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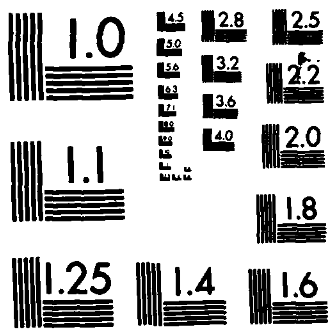

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Monterey, California

THESIS

COMPUTER PROGRAM FOR PERFORMANCE
PREDICTION OF TANDEM-ROTOR HELICOPTERS

by

Dave L. Cotner

June 1985

Thesis Advisor: D. M. Layton

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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.

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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.

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Computer Program for Performance Prediction of Tandem-Rotor Helicopters

by

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Submitted in partial fulfillment of the requirements for the degrees of

MASTER OF SCIENCE IN AERONAUTICAL ENGINEERING

and

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June 1985

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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 tandem-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:

$$P_i = T \cdot v_{ih} \cdot K \cdot K_u \tag{2.1}$$

where

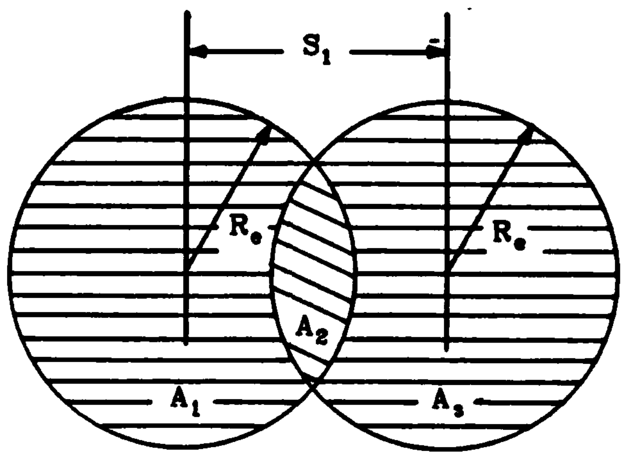
$$v_{ih} = \left(\frac{T}{2\rho A_e}\right)^{1/2} \tag{2.2}$$

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

$$K = 1.46 - .253 \cdot S_R \tag{2.3}$$

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

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



$A_e = A_1 + A_2 + A_3$

Figure 2.1 Effective Rotor Disk Area.

The forward flight correction factor, K_u, is computed from

$$K_u^4 + \left(\frac{A_v}{A_e}\right)^2\left(\frac{V_f}{v_{ih}}\right)^2\cdot K_u^2 = 1 \tag{2.5}$$

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

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

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

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

and uses the approximation

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

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

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

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

where

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

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 $2v_{i_{fr}}$.

$$k_{indo} = 2\left[\frac{1}{4} + \left(\frac{\pi R^2}{4}\right) A_{re_{free}} + A_{re_{mix}}\right] \qquad (2.15)$$

