBL "DA"
12 STO 02	57 STO 25	102 "PA?"
13 RCL 04	58 RCL 14	103 PROMPT
14 "b=?"	59 +	104 X=0?
15 PROMPT	60 RCL 00	105 GTD "DNA"
16 STO 04	61 /	106 SF 05
17 RCL 01	62 2	107 "PA=?"
18 "c=?"	63 /	108 PROMPT
19 PROMPT	64 STO 26	109 STO 20
20 STO 01	65 1.55	110*LBL "ICAO"
21 RCL 03	66 -	111 6.875 E-06
22 "Cd0=?"	67 X<0?	112 *
23 PROMPT	68 GTD "GE"	113 CHS
24 STO 03	69 1	114 1
25 RCL 00	70 STO 45	115 +
26 "R=?"	71 GTD "VT"	116 FS? 05
27 PROMPT	72*LBL "GE"	117 5.2561
28 STO 00	73 RCL 26	118 FS? 04
29 RCL 05	74 1.3432	119 4.2561
30 "S1=?"	75 *	120 Y↑X
31 PROMPT	76 RCL 26	121 FS? 04
32 STO 05	77 X↑2	122 GTD "RHO"
33 RCL 07	78 -1.4569	123 FS? 05
34 "G=?"	79 *	124 STO 47
35 PROMPT	80 +	125*LBL "TEMP"
36 STO 07	81 RCL 26	126 "TEMP(F)=?"
37 RCL 12	82 3	127 PROMPT
38 "FF=?"	83 Y↑X	128 459.68
39 PROMPT	84 .7880	129 +
40 STO 12	85 *	130 STO 21
41 RCL 13	86 +	131 518.68
42 "FV=?"	87 RCL 26	132 /
43 PROMPT	88 4	133 1/X
44 STO 13	89 Y↑X	134 RCL 47
45 RCL 14	90 -.1276	135 *

	Input temperature in degrees F	59	R/S	VF=?<KTS>
or	b. Answer 0 for no	0	R/S	DA=?
	Input density altitude (ft)	0	R/S	VF=?<KTS>
16.	Input forward velocity (kts)	100	R/S	VV=?<FPM>
17.	Input vertical velocity (ft/min)	0	R/S	
18.	Output total aircraft power (shp)			PT<AC>=1524.6

TANPWR

271 RCL 23	316 RCL 00	361 *
272 /	317 X12	362 RCL 19
273 SQR	318 *	363 RCL 30
274 STO 31	319 PI	364 *
275•LBL "KII"	320 *	365 +
276 RCL 18	321 RCL 27	366 1100
277 RCL 31	322 3	367 /
278 /	323 Y+X	368 STO 38
279 RCL 24	324 *	369•LBL "PT"
280 *	325 RCL 03	370 RCL 35
281 RCL 23	326 *	371 +
282 /	327 2200	372 RCL 36
283 X12	328 /	373 +
284 2	329 RCL 22	374 RCL 37
285 /	330 *	375 +
286 STO 50	331 STO 51	376 STO 39
287 X12	332 RCL 18	377 STO 44
288 1	333 RCL 27	378 "PT(AC)"=
289 +	334 /	379 ARCL X
290 SQR	335 X12	380 RVIEW
291 RCL 50	336 4.3	381 STOP
292 -	337 *	382 "HI SPD?"
293 SQR	338 1	383 PROMPT
294 STO 43	339 +	384 X=0?
295•LBL "PI"	340 RCL 51	385 GTO "VF"
296 RCL 31	341 *	386 SF 03
297 *	342 STO 36	387 GTO "HSE"
298 RCL 45	343•LBL "PP"	388 END
299 *	344 RCL 18	
300 RCL 30	345 3	
301 *	346 Y+X	
302 RCL 42	347 RCL 12	
303 *	348 *	
304 550	349 RCL 22	
305 /	350 *	
306 STO 35	351 1100	
307•LBL "PO"	352 /	
308 RCL 04	353 STO 37	
309 RCL 01	354•LBL "PC"	
310 *	355 RCL 19	
311 PI	356 3	
312 /	357 Y+X	
313 RCL 00	358 RCL 13	
314 /	359 *	
315 STO 15	360 RCL 22	

