THESIS

Computer Programs for Helicopter
High Speed Flight Analysis

by

Waldo Francisco Carmona

September 1983

Thesis Advisor: Donald M. Layton

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**Abstract**

This report gives the user of the HP41-CV handheld programmable calculator or the IBM 3033 computer, a blade element method for calculating the total power required in forward, straight and level high-speed flight for an isolated rotor. The computer programs consist of a main program which calculates the necessary dynamic parameters of the main rotor and several...
subroutines which calculate power required as well as maximum forward velocity, stall onset velocity, and velocity for best endurance.
Computer Programs for Helicopter High Speed Flight Analysis

by

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Submitted in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE IN AERONAUTICAL ENGINEERING

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September 1983

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This report gives the user of the HP41-CV handheld programmable calculator or the IBM 3033 computer, a blade element method for calculating the total power required in forward, straight and level high speed flight for an isolated rotor. The computer programs consist of a main program which calculates the necessary dynamic parameters of the main rotor and several subroutines which calculate power required as well as maximum forward velocity, stall onset velocity, and velocity for best endurance.
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I. INTRODUCTION

A. GENERAL

The basis for helicopter rotor analysis was developed in the early 1920's when Glauert extended propeller theory to the special case of rotating wings. Since that time, the development of the digital computer has permitted many improvements on Glauert's analysis.

In order to develop a method for predicting the total rotor power required in forward flight, it is necessary to develop a method that accurately predicts rotor dynamics. The prediction of rotor dynamics in forward flight is a complex one. Typically, a helicopter rotor blade encounters a flow environment which changes rapidly as it moves around in azimuth.

In forward flight, rotor blade sections are subjected to azimuthal variations in not only angle of attack but also Mach number. As a result, comprehensive performance analysis of a helicopter is much more involved than that of a conventional aircraft.

Recent helicopter design trends have been in the direction of increasing the maximum forward velocity possible as well as higher blade tip speeds. Since the
speed of the helicopter is added to the speed of rotation of the advancing blade, the highest relative velocities occur at the tip of the advancing blade. When the section Mach number of the blade tip exceeds the critical Mach number of the airfoil, compressibility effects result. These effects include a large increase in profile drag and change in pitching moments, therefore creating additional power requirements.

In all current helicopters there is a tendency for the retreating blade to stall. Just as the stall of an airplane wing limits the low speed performance of an airplane, the stall of a rotor limits the high speed potential of a helicopter. The relative velocity of the retreating blade decreases as forward speed increases. However, the retreating blades must produce the same amount of lift as the advancing blade. Therefore, as the relative velocity of the the retreating blade decreases with forward speed, the blade angle of attack must be increased to equalize lift throughout the the rotor disc area. As this angle increases the blade will eventually stall at some forward speed. For these reasons, stall and compressibility thus combine to limit the performance fo a helicopter at higher speeds.
For efficient design of a helicopter, the helicopter designer should have the analytical tools necessary to predict the performance of a helicopter. This report gives the user of the HP41-CV and the IBM 3033 computer a means of calculating the total power required in forward, straight and level flight.

3. OBJECTIVE

The objective was to provide an interactive computer program which can be used during the initial design stage to estimate the total power required by the main rotor of a helicopter, as well as maximum forward velocity possible, stall onset velocity, and best endurance velocity.

Additionally, the desired accuracy chosen at the beginning of this effort was to obtain angle of attack within a plus or minus one half degree, power estimates within ten percent of the actual power required, and to obtain the needed accuracy in as short a running time as possible.
II. PROBLEM DEFINITION

A. DESCRIPTION OF PROBLEM

For a helicopter in level flight, the maximum forward speed is limited by the power available as well as stall and compressibility effects. It is therefore advantageous to develop a simple-to-use computer program that estimates blade stall and compressibility effects on helicopter performance.

B. METHOD OF SOLUTION

In forward flight, the aerodynamic environment of the rotor blade varies as the rotor blade rotates with respect to the direction of flight. The method chosen to obtain the objective accuracy ignores any variables not immediately impacting on the accuracy of the determination of angle of attack and power requirements.

The method utilized herein uses a combination of momentum and blade element theory to perform rotor performance calculations. This theory is initially used to determine the induced, profile, and parasite power required.

The solution method then utilizes a blade element analysis to predict the cyclic, collective, and inflow angles.
associated with the rotor. These angles are then used in the calculation of the rotor blade's angle of attack at the azimuthal positions of 90 and 270 degrees. Compressibility and stall power are then estimated as a function of angle of attack and forward velocity.
III. DESCRIPTION OF THE PROBLEM SOLUTION

A. GENERAL

The calculation/prediction of helicopter performance is primarily a matter of determining the power required and power available over the desired flight regime. The power information may then be used to predict the operational capabilities of the aircraft.

For the ideal helicopter (no losses), in forward, straight and level flight, power required can be subdivided into five parts: induced power, $P_I$, required to produce rotor thrust; profile power, $P_O$, required to overcome the skin friction and pressure drag of the main rotor; parasite power, $P_p$, required to overcome the parasite drag of the helicopter; compressibility power, $P_M$, required to overcome the increase in profile drag when the tip Mach number exceeds the drag divergence Mach number of the airfoil; and stall power, $P_s$, required to account for the increase in rotor torque as a result of retreating blade stall. The HP41-CV and IBM 3033 computer programs contained herein provides a simple, quick means of evaluating the power required by an isolated rotor.
B. ASSUMPTIONS

The major task in helicopter performance analysis is the determination of rotor forces, angles, and power. The method chosen ignores any variable that does not directly impact on the desired accuracy. Therefore, in order to simplify the computational process used, the following assumptions are made:

1. Steady flow through the rotor system.
2. Small angle approximations are a valid representation of the real world phenomena.
3. All blades considered are rectangular (non-tapered) with only uniform twist possible.
4. Hinge off-set is zero (i.e., the thrust vector passes through the C.G.).
5. The stall angle on most helicopter blades can be approximated by the angle that occurs at CLMAX for a 2-D airfoil.
6. The helicopter is trimmed. This implies that the sum of all the moments about the center of gravity (C.G.) is zero, all forces are in balance, and that no lateral flapping is present.
7. At stall onset, the value of section drag coefficient jumps approximately 0.08.

8. The rotor rotates counterclockwise.

C. NOMENCLATURE

"Standard" nomenclature is used. Appendix A contains an alphabetical list defining all the symbols and acronyms used in the development of this report. Appendix B contains an alphabetical list of all HP41-CV displays used in the HP41-CV program.

D. INITIALIZATION

It is assumed that the initial design of the helicopter has been completed and that the helicopters weight as well as the chord, radius, tip velocity, twist, zero-lift drag coefficient, and number of blades of the rotor are known. Finally, it is assumed that an initial estimation of equivalent flat plate area is available, and that the forward velocity of the helicopter is known.