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

$$A_v = \pi R^2 + 2R \cdot g \tag{2.7}$$

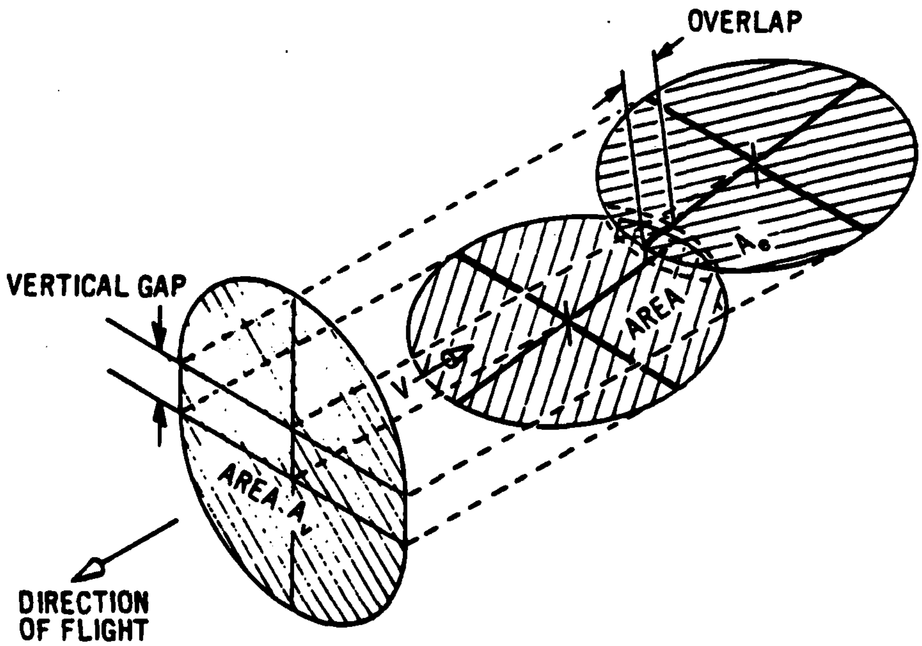


Figure 2.2 Tandem-rotor Geometry.

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

$$K_u = 1 + \frac{d_f}{2} \tag{2.8}$$

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

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

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

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

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_f, was assumed to be zero in this project.

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

$$\gamma = \theta_f - \varepsilon - \gamma_o \tag{2.21}$$

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

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

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

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

$$K_d = \frac{.043}{.043 + \mu} \tag{2.26}$$

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

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

$$A_{re_{free}} = \pi R^2 - A_{re_{mix}} \tag{2.17}$$

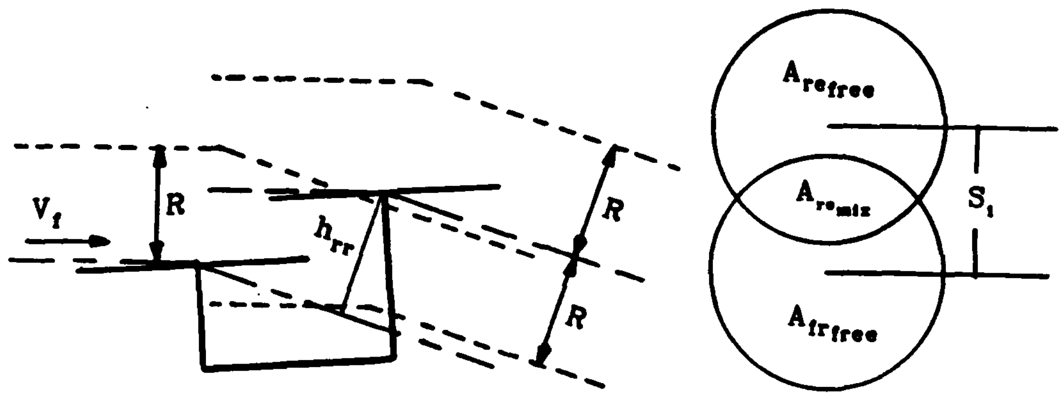


Figure 2.3 Streamtube Mix of Two Rotors.

Substituting into equation 2.15 and including tip losses

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

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.

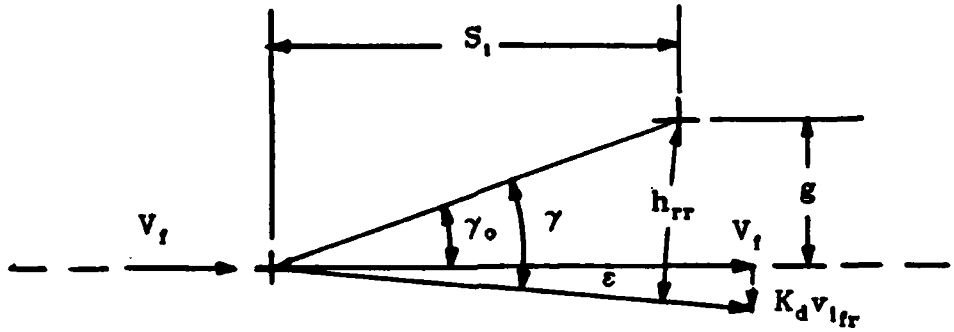


Figure 2.4 Wake Separation Distance, h_{rr}.

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

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

where v_{ih} is the same as $v_{i_{fr}}$ 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.