TANPWR

136 STO "PHQ"	181 *	226 CHS
137*LBL "DNA"	182 STO 30	227 PI
138 RCL 20	183*LBL "CT"	228 +
139 "DA=?"	184 RCL 30	229 2
140 PROMPT	185 PI	230 *
141 STO 20	186 /	231 RCL 41
142 SF 04	187 RCL 00	232 X12
143 STO "ICAO"	188 X12	233 *
144*LBL "PHQ"	189 /	234 RCL 41
145 STO 40	190 RCL 22	235 X12
146 .0023769	191 /	236 RCL 05
147 *	192 RCL 27	237 X12
148 STO 22	193 X12	238 4
149 FS? 05	194 /	239 /
150 STO "VF"	195 STO 29	240 -
151 RCL 20	196*LBL "TL"	241 SORT
152 6.875 E-6	197 RCL 29	242 RCL 05
153 *	198 2	243 *
154 CHS	199 *	244 +
155 1	200 SORT	245 STO 23
156 +	201 RCL 04	246*LBL "K"
157 518.6	202 /	247 RCL 06
158 *	203 CHS	248 -.253
159 STO 21	204 1	249 *
160 518.6	205 +	250 1.46
161 /	206 STO 33	251 +
162 RCL 40	207*LBL "AREA"	252 STO 42
163 *	208 RCL 05	253*LBL "AV"
164 STO 47	209 RCL 00	254 RCL 00
165*LBL "VF"	210 /	255 X12
166 "VF=?KTS?"	211 STO 06	256 PI
167 PROMPT	212 RCL 00	257 *
168 1.68889	213 RCL 33	258 RCL 00
169 *	214 *	259 RCL 07
170 STO 18	215 STO 41	260 *
171 "VV=?FPM?"	216 RCL 05	261 2
172 PROMPT	217 RCL 41	262 *
173 60	218 /	263 +
174 /	219 2	264 STO 24
175 STO 19	220 /	265*LBL "VI"
176 CF 05	221 ACOS	266 RCL 30
177 CF 04	222 PI	267 2
178*LBL "T"	223 *	268 /
179 RCL 11	224 190	269 RCL 22
180 1.055	225 /	270 /

BIBLIOGRAPHY

Royal Aircraft Establishment Library Translation No 1160, Some Considerations on Performance Estimation of Helicopters, by Kunihisa Wada, April 1966.

U.S. Army Materiel System Analysis Agency Technical Report 78, Simplified Aircraft Performance Methods: Power Required for Single and Tandem Rotor Helicopters in Hover and Forward Flight, by C.R. Dietz, August 1973.

LIST OF REFERENCES

1. Layton, Donald M., Helicopter Performance Computer Programs for HP-41 Hand-held Computer, Naval Postgraduate School, Monterey, California.
2. Davis, S.J., Rosenstein, H. and Stanzione, K.A., User's Manual for HESCOMP, Boeing Vertol Co., 1979
3. Layton, Donald M., Helicopter Performance, Matrix Publisher Inc., 1984.
4. U.S. Army Material Command, Engineering Design Handbook, Helicopter Engineering (AMCP 706-201), HQ. U.S. Army Material Command, 1974.
5. Hiller Helicopter Report No. 473.6, Transport Helicopter Design Analysis Methods, November 1955.
6. McCormick, Barnes W. Jr., Aerodynamics of V/STOL Flight, pp. 148-153, Academic Press Inc., 1967.
7. NASA Contractor Report 3082, Rotary-Wing Aerodynamics, Volume I - Basic Theories of Rotor Aerodynamics, by W.Z. Stepniewski, pp. 83-87, January 1979.
8. NASA Contractor Report 3083, Rotary-Wing Aerodynamics, Volume II - Performance Prediction of Helicopters, by C.N. Keys, January 1979.
9. Ibid., pp.182-205.

INITIAL DISTRIBUTION LIST

	No.	Copies
1. Defense Technical Information Center Cameron Station Alexandria, Virginia 22304-6145	2	
2. Library, Code 0142 Naval Postgraduate School Monterey, California 93943-5100	2	
3. Department Chairman, Code 67 Department of Aeronautics Naval Postgraduate School Monterey, California 93943-5100	1	
4. LT Dave L. Cotner, USN c/o Janna Brannan 101 Mossridge Universal City, Tx 78148	3	
5. Professor Donald M. Layton Code 67Ln Department of Aeronautics Naval Postgraduate School Monterey, California 93943-5100	4	

END

FILMED

11-85

DTIC