E. ROTOR DYNAMICS

There are four rotor parameters which will help expedite later calculations. The first of these is the rotor advance ratio, \( \mu \); \( \mu \) is the ratio of the helicopter's forward
velocity to the rotational velocity. The advance ratio can be represented as

\[ \mu = \frac{v_p \cos \alpha}{v_T} \quad \text{(dimensionless)} \]

Applying small angle approximations the advance ratio becomes

\[ \mu = \frac{v_p}{v_T} \]

where,

\[ v_T = \left( \frac{\Omega R}{2} \right) \]

The second dimensionless ratio that needs to be calculated is the inflow ratio, \( \lambda \). The inflow ratio is the ratio of the net velocity up through the rotor system to the tip speed. For the near hover case, \( \mu \approx 0.1 \), the \( \tan \alpha = 0 \) and the inflow ratio can be approximated by

\[ \lambda = -\sqrt{CT/2} \]

In forward flight, the calculation of \( \lambda \) requires the determination of the angle of attack of the rotor disc. Letting the angle of attack between the disc plane and the
incoming free-stream velocity be \( \alpha_3 \), and assuming \( \alpha_3 \) to be small, the inflow velocity can be calculated using

\[
\lambda = \frac{-C_T}{2\sqrt{\lambda^2 + u^2}} + u \tan \alpha_3
\]

where

\[
\alpha_3 = -\tan \left( \frac{D_p}{L} \right) = -\tan \left( \frac{D_p}{A} \right)
\]

\[
D_p = \frac{(P_p \times 550)}{V_F}
\]

The last dimensionless parameter that needs to be calculated is solidity. Solidity is the fraction of the rotor disc area that is composed of blades. For a blade of constant chord (i.e., non-tapered) solidity can be expressed as

\[
\sigma = \frac{b \times C}{(\pi \times r)}
\]

Finally, the tip loss factor, \( B_{TL} \), must be considered. The tip loss factor is used to account for the loss of lift that a rotor blade experiences due to flow from the rotor's lower surface to its upper surface. The tip loss factor of a rotor can be approximated by

\[
B_{TL} = 1.0 - \sqrt{2 \times C_T / b}
\]
P. VELOCITY CALCULATIONS

There are four velocities that are of interest. The first of these is the downwash velocity, \( w \). Assuming steady flow through the rotor, the downwash velocity can be approximated by

\[
(6) \quad w = \frac{W}{2 \rho A_D v_F} \quad (f/s)
\]

**NOTE:** This equation is not valid for small values of forward velocity.

The second velocity that needs to be calculated is the stall onset velocity, \( V_S \). The stall onset velocity is the velocity at which the retreating blade tip first exceeds the static stall angle. The forward speed at which stall onset is first noted can be approximated by the velocity for best range, \( V_{BR} \). This is due to the marked increase in profile power required at speeds higher than velocity for best range. A typical set of power curves for a helicopter are shown in Figure 3.1.

The forward velocity for minimum \( P/V \) (i.e., best range velocity) is easily found graphically on the power required curve as the point where a straight line through the origin
is tangent to the curve (see Figure 3.2). Since the power curves are not initially known, an analytical expression needs to be developed which will estimate the velocity for best range. The following is the derivation of one such expression.
As shown below, if the parasite power required is set equal to the profile power required and the equality is then solved for an equation in which forward velocity is the variable, the result is a cubic equation in which the largest root defines the point where the profile power and parasite power are equal.

\[ P_p = P_0 \]

\[ \frac{1}{2} C_p V^2 = \frac{1}{8} \sigma \, C_{l0} \rho A_D (1 + 4.25 \, \mu^2 ) \]

(7) \[ V_F^3 - (4.25 /4f) C_{l0} \, A_D \, V_F \, V_F^2 - (\sigma/4f) C_{l0} \, A_D \, V_F^3 = 0 \]

Next, the largest root of equation 7 needs to be determined. This can be simply done using the cubic root equation. Letting

\[ p = -(4.25 \sigma/4f) C_{l0} \, A_D \, V_T \]

\[ z = -(\sigma/4f) C_{l0} \, A_D \, V_T^3 \]

Equation 7 can now be written as

(7a) \[ V_F^3 - p V_F^2 - z = 0 \]

Substituting
for \( V_p \) in equation 7a yields an equation of the form

\[(7b) \quad x^3 + ax + b = 0\]

where,

\[a = -\frac{1}{3} p^2\]
\[b = \frac{1}{27} (2p^2 + 27r)\]

The largest root of equation 7b is then given by

\[(8) \quad V = A + B\]

where,

\[A = \left[ -\frac{b}{2} + \sqrt{\frac{b^2}{4} + \frac{a^3}{27}} \right]^{1/3}\]
\[B = \left[ -\frac{b}{2} - \sqrt{\frac{b^2}{4} + \frac{a^3}{27}} \right]^{1/3}\]

Equation 8 can now be used as the initial approximation for stall onset velocity.

The third velocity which is of interest is the helicopter's maximum forward velocity, \( V_{MAX} \). As shown in
Figure 3.2, the maximum forward velocity is given by the intersection of the power required and power available curves for a given gross weight and altitude [Ref. 1].

\[ \text{POWER REQUIRED VS VELOCITY} \]

\[ \text{MAX POWER AVAILABLE} \]

\[ \text{TOTAL POWER} \]

\[ \text{VMAX} \]

\[ \text{VMAX RANGE} \]

\[ \text{VBE} \]

\[ \text{FORWARD VELOCITY (KT)} \]

Therefore, whenever \( V_F > V_{\text{MAX}} \), there is insufficient power available to sustain level flight.

The power-limited maximum speed may be estimated by
Equation 9 can be simplified by assuming that the power required at maximum speed is about the same as that required at hover. Therefore, assuming

\[ \frac{P_{\text{AVAIL}} - P}{P_0} = \frac{P_{\text{HOVER}}}{P_0} \]

and that

\[ \frac{P_{\text{AVAIL}} - P_0}{P_0} = \frac{P_{\text{HOVER}}}{P_0} \]

Equation 9 can then be written as

\[ v_{\text{MAX}} = v_I \times \left( \frac{4}{\rho A_D} \right)^{1/3} \text{ (ft/sec)} \]

where,

\[ v_I = \sqrt{\frac{4}{2 \rho A_D}} \]

The last velocity that needs to be calculated is the best endurance velocity, VBE. In the normal operating range the total helicopter power can be represented by

\[ P_T = P_I + P_0 + P_p \]
Assuming that the variation of profile power with forward velocity is negligible, the velocity for best endurance (also the best rate of climb velocity) can be found. If equation is differentiated with respect to forward velocity, \( V_F \), and is set equal to zero, it can be seen that

\[
(11a) \quad P_I = 3 P_p \\
\]

\[
(11b) \quad \frac{\dot{W}^2}{2} = 3 \rho f \frac{V_F^2}{A_D V_{BE}} \\
\]

Solving equation for the best endurance velocity, \( V_{BE} \), results in

\[
(11c) \quad V_{BE} = \left[ \frac{\bar{W}}{\rho A_D \left[ \frac{A_D}{3F} \right]^h} \right]^{\frac{1}{h}} \quad (ft/s)
\]

G. INITIAL POWER CALCULATIONS

As forward velocity increases, the induced power decreases, the profile power increases slightly, and the parasite power increases until it becomes the dominant loss at high speeds [Ref. 2]. For forward, straight and level flight, the induced power can be calculated by
(12) \[ p = \pi \left[ -\frac{V_p^2}{2\mu I} + \sqrt{\left(\frac{V_p^2}{2\mu I}\right)^2 + 1}\right] \frac{I}{550} \] (hp)

If tip losses are taken into effect (equation 5), the induced power now becomes

(12a) \[ P_I = (1/3_{TL}) * P_I \] (TL)

Since the induced power required in ground effect is less than that required cut of ground effect, equation 12 should be written as

(12b) \[ P_I = (1/2_{TL}) \cdot (GE) \cdot P_I \] (TL+GE)

where,

\[ GE = (-0.1276 \cdot (h/D) + 0.708 \cdot (h/D)^3)
-1.4569 \cdot (h/D)^2 + 1.3432 \cdot (h/D)
+ 0.5147) \]

The profile power required is given by

(13) \[ P_O = \frac{\sigma C \rho \rho A D \cdot v^3}{4400} (1 + 4.25 \mu z) \] (hp)

Finally, parasite power given by
\[ (14) \quad P_p = \frac{v_F^3}{1100} \quad (hp) \]

\[ (15) \quad \alpha(r, \psi) = \frac{\theta - v_F^2 \cos \alpha + \omega - \omega_0}{\Omega R + v_p \sin \psi} \]

where,

\[ (15a) \quad \theta = \theta_0 + \theta_1 \cos \gamma + \theta_2 \sin \gamma + K_B \beta \]

\[ (15b) \quad \beta = \beta_0 - a_1 \cos \psi - b_1 \sin \psi \]

IV. ANGLE OF ATTACK

The determination of angle of attack at the azimuthal positions of 90 and 270 degrees are important in the determination of compressibility and stall effects. It is because of this effect that the dynamics of the blade motion are important in analyzing helicopter performance.