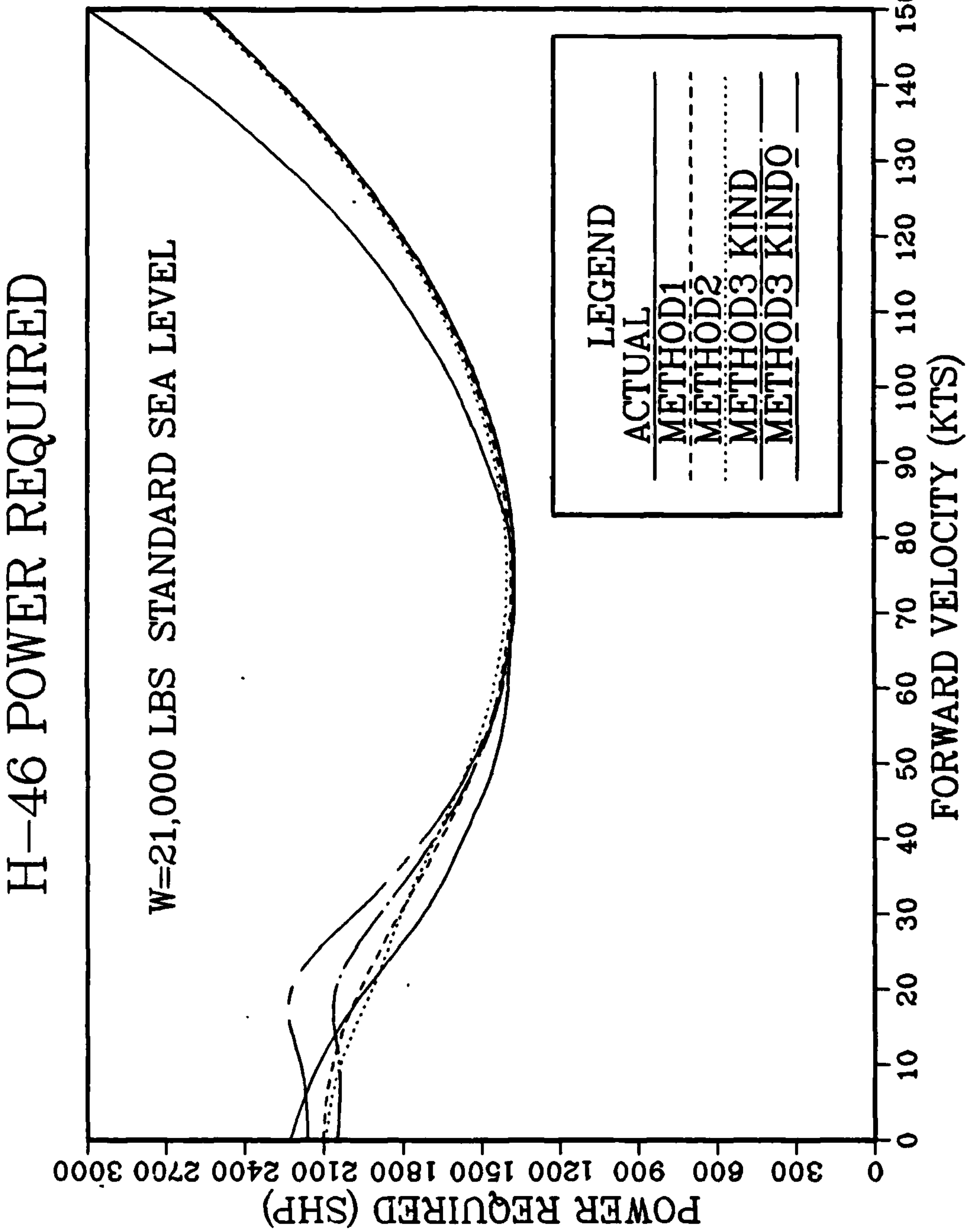


Figure 3.1 Comparison of Methods to Actual Power Required.