The angle of attack of the rotor is a function of radius, \( r \), and azimuthal position, \( \psi \). Figure 3.3 illustrates the sign convention used in determining blade angle of attack. The angle of attack of a rotor can thus be estimated by,
To determine angle of attack, it is then necessary to determine the longitudinal collective and cyclic angles $\theta_0$ and $\theta_2$. This can be accomplished by expressing the coefficient of thrust as
\[ C_T = \frac{3\alpha}{2} \lambda T_1 + (\gamma + K_B) T_2 + \lambda T_3 + (\gamma - K_B) T_4 \]

where,

\[ T_1 = 0.5 \left( \frac{B^2}{T_L} + 0.5 \mu^2 \right) \quad T_3 = 0.25 \left( \frac{B^2}{T_L} + \mu^2 \right) \]

\[ T_2 = (0.5B^3 + 0.5\mu^2B) \quad T_4 = 0.5 \left( \frac{B^2}{T_L} + 0.25 \mu^2 \right) \]

Additionally, the longitudinal flapping coefficient \( a_1 \), needs to be determined. The longitudinal flapping coefficient can be written as

\[ a_1 = \lambda A_{11} + (\gamma + K_B) A_{12} + \lambda A_{13} + (\gamma - K_B) A_{14} \]

where,

\[ D_1 = (B^2 - 0.5 \mu^2) \]

\[ A_{11} = 0.25 \left( B^2 \frac{T_L}{T_L^3} - \mu^3 / 8 \right) \quad A_{13} = 2 \mu \frac{B^2}{T_L} \]

\[ A_{12} = 8 \mu \frac{B}{T_L} \quad A_{14} = B \frac{D_1}{T_L} \]

Assuming that there is no lateral flapping and that the effect is zero (i.e., \( K_B = 0.0 \)), equations 16 and 17 become
\[ \frac{2}{a} CT = \lambda T^2 + \theta T^2 + \theta T^3 + \theta T^4 \]  

\[ a_1 = \lambda A_{11} + \theta A_{12} + \theta A_{13} + \theta A_{14} \]

**Note:** Since the analysis is only looking at the azimuthal positions of 90 and 270 degrees, it can be seen from equation 15b that the contribution of the longitudinal flapping coefficient, \( a_1 \), will always be zero at these positions.

Equations 18 and 19 now represent a set of simultaneous equations in which the only unknowns are the collective and cyclic angles and can thus be determined. Knowing the values of the cyclic and collective angles, the blade tip angle of attack at the 90 and 270 degree positions can be estimated by

\[ \alpha_{90} = \theta + \theta \frac{\lambda}{1+u} \]  

\[ \alpha_{270} = \theta - \theta \frac{\lambda}{1+u} \]

**Note:** The angle of attack, \( \alpha \), is defined positively if the disk plane is nose up, see Figure 3.2.
I. STALL POWER

In the helicopter stall normally starts at the tip of the retreating blade, since the highest angles of attack are usually at the blade tip. As the forward speed increases, the stalled area of the rotor blade spreads inboard.

At the higher values of \( \mu \), the effects of stall on power required are great and therefore need to be estimated. Assuming a jump of 0.08 in the value of \( C_{10} \) at stall onset, that the rotor area within which the blade stall exists is a segment of minimum dimensionless radius \( X_s \) and that the stall area is symmetric about \( \psi = 270 \) degrees, Castles and New found that the effects of tip stall on power required at the higher values of \( \mu \) are large and can be approximated for high speed flight by

\[
C_{PS} = \frac{\sigma}{24 \pi} \left( 1 - \mu \right)^2 \left( 1 - X_s \right) \sqrt{1 - X_s^2}
\]

where \( X_s \) is the nondimensional radius outboard of which the retreating blade is stalled [Ref. 3]. The dimensionless radius, \( X_s \), can be estimated by equating the section angle of attack, at \( \psi = 270 \) degrees, to \( \pi \) [Ref. 4]. Setting equation 15 at \( \psi = 270 \) degrees equal to \( \pi \) results in the quadratic listed below.
Applying the quadratic formula to equation 23 yields the roots

\[(23a) \quad X_S = \frac{-B_S + \sqrt{B_S^2 - 4\Theta_T C_S}}{2\Theta_T}\]

\[(23b) \quad X_0 = \frac{-B_S - \sqrt{B_S^2 - 4\Theta_T C_S}}{2\Theta_T}\]

where,

\[(23c) \quad \Gamma = \alpha_{\text{MAX}} - \Theta_0 - \Theta_2\]

\[(23b) \quad C_S = \mu T + \lambda\]

\[(23e) \quad B = -\mu T - \Gamma\]

Equation 22 is satisfactory for most cases. It is possible however, for the blade section angle of attack to be higher inboard than at the tip creating a situation which is usually referred to as inboard stalling [Ref. 5].

For the special case of inboard stalling, see Figure 3.4, the incremental stall power coefficient defined by equation 22 is too large and needs to be corrected.
Assuming the stalled region is diamond shaped as shown in Figure 3.5 and that the stalled area is symmetric about $\psi = 3\pi/2$, it can be seen that as $X_0$ approaches $X_G$, the correction to the incremental stall power coefficient, $C_{PS}$, must vanish.
Similarly, as the average of $X_0$ and $k_s$ approaches unity, the value of $C_{ps}$ goes to the value defined by equation 22.

Therefore, in order to correct for the possibility of inboard stalling, the correction factor, $k_s$, is defined such that
\[ k_S = \frac{B_S}{2\Theta T} \quad \text{for} \quad \frac{B_S}{2\Theta T} > 1.0 \]

\[ k = \frac{B_S / 2\Theta T + X_S}{1 - X_S} \quad \text{for} \quad \frac{B_S}{2\Theta T} < 1.0 \]

The corrected equation for stall power required thus becomes

\[ C_{PS}^* = k_S * C_{PS} \]

J. COMPRESSIONIBILITY POWER

The individual effects of stall and compressibility on rotor profile power are substantial at high advance ratios. When both effects are present the losses due to each source are difficult to distinguish. Therefore, as a helicopter's forward velocity and tip speed increase, the need for a simple estimate of how the compressibility of the air influences the rotor performance is necessary.