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 Vmax 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

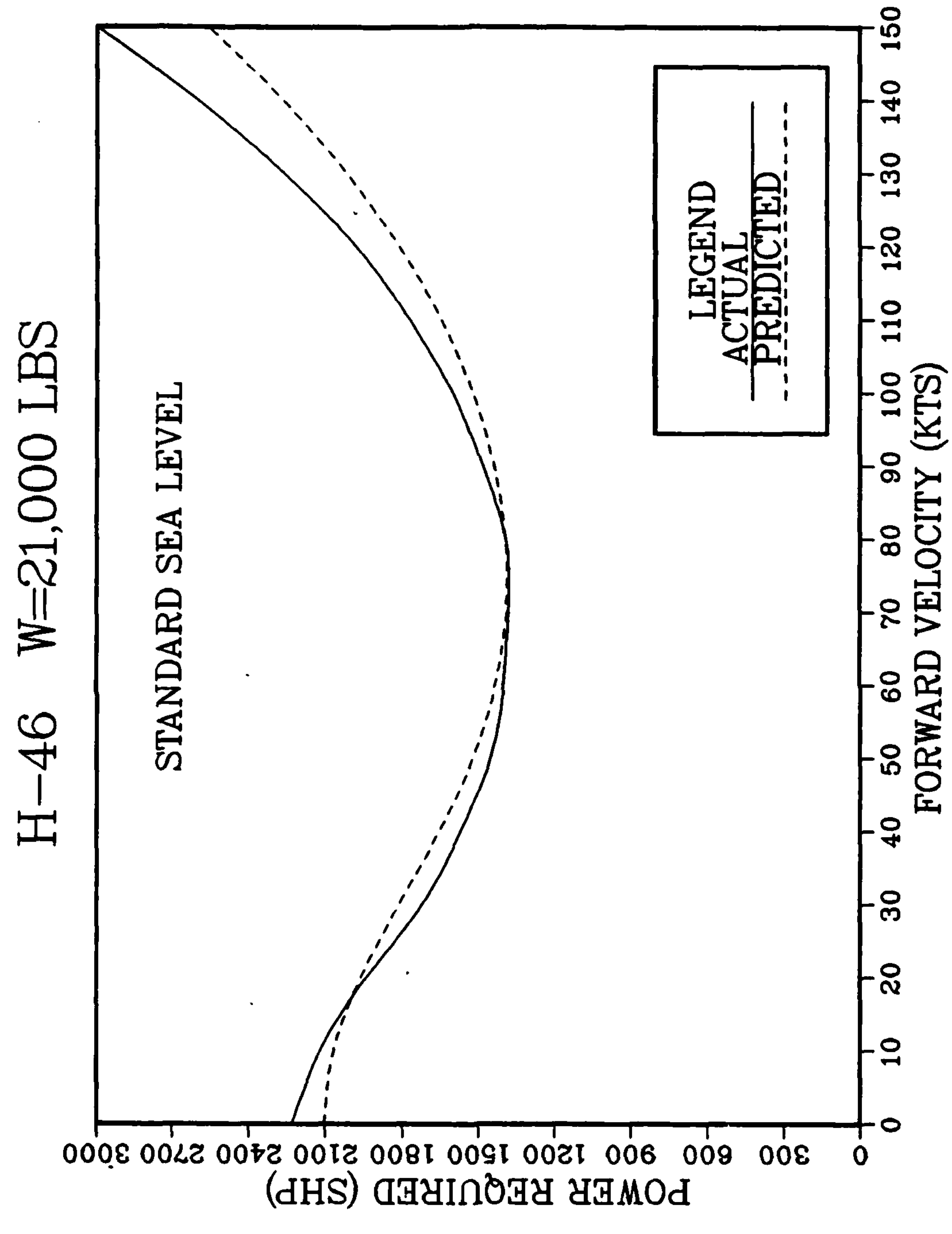


Figure 3.2 H-46 SSL Power Required.

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.