In forward flight, the Mach number of the advancing blade is given by
(27) \[ M = M_{\text{TIP}}(x + \mu \sin \psi) \]

where,

(27a) \[ M_{\text{TIP}} = \frac{\Omega R}{a} = \frac{\sqrt{a}}{a} \]

(27b) \[ x = r/R = \text{non-dimensional radius} \]

Since the highest Mach number occurs at the tip of the advancing blade at $\psi = 90$ degrees, equation 27 can be written as

(28) \[ M_{90} = M_{\text{TIP}}(1 + \mu) \]

Reference 3.5 showed that the critical Mach number for drag divergence can be estimated by

(29) \[ M_{\text{CRIT}} = M_{90} - 3 \frac{M_{90} - 1}{1 - \frac{1}{2} M_{90}} \]

Gessow and Grin, in their investigation of compressibility found that the compressibility effect on rotor performance was a rapid increase in the profile power when the tip Mach number exceeded the critical Mach number for drag divergence [Ref. 6]. The increase in profile power coefficient due to Mach effects can be estimated by
\[ C_{PC} = 0.51 \Delta m_D + 0.1 (\Delta m_D)^2 \]

where,

\[ \Delta m_D = \dot{m}_{\infty} - \dot{m}_{CRIT} 0.05 \]
IV. CONCLUSIONS AND RECOMMENDATIONS

The objective of this project was to provide an easy to use, interactive computer program which could be used during the initial design phase to estimate the total power required by the main rotor of a helicopter. The computer programs contained herein provide results which are well within the objective accuracies (see Figures C.1, C.2, C.3) and provide acceptable results as a first cut estimate of compressibility and stall power requirements.

In the development of the computational model, many simplifying assumptions were made to ease the amount of computation required. The assumption which most impacts on the accuracy of the program is that of steady flow through the rotor.

The flow environment encountered by the rotor changes rapidly due to the rate of change of blade angle of attack. Additionally, rotor operation at high advance ratios also produces considerable radial flow along the blade span. The steady flow assumption ignores the time-variant aspect of rotor aerodynamics. The dynamic nature of the rotor, especially when operating at or near the stall regime, requires the application of unsteady aerodynamics, and a
close examination of how the pitching moments generated by the retreating blade stalling affects controllability [Ref. 7]. It is therefore recommended that additional investigations consider how the unsteady aerodynamics, and pitching moments generated, influence the performance of the helicopter.
# Appendix A

## Nomenclature

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<th>Term</th>
<th>Mnemonic</th>
<th>Definition</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>a</td>
<td>Slope of airfoil section lift curve.</td>
<td>rad</td>
</tr>
<tr>
<td>iD</td>
<td>AD</td>
<td>Rotor disc area.</td>
<td>ft</td>
</tr>
<tr>
<td>a3</td>
<td>Alpha3</td>
<td>Disk plane angle of attack.</td>
<td>rad</td>
</tr>
<tr>
<td>aMAX</td>
<td>AMAX</td>
<td>The steady flow stall angle of the airfoil (given by $a \cdot CL_{MAX}$).</td>
<td>rad</td>
</tr>
<tr>
<td>a90</td>
<td>A90</td>
<td>Angle of attack of the advancing blade at $\psi = 90$ degrees.</td>
<td>rad</td>
</tr>
<tr>
<td>a270</td>
<td>A270</td>
<td>Angle of attack of the retreating blade at $\psi = 270$ degrees.</td>
<td>rad</td>
</tr>
<tr>
<td>a11</td>
<td>A11</td>
<td>Longitudinal flapping</td>
<td>rad</td>
</tr>
<tr>
<td>A11</td>
<td>A11</td>
<td>Term in definition of THETA2.</td>
<td>dimensionless</td>
</tr>
<tr>
<td>A12</td>
<td>A12</td>
<td>Term in definition of THETA2.</td>
<td>dimensionless</td>
</tr>
<tr>
<td>Symbol</td>
<td>Definition</td>
<td>Units</td>
<td></td>
</tr>
<tr>
<td>--------</td>
<td>------------</td>
<td>-------</td>
<td></td>
</tr>
<tr>
<td>A13</td>
<td>Term in definition of $\Theta_2$.</td>
<td>dimensionless</td>
<td></td>
</tr>
<tr>
<td>A14</td>
<td>Term in definition of $\Theta_2$.</td>
<td>dimensionless</td>
<td></td>
</tr>
<tr>
<td>$b$</td>
<td>Number of blades on the main rotor.</td>
<td>dimensionless</td>
<td></td>
</tr>
<tr>
<td>$\beta$</td>
<td>Main rotor coning angle.</td>
<td>rad</td>
<td></td>
</tr>
<tr>
<td>$\beta_0$</td>
<td>Term in definition of $X_s$.</td>
<td>dimensionless</td>
<td></td>
</tr>
<tr>
<td>$BTL$</td>
<td>Tip loss factor.</td>
<td>dimensionless</td>
<td></td>
</tr>
<tr>
<td>$C$</td>
<td>Mean chord of main rotor blade.</td>
<td>ft</td>
<td></td>
</tr>
<tr>
<td>$C_{1c}$</td>
<td>Main rotor coefficient of drag at zero lift.</td>
<td>dimensionless</td>
<td></td>
</tr>
<tr>
<td>$C_{L_{\text{MAX}}}$</td>
<td>Maximum coefficient of lift ($C_{L_{\text{MAX}}}$).</td>
<td>dimensionless</td>
<td></td>
</tr>
<tr>
<td>$C_{PC}$</td>
<td>Correction to power coefficient due to compressibility effects.</td>
<td>dimensionless</td>
<td></td>
</tr>
<tr>
<td>$C_{PS}$</td>
<td>Correction to power coefficient due to stall.</td>
<td>dimensionless</td>
<td></td>
</tr>
<tr>
<td>$C_S$</td>
<td>Term in definition of $X_s$.</td>
<td>dimensionless</td>
<td></td>
</tr>
<tr>
<td>Symbol</td>
<td>Definition</td>
<td>Units</td>
<td></td>
</tr>
<tr>
<td>--------</td>
<td>------------------------------------------------</td>
<td>---------------------</td>
<td></td>
</tr>
<tr>
<td>CT</td>
<td>Coefficient of thrust of the main rotor.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DP</td>
<td>Rotor disc diameter.</td>
<td>ft</td>
<td></td>
</tr>
<tr>
<td>D</td>
<td>Parasite drag of the helicopter.</td>
<td>lb</td>
<td></td>
</tr>
<tr>
<td>M_D</td>
<td>Term in the definition of compressibility power.</td>
<td>dimensionless</td>
<td></td>
</tr>
<tr>
<td>s</td>
<td>Rate of change of blade pitch with respect to blade flapping.</td>
<td>dimensionless</td>
<td></td>
</tr>
<tr>
<td>s</td>
<td>Equivalent flat plate area of the helicopter in forward flight.</td>
<td>ft</td>
<td></td>
</tr>
<tr>
<td>F</td>
<td>Term in definition of B and C.</td>
<td>dimensionless</td>
<td></td>
</tr>
<tr>
<td>G.E.</td>
<td>Ground effect ratio.</td>
<td>dimensionless</td>
<td></td>
</tr>
<tr>
<td>h</td>
<td>Height of main rotor above the ground.</td>
<td>ft</td>
<td></td>
</tr>
<tr>
<td>h_p</td>
<td>Horsepower.</td>
<td>hp</td>
<td></td>
</tr>
<tr>
<td>K</td>
<td>effect.</td>
<td>dimensionless</td>
<td></td>
</tr>
<tr>
<td>Symbol</td>
<td>Meaning</td>
<td>Unit</td>
<td></td>
</tr>
<tr>
<td>--------</td>
<td>---------</td>
<td>------</td>
<td></td>
</tr>
<tr>
<td>(\lambda)</td>
<td>LAM B</td>
<td>Ratio of the net velocity up through the rotor system to the tip speed.</td>
<td>dimensionless</td>
</tr>
<tr>
<td>(\text{MACH})</td>
<td>Mach number of rotor blade.</td>
<td>dimensionless</td>
<td></td>
</tr>
<tr>
<td>(\text{MCRT})</td>
<td>Critical Mach number of advancing blade at (\psi = 90) degrees.</td>
<td>dimensionless</td>
<td></td>
</tr>
<tr>
<td>(\text{MT})</td>
<td>Tip Mach number of rotor blade.</td>
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<td></td>
</tr>
<tr>
<td>(\text{MCRTO})</td>
<td>Critical Mach number for (C_l = 0.0).</td>
<td>dimensionless</td>
<td></td>
</tr>
<tr>
<td>(\text{\mu})</td>
<td>Main rotor advance ratio.</td>
<td>dimensionless</td>
<td></td>
</tr>
<tr>
<td>(m_1)</td>
<td>Constant in definition of critical Mach number ((m_1 = 0.113)).</td>
<td>ft-lb</td>
<td></td>
</tr>
<tr>
<td>(\Omega)</td>
<td>OMEGA</td>
<td>Rotational velocity.</td>
<td>rad/s</td>
</tr>
<tr>
<td>(P_C)</td>
<td>PM</td>
<td>Power required due to compressibility effects.</td>
<td>hp</td>
</tr>
<tr>
<td>(P_l)</td>
<td>PI</td>
<td>Induced power.</td>
<td>hp</td>
</tr>
<tr>
<td>Symbol</td>
<td>Definition</td>
<td></td>
<td></td>
</tr>
<tr>
<td>--------</td>
<td>------------</td>
<td></td>
<td></td>
</tr>
<tr>
<td>P₀</td>
<td>Profile power.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pₚ</td>
<td>Parasite power.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pₛ</td>
<td>Power required due to stall effects.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>R</td>
<td>Main rotor radius.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ρ</td>
<td>Air density.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>δ₀</td>
<td>Main rotor solidity.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>θ</td>
<td>Ratio of ambient temperature to standard sea level temperature.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>θ₀</td>
<td>Main rotor collective pitch.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>θ₂</td>
<td>Main rotor lateral pitch.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>θ₃</td>
<td>Main rotor longitudinal cyclic pitch.</td>
<td></td>
<td></td>
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<td>T₁</td>
<td>Term in definition of θ₀.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>T₂</td>
<td>Term in definition of θ₀.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>T₃</td>
<td>Term in definition of θ₀.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>T₄</td>
<td>Term in definition of θ₀.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Symbol</td>
<td>Description</td>
<td>Unit</td>
<td></td>
</tr>
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<td>--------</td>
<td>--------------------------------------------------</td>
<td>---------------</td>
<td></td>
</tr>
<tr>
<td>( v_I )</td>
<td>Induced velocity</td>
<td>ft/s</td>
<td></td>
</tr>
<tr>
<td>( v_F )</td>
<td>Aircraft forward speed</td>
<td>ft/s</td>
<td></td>
</tr>
<tr>
<td>( V )</td>
<td>Aircraft forward speed</td>
<td>kt</td>
<td></td>
</tr>
<tr>
<td>( V_{\text{MAX}} )</td>
<td>Maximum forward velocity possible.</td>
<td>kt</td>
<td></td>
</tr>
<tr>
<td>( V_S )</td>
<td>Stall onset velocity (velocity at which ( \alpha_{27} ) equal ( \alpha_{\text{MAX}} ))</td>
<td>kt</td>
<td></td>
</tr>
<tr>
<td>( V_T )</td>
<td>Rotor tip speed</td>
<td>ft/s</td>
<td></td>
</tr>
<tr>
<td>( a_{S\text{VEL}} )</td>
<td>Speed of sound</td>
<td>ft/s</td>
<td></td>
</tr>
<tr>
<td>( a_{D\text{W}} )</td>
<td>Rotor downwash velocity</td>
<td>ft/s</td>
<td></td>
</tr>
<tr>
<td>( W )</td>
<td>Aircraft gross weight</td>
<td>lb</td>
<td></td>
</tr>
<tr>
<td>( X_{S} )</td>
<td>Radius outboard of which the main rotor is stalled.</td>
<td>dimensionless</td>
<td></td>
</tr>
<tr>
<td>( X_{O} )</td>
<td>Radius inboard of which rotor blade stall may be present due to inflow ratio and blade twist.</td>
<td>dimensionless</td>
<td></td>
</tr>
</tbody>
</table>
APPENDIX B

HP 41-CV PROGRAM DOCUMENTATION

A. GENERAL

The HP 41-CV program uses 45 program storage registers. Prior to program initialization, the handheld calculator should be sized to 46.

The computer program consists of a main program which calculates the necessary dynamic parameters of the main rotor and several subroutines which calculate power required as well as the maximum forward velocity, stall onset velocity, and best endurance velocity.

The documentation for the HP 41-CV program is divided into the following sections:

1. PURPOSE

   This section describes the intended purpose of the program or subroutine.

2. ASSUMPTIONS

   This section lists any assumptions made which are applicable to the program or subroutine.

2. EQUATIONS

   This section lists the equations utilized within the main program or subroutine. The primary references for
the equations used are *Aerodynamics* and *FINST Rails*, Reference 3.1, *Helicopter Theory*, Reference 3.2, and *Aircraft Performance*, Reference 3.3.

4. **FLOWCHART**

Both the handheld computer and the IBM 3033 normally execute instructions in a program in a sequential manner unless it is instructed to do otherwise. This section will graphically represent the step by step method used to solve the problem as well as the flow of control between the various parts of the program. In a flowchart, different types of operations are indicated by different shaped boxes as illustrated below:

- Oval: For start or stop.
- Rectangle: For a calculation or process other than a decision.

---

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Modified  For the execution of
Rectangle  a subroutine.

Diamond  For a decision.

Parallelogram  For input or output.

Small Circle  For an on page
connection when a
flowchart continues
on the same page, or
when it is difficult
to connect two boxes.

Pentagon  For connection when
a flowchart continues
to another page.
5. PROGRAMS AND SUBROUTINES

This section lists all the programs or subroutines which must be present in the HP 41-CV prior to program execution.

6. PROGRAM LISTING

This section contains the HP 41-CV listing of the program or subroutine.

3. QUICK REFERENCE TABLES

The tables in this section will be useful to the user of the HP 41-CV handheld calculator as a source of quick reference. Table 1 is an alphabetical listing of all calculator displays with an explanation of their respective meaning. Table 2 lists all storage registers used and describes how they are utilized.
1. HPU1-CV Displays

**TABLE 1**

<table>
<thead>
<tr>
<th>DISPLAY</th>
<th>DEFINITION</th>
<th>UNITS</th>
</tr>
</thead>
<tbody>
<tr>
<td>a = ?</td>
<td>Slope of airfoil lift curve.</td>
<td>rad</td>
</tr>
<tr>
<td>b = ?</td>
<td>Number of main rotor blades.</td>
<td>N/A</td>
</tr>
<tr>
<td>c = ?</td>
<td>Chord length of main rotor.</td>
<td>ft</td>
</tr>
<tr>
<td>DA = ?</td>
<td>Density altitude.</td>
<td>ft</td>
</tr>
<tr>
<td>Cdc = ?</td>
<td>Main rotor coefficient of drag at zero lift.</td>
<td>N/A</td>
</tr>
<tr>
<td>PPA = ?</td>
<td>Equivalent horizontal flat plate area of the helicopter.</td>
<td>ft</td>
</tr>
<tr>
<td>h = ?</td>
<td>Weight of the main rotor above the ground.</td>
<td>ft</td>
</tr>
<tr>
<td>MCRO = ?</td>
<td>Critical Mach number for the coefficient of lift equal to zero.</td>
<td>N/A</td>
</tr>
<tr>
<td>R = ?</td>
<td>Main rotor radius.</td>
<td>ft</td>
</tr>
<tr>
<td>TWIST = ?</td>
<td>Geometric twist of the rotor.</td>
<td>rad</td>
</tr>
<tr>
<td>VF (KT) = ?</td>
<td>Forward velocity.</td>
<td>Kt</td>
</tr>
<tr>
<td>VT = ?</td>
<td>Rotor tip speed.</td>
<td>ft/s</td>
</tr>
<tr>
<td>W = ?</td>
<td>Aircraft gross weight.</td>
<td>lbs</td>
</tr>
<tr>
<td>COLL =</td>
<td>Main rotor collective pitch.</td>
<td>rad</td>
</tr>
</tbody>
</table>
CYCLIC = Main rotor cyclic pitch. rad

PT = Induced power required hp

compensated for tip losses and ground effect.