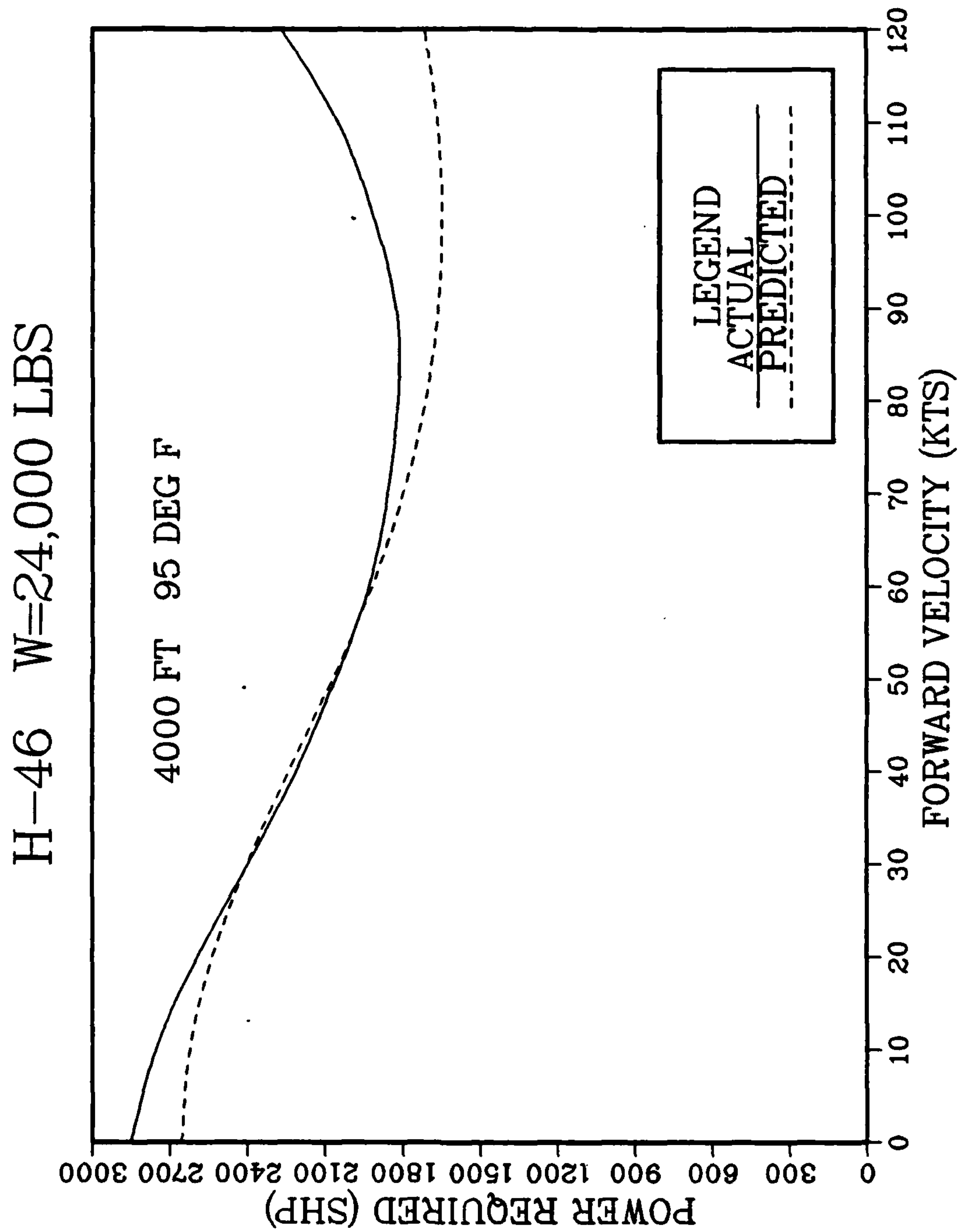


Figure 3.4 H-46 at Altitude: Power Required.