PM = Power required due to compressibility effects. hp

PO = Profile power required. hp

PS = Power required due to the retreating blade stall ing. hp

VBE = Maximum endurance velocity. Kt

VP > VMAX The forward velocity that has been input is larger than the one calculated by subroutine VMAX.

VMAX = Maximum forward velocity. Kt

VS = Initial estimate for finding onset velocity. Kt

XS = Radius outboard of which the main rotor is stalled. N/A

XO = Radius inboard of which rotor blade stall may be present. N/A

\( \alpha_90 \) = Angle of attack of the advancing blade at \( \alpha = 90 \) degrees. deg

\( \alpha_{270} \) = Angle of attack of the retreating blade.
blade at $\psi = 270$ degrees.

2. **HYDRAULIC REGISTER UTILIZATION**

### Table II

<table>
<thead>
<tr>
<th>REGISTER</th>
<th>STORED QUANTITY/USE</th>
</tr>
</thead>
<tbody>
<tr>
<td>00</td>
<td>Ground effect ratio (GE).</td>
</tr>
<tr>
<td>01</td>
<td>Maximum forward velocity (VMAX).</td>
</tr>
<tr>
<td>02</td>
<td>Stall onset velocity (VS).</td>
</tr>
<tr>
<td>05</td>
<td>Rotor radius (R).</td>
</tr>
<tr>
<td>06</td>
<td>Number of blades (h).</td>
</tr>
<tr>
<td>07</td>
<td>Zero-lift drag coefficient (Cio).</td>
</tr>
<tr>
<td>09</td>
<td>Rotor height above the ground (h).</td>
</tr>
<tr>
<td>10</td>
<td>Aircraft gross weight (W).</td>
</tr>
<tr>
<td>11</td>
<td>Air density (RHO).</td>
</tr>
<tr>
<td>12</td>
<td>Lift curve slope (a).</td>
</tr>
<tr>
<td>13</td>
<td>Rotor tip velocity (VT).</td>
</tr>
<tr>
<td>14</td>
<td>Coefficient of thrust (CT).</td>
</tr>
<tr>
<td>15</td>
<td>Tip-loss factor (STL).</td>
</tr>
<tr>
<td>16</td>
<td>Main rotor induced power (PI).</td>
</tr>
<tr>
<td>17</td>
<td>Rotor weight to rotor diameter ratio (h/d).</td>
</tr>
<tr>
<td>18</td>
<td>Compressibility power (PC).</td>
</tr>
</tbody>
</table>

53
19 Solidity (SD).
20 Induced velocity (VI).
21 Main rotor profile power (PP).
22 Advance ratio (MU).
23 Stall power (PS).
24 Advance ratio squared (MU²).
25 Forward velocity (VF).
26 Equivalent horizontal flat plate area (PPA).
27 Maximum 2-D lift coefficient (CLMAX).
28 Main rotor parasite power (PP).
29 Main rotor geometric twist (TWIST).
31 Angle of attack at 270 degrees (A270).
32 Angle of attack at 90 degrees (A90).
33 Sonic velocity (SVEL).
34 Critical Mach number for coefficient of lift equal to zero (MCRO).
35 Density altitude.

OTHERS Scratch pad calculations.
C. PROGRAM DOCUMENTATION

This section contains the necessary documentation for the HP 41-CV computer program. The main program as well as all of the subroutines used in the solution of the problem are outlined in this section.
1. Main Program

(a) PURPOSE

This program calculates the dynamic parameters of the main rotor which are necessary for calculating the total main rotor power required in forward, high speed straight and level flight. It additionally controls the execution sequence of the various subroutines which are used to calculate main rotor power required, in terms of horsepower, as well as maximum forward velocity, stall onset velocity and velocity for best endurance in knots.

(b) ASSUMPTIONS

(1) All angles are small.

(2) Steady flow through the rotor.

(3) All rotor blades are rectangular (non-tapered) with only uniform twist being possible.

(4) Only the first harmonic of flapping is necessary for calculating power required.

(5) The effective dimensionless radius can be approximated by the tip-loss factor.

(6) The thrust vector passes through the C.G.

(7) The static stall angle for blades on most helicopters can be approximated by the angle at which CLMAX occurs for the 2-D airfoil.
(8) The δ 3 effect, or the result of cocking the flapping axis of the blade so that its pitch varies as the blade flaps is zero (i.e., no lateral flapping is present).

(c) EQUATIONS

\[ \mu = \frac{V_p}{V_T} \]

\[ V_p (ft/s) = \frac{V \times 1.68834}{100} \]

\[ T_1 = 0.5 (B_{TL}^2 + 0.5 \mu^2) \]

\[ T_2 = 0.3346 B_{TL}^3 + 0.5 \mu^2 B_{TL} \]

\[ T_3 = 0.25 B_{TL}^2 (B_{TL}^2 + 0.25 \mu^2) \]

\[ T_4 = 0.5 \mu (B_{TL}^2 + 0.25 \mu^2) \]

\[ D_1 = (B_{TL}^2 - 0.5 \mu^2) \]

\[ A_{11} = 4 \left( 0.5 B_{TL}^2 - \frac{\mu^3}{8} \right) / D_1 \]

\[ A_{12} = 8 \mu B_{TL} / 3D_1 \]

\[ A_{13} = 2 \mu B_{TL}^2 / D_1 \]

\[ A_{14} = (B_{TL}^2 + 1.5 \mu^2) / D_1 \]

\[ (2C/T/\sigma_5) = \lambda T_1 + \theta \gamma 2 + \theta \gamma 3 + \theta \gamma 4 \]

\[ \theta = \lambda A_{11} + \theta A_{12} + \theta A_{13} + \theta A_{14} \]

\[ A_{max} = C_{max}/C_{LA} \]

\[ a_{max} = \theta_0 - \theta_2 + \theta \gamma 2 \left( \lambda / T_2 + \mu \right) \]

\[ \Gamma = A_{max} - \theta_0 - \theta_2 \]

\[ C_S = \mu T + \lambda \]

\[ B_S = -\mu \theta_T - \Gamma \]

\[ X_S = -B_S^2 \left( 3S^2 - 4\theta_T C_S \right)^2 / 2\theta_T \]

\[ X_S = -B_S^2 \left( 3S^2 - 4\theta_T C_S \right)^2 / 2\theta_T \]
d. FLOWCHART

```
start

Input: 
A

SP subroutine

DEN subroutine

OW subroutine

PIT subroutine

PQ1 subroutine

B
```
e. PROGRAMS AND SUBROUTINES USED

- SD
- PIT
- PO1
- PP1
- VS
- VMAX
- DEN
- CT
- LAMB
- CPS
- CPC
- a90
- CNG

GO TO A

YES = 1

D

PT1 subroutine

FINISHED?

NO = 0

END

CG subroutine
<table>
<thead>
<tr>
<th>Line</th>
<th>Description</th>
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</thead>
<tbody>
<tr>
<td>81</td>
<td>LBL &quot;WB&quot;</td>
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<tr>
<td>82</td>
<td>PROMPT</td>
</tr>
<tr>
<td>83</td>
<td>STO 05</td>
</tr>
<tr>
<td>84</td>
<td>PROMPT</td>
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<td>&quot;Ce&quot;</td>
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<td>STO 04</td>
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<td>PROMPT</td>
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<td>92</td>
<td>PROMPT</td>
</tr>
<tr>
<td>93</td>
<td>&quot;Cao&quot;</td>
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<td>94</td>
<td>XEQ &quot;D&quot;</td>
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<td>95</td>
<td>PROMPT</td>
</tr>
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<td>&quot;W&quot;</td>
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<td>&quot;VT&quot;</td>
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<td>PROMPT</td>
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<td>100</td>
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</tr>
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<td>PROMPT</td>
</tr>
<tr>
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<td>STO 13</td>
</tr>
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<td>103</td>
<td>&quot;VF(KT)=?&quot;</td>
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<tr>
<td>104</td>
<td>PROMPT</td>
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<td>105</td>
<td>*</td>
</tr>
<tr>
<td>106</td>
<td>XEQ &quot;Vmax&quot;</td>
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<td>PROMPT</td>
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<td>STO 26</td>
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<td>STO 29</td>
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<td>&quot;Me&quot;</td>
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<td>113</td>
<td>STO 12</td>
</tr>
<tr>
<td>114</td>
<td>XEQ &quot;CT&quot;</td>
</tr>
<tr>
<td>115</td>
<td>STO 09</td>
</tr>
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<td>116</td>
<td>STO 06</td>
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<tr>
<td>117</td>
<td>XEQ &quot;X9/2&quot;</td>
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<td>118</td>
<td>STO 30</td>
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<td>STO 08</td>
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<tr>
<td>120</td>
<td>XEQ &quot;Sd&quot;</td>
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<tr>
<td>121</td>
<td>STO 05</td>
</tr>
<tr>
<td>122</td>
<td>XEQ &quot;Den&quot;</td>
</tr>
<tr>
<td>123</td>
<td>PROMPT</td>
</tr>
<tr>
<td>124</td>
<td>&quot;W&quot;</td>
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<td>125</td>
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<td>126</td>
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<td>127</td>
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<td>128</td>
<td>PROMPT</td>
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<td>129</td>
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<td>130</td>
<td>PROMPT</td>
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<tr>
<td>131</td>
<td>STO 04</td>
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<tr>
<td>132</td>
<td>PROMPT</td>
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<tr>
<td>133</td>
<td>STO 03</td>
</tr>
<tr>
<td>134</td>
<td>PROMPT</td>
</tr>
<tr>
<td>135</td>
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</tr>
<tr>
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<td>137</td>
<td>&quot;YfX&quot;</td>
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<td>138</td>
<td>PROMPT</td>
</tr>
<tr>
<td>139</td>
<td>STO 06</td>
</tr>
<tr>
<td>140</td>
<td>PROMPT</td>
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<tr>
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<td>STO 03</td>
</tr>
<tr>
<td>142</td>
<td>PROMPT</td>
</tr>
<tr>
<td>143</td>
<td>STO 04</td>
</tr>
</tbody>
</table>

61
124 * 125 RCL 30 126 ENTER† 127 RCL 24 128 2 129 / 130 - 131 STO 32 132 RCL 30 133 * 134 / 135 STO 37 136 RCL 22 137 RCL 15 138 * 139 8 140 * 141 3 142 / 143 RCL 32 144 / 145 STO 38 146 RCL 22 147 2 148 * 149 RCL 30 150 * 151 RCL 32 152 / 153 STO 39 154 RCL 38 155 ENTER† 156 RCL 24 157 1.5 158 * 159 + 160 RCL 32 161 / 162 STO 40 163 RCL 14 164 2 165 * 166 RCL 12 167 / 168 RCL 19 169 / 170 STO 42 171 XEQ "LAMB"+ 172 RCL 43 173 RCL 33 174 * 175 CHS 176 RCL 42 177 * 178 RCL 29 179 RCL 35 180 * 181 - 182 STO 31 183 RCL 63 184 CHS 185 RCL 37 186 * 187 RCL 29 188 RCL 39 189 * 190 - 191 STO 32 192 RCL 34 193 * 194 ENTER† 195 RCL 31 196 RCL 38 197 * 198 - 199 RCL 34 200 ENTER† 201 RCL 48 202 * 203 RCL 36 204 ENTER† 205 RCL 38 206 *
2. **Solidity**

a. **PURPOSE**
   This subroutine calculates the ratio of total blade area to the total rotor disc area.

b. **ASSUMPTIONS**
   None

c. **EQUATIONS**

\[
\frac{b}{c} = \frac{D \times C \times R}{\pi \times R^2} = \frac{D \times C}{\pi \times R}
\]

d. **FLOWCHART**

```
start
\rightarrow calculate solidity
\rightarrow return
```
II. PROGRAMS AND SUBROUTINES USED

' WBS '

I. PROGRAM LISTING

01 LBL "SD"
02 RCL 06
03 RCL 04
04 *
05 RCL 05
06 /
07 PT
08 /
09 STO 10
10 END
3. **Downwash Velocity**

a. **PURPOSE**
   The purpose of this subroutine is to compute the induced velocity of a rotor system.

b. **ASSUMPTIONS**
   Steady flow through the rotor system.

c. **EQUATIONS**
   \[ w = \frac{W}{2\rho A V_f} \]

d. **FLOWCHART**

   ![Flowchart](image)

   - start
   - calculate downwash velocity
   - store DW in R32
   - return

e. **PROGRAMS AND SUBROUTINES USED**
   "WBS"
f. PROGRAM LISTING

01 LBL "M"
02 RCL 25
03 X=0?
04 GTO 05
05 RCL 10
06 2
07 RCL 11
08 *
09 RCL 25
10 *
11 PI
12 *
13 RCL 05
14 ×12
15 *
16 /
17 STO 64
18 GTO 06
19 LBL 05
20 SF 03
21 LBL 06
22 END
4. Coefficients of Thrust

a. PURPOSE
   This subroutine calculates the coefficient of thrust for an arbitrary rotor.

b. ASSUMPTIONS
   Steady flow through the rotor system.

c. EQUATIONS
   \[ CT = \frac{W}{\rho A v^2} \]

d. FLOWCHART
II. PROGRAMS AND SUBROUTINES USED

' WBS '

I. PROGRAM LISTING

01 LBL "CT"
02 RCL 05
03 X^2
04 PI
05 *
06 RCL 11
07 *
08 RCL 13
09 X^2
10 *
11 1/X
12 RCL 10
13 *
14 STO 14
15 END
5. **Induced Power**

(a) **PURPOSE**

This subroutine calculates the power required by the rotor to produce thrust at hover and forward flight. Additionally, this subroutine corrects for tip losses (losses in lift at the tips due to tip vortices) as well as ground effect.

(b) **ASSUMPTIONS**

Steady flow through the rotor system.