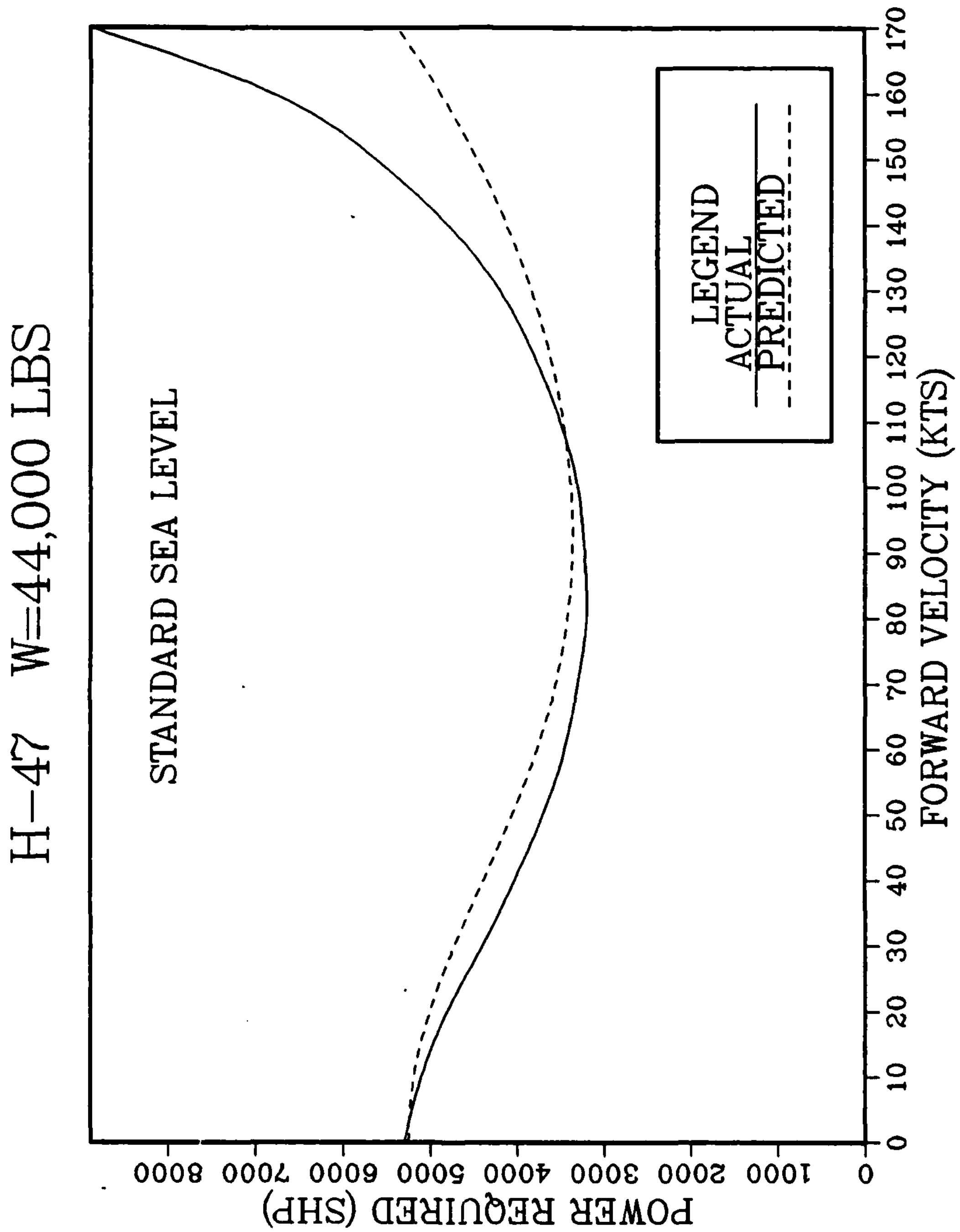


Figure 3.3 H-47 SSL Power Required.

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
$A_{re_{free}}$	-	area of the nonmixed part of the rear-rotor airstream	ft^2
$A_{re_{mix}}$	-	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
$P_{i_{single}}$	- 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
$V_{i_{fr}}$	- 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_f	- fuselage pitch attitude	degrees

VI

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

KU

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

PI

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

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

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

VT

$$V_T = RV \cdot R$$

ICAO

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

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

TEMP

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

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

RHO

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

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

$$S_R = S_l/R$$

$$R_e = B \cdot R$$

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

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_o} - 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	$P_i/P_{i_{OGE}}$ - 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"
02 FIX 2
03 CF 04
04 CF 05
05 "NEED DATA?"
06 PROMPT
07 X=0?
08 GTO "PGM"
09 RCL 02
10 "RV=?"
11 PROMPT
12 STO 02
13 RCL 04
14 "b=?"
15 PROMPT
16 STO 04
17 RCL 01
18 "c=?"
19 PROMPT
20 STO 01
21 RCL 03
22 "CdO=?"
23 PROMPT
24 STO 03
25 RCL 00
26 "R=?"
27 PROMPT
28 STO 00
29 RCL 05
30 "S1=?"
31 PROMPT
32 STO 05
33 RCL 07
34 "G=?"
35 PROMPT
36 STO 07
37 RCL 12
38 "FF=?"
39 PROMPT
40 STO 12
41 RCL 13
42 "FV=?"
43 PROMPT
44 STO 13
45 RCL 14
46 "RTR HT=?"
47 PROMPT
48 STO 14
49♦LBL "PGM"
50 RCL 11
51 "W=?"
52 PROMPT
53 STO 11
54 RCL 25
55 "WHEEL HT=?"
56 PROMPT
57 STO 25
58 RCL 14
59 +
60 RCL 00
61 /
62 2
63 /
64 STO 26
65 1.55
66 -
67 X<0?
68 GTO "GE"
69 1
70 STO 45
71 GTO "VT"
72♦LBL "GE"
73 RCL 26
74 1.3432
75 *
76 RCL 26
77 X↑2
78 -1.4569
79 *
80 +
81 RCL 26
82 3
83 Y↑X
84 .7080
85 *
86 +
87 RCL 26
88 4
89 Y↑X
90 -.1276
91 *
92 +
93 .5147
94 +
95 STO 45
96♦LBL "VT"
97 RCL 00
98 RCL 02
99 *
100 STO 27
101♦LBL "DA"
102 "PA?"
103 PROMPT
104 X=0?
105 GTO "DNA"
106 SF 05
107 "PA=?"
108 PROMPT
109 STO 20
110♦LBL "ICAO"
111 6.875 E-06
112 *
113 CHS
114 1
115 +
116 FS? 05
117 5.2561
118 FS? 04
119 4.2561
120 Y↑X
121 FS? 04
122 GTO "RHO"
123 FS? 05
124 STO 47
125♦LBL "TEMP"
126 "TEMP(F)=?"
127 PROMPT
128 459.68
129 +
130 STO 21
131 518.68
132 /
133 1/X
134 RCL 47
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
272 /
273 SQRT
274 STO 31
275♦LBL "KW"
276 RCL 18
277 RCL 31
278 /
279 RCL 24
280 *
281 RCL 23
282 /
283 X↑2
284 2
285 /
286 STO 50
287 X↑2
288 1
289 +
290 SQRT
291 RCL 50
292 -
293 SQRT
294 STO 43
295♦LBL "PI"
296 RCL 31
297 *
298 RCL 45
299 *
300 RCL 30
301 *
302 RCL 42
303 *
304 550
305 /
306 STO 35
307♦LBL "PO"
308 RCL 04
309 RCL 01
310 *
311 PI
312 /
313 RCL 00
314 /
315 STO 15
316 RCL 00
317 X↑2
318 *
319 PI
320 *
321 RCL 27
322 3
323 Y↑X
324 *
325 RCL 03
326 *
327 2200
328 /
329 RCL 22
330 *
331 STO 51
332 RCL 18
333 RCL 27
334 /
335 X↑2
336 4.3
337 *
338 1
339 +
340 RCL 51
341 *
342 STO 36
343♦LBL "PP"
344 RCL 18
345 3
346 Y↑X
347 RCL 12
348 *
349 RCL 22
350 *
351 1100
352 /
353 STO 37
354♦LBL "PC"
355 RCL 19
356 3
357 Y↑X
358 RCL 13
359 *
360 RCL 22
361 *
362 RCL 19
363 RCL 30
364 *
365 +
366 1100
367 /
368 STO 38
369♦LBL "PT"
370 RCL 35
371 +
372 RCL 36
373 +
374 RCL 37
375 +
376 STO 39
377 STO 44
378 "PT(AC)="
379 ARCL X
380 AVIEW
381 STOP
382 "HI SPD?"
383 PROMPT
384 X=0?
385 GTO "VF"
386 SF 03
387 GTO "HSE"
388 END
```

TANPWR

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

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