(c) **EQUATIONS**

\[
\begin{align*}
\Phi_I &= \frac{w}{2\pi} \left[ -\frac{v_i^2}{2v_i^2} + \sqrt{\left(\frac{v_i^2}{2v_i^2}\right)^2 + 1} \right]^{\frac{1}{2}} v_i \\
B &= 1.0 - \sqrt{\frac{2 \cdot C_T}{\delta}} \\
GE &= -0.1276 (h/D)^2 + 0.709 (h/D)^3 \\
&\quad - 1.4563 (h/D)^2 + 3.432 (h/D) + 0.5147 \\
FIT &= \left(\frac{1}{B}\right) \ast (GE) \ast \Phi_I
\end{align*}
\]
d. FLOWCHART

```
start

calculate tip loss factor

(\(\frac{n}{d}\) \(\geq\) 1.55 ?)

YES

\(G.E. = 1.0\)

calculate GE ratio

NO

calculate induced power

compensate for tip losses

compensate for GE

return
```
e. PROGAMS AND SUBRINTINES USED

' WBS '

f. PROGRAM LISTING

01 LBL *PIT*
02 RCL 14
03 2
04 *
05 SORT
06 RCL 06
07 /
08 CHS
09 1
10 *
11 STO 15
12 RCL 09
13 RCL 05
14 2
15 *
16 /
17 STO 17
18 1.5
19 X>Y
20 XY^2
21 GTO 05
22 RCL 17
23 1.3432
24 *
25 RCL 17
26 X^2
27 -1.4569
28 *
29 *
30 RCL 17
31 3
32 Y+X

33 .708
34 *
35 +
36 RCL 17
37 4
38 Y+X
39 -1.276
40 *
41 +
42 .5147
43 +
44 STO 00
45 GTO 06
46 LBL 05
47 1
48 STO 00
49 LBL 06
50 RCL 25
51 X^2
52 STO 32
53 RCL 10
54 2
55 /
56 RCL 11
57 /
58 PI
59 /
60 RCL 05
61 X^2
62 /

63 SORT
64 STO 20
65 X^2
66 1/X
67 RCL 32
68 *
69 2
70 /
71 CHS
72 STO 34
73 X^2
74 1
75 +
76 SORT
77 RCL 34
78 +
79 SORT
80 RCL 10
81 *
82 RCL 20
83 *
84 550
85 /
86 RCL 15
87 *
88 RCL 00
89 *
90 STO 16
91 -PI=
92 ARCL X
93 AVIEW
94 STOP
95 END

72
6. **Profile Power**

a. **PURPOSE**
   This subroutine calculates the profile power required for forward, straight and level flight in terms of horsepower.

b. **ASSUMPTIONS**
   Steady flow through the rotor system.

c. **EQUATIONS.**
   \[
   P_o = \frac{\sigma C_d \rho A_0 V_r^2 (1 + 4.25 \omega^2)}{4400}
   \] (hp)

d. **FLOWCHART**

   ![Flowchart Diagram]

   - **start**
   - calculate profile power
   - store \( P_0 \) in R21
   - return

e. **PROGRAMS AND SUBROUTINE USED**
   "WBS"
f. PROGRAM LISTING

01 LBL "PO1"
02 RCL 19
03 RCL 07
04 *
05 RCL 11
06 *
07 RCL 05
08 X^2
09 *
10 PI
11 *
12 RCL 13
13 3
14 Y^X
15 *
16 0
17 /
18 STO 21
19 RCL 24
20 4.25
21 *
22 1
23 +
24 RCL 21
25 *
26 550
27 /
28 STO 21
29 "PO="
30 ARCL X
31 AVIEW
32 STOP
33 END

74
7. **Parasite Power**

a. **PURPOSE**
   This subroutine calculates the parasite power required in forward, straight and level flight.

b. **ASSUMPTIONS**
   Steady flow through the rotor system.

c. **EQUATIONS**
   \[ PP = \frac{pfy^2}{1100} \] (hp)

d. **FLOWCHART**

```
start
  calculate parasite power
  store PP in R28
  return
```

6. **PROGRAMS AND SUBROUTINES USED**

   "WBS"
f. PROGRAM LISTING

01 LBL "PRI"
02 RCL 11
03 RCL 26
04 =
05 .5
06 =
07 RCL 25
08 3
09 *X
10 =
11 550
12 /
13 STO 29
14 *PP=
15 ARCL X
16 AVIEW
17 STOP
18 END
8. **Maximum Forward Velocity**

**a. Purpose**

This subroutine calculates the power-limited maximum speed of the specified helicopter.

**b. ASSUMPTIONS**

a. The power-limited maximum velocity may be estimated by neglecting the variation of induced power and profile power with speed.

b. Power required to hover is approximately equal to power required for maximum speed.

c. Steady flow through the rotor system.

**c. EQUATIONS.**

\[
V_{MAX} = \frac{v_f}{f/A_0} \left( \frac{4}{f/A_0} \right)^{1/3}
\]

\[
v_f = \left[ \frac{W}{2 \rho A_0} \right]^{1/2}
\]
D. FLOWCHART

start

calculate induced velocity

calculate max fwd velocity

NO
vf > vmax?
YES

return

set flag 02

NO
flag 02 set?
YES

return
display VF > VMAX
execute subroutine change
e. PROGRAMS AND SUBROUTINES USED

f. PROGRAM LISTING

01 LBL "VMAX"
02 RCL 26
03 PI
04 /  
05 RCL 05
06 X+2
07 /  
08 1 /  
09 4
10 *  
11 .3333334
12 .47
13 RCL 26
14 *  
15 STD 01
16 1.6804
17 /  
18 "VMAX="  
19 ARCL X
20 AVIEW
21 STOP
22 RCL 01
23 RCL 26
24 X+Y
25 GTO 12
26 X=Y?
27 GTO 13

28 LBL 12
29 "VF > VMAX"
30 AVIEW
31 XEQ "CMG"

32 LBL 13
33 END
9. **Best Endurance Velocity**

A. **PURPOSE**
   To calculate the value of velocity corresponding to minimum power (i.e., best endurance velocity and/or best rate of climb).

B. **ASSUMPTIONS**
   1. Steady flow through the rotor system.
   2. The variation of profile power with forward velocity is negligible.

C. **EQUATIONS**

\[
V_{BE} = \left[ \frac{W}{\rho \cdot A} \times \left( \frac{A}{3 \cdot f} \right)^{1/2} \right]^{1/2} \text{ (ft/s)}
\]

D. **FLOWCHART**

```
start
  ↓
  calculate VBE
  ↓
  convert VBE to knots
  ↓
  return
```
e. PROGRAMS AND SUBROUTINES USED

* WBS *

f. PROGRAM LISTING

10 LBL "VBE"
20 RCL 05
30 1 = 2
40 0 = 0
50 3
60 8 RCL 26
70 /
80 SORT
90 RCL 10
100 /
110 RCL 11
120 /
130 RCL 05
140 /
150 RCL 12
160 /
170 RCL 11
180 /
190 RCL 05
200 /
210 VBE = 2
220 /
230 "VBEK="
240 ARCL X
250 RVIEW
260 STOP
270 END
10. **Stall Onset Velocity**

a. **PURPOSE**
   This subroutine gives the user of the HP 41-CV an initial approximation for the velocity at which the retreating blade angle of attack is approximately equal to the static stall angle of the rotor blade.

b. **ASSUMPTIONS**
   1. Steady flow through the rotor system.
   2. Stall onset velocity is approximately equal to the velocity for best range (i.e., minimum P/V).

c. **EQUATIONS**

\[
p = \frac{(-4.25 \lambda C_{d_{0}} A_{o} V_{t})}{(4f)}
\]

\[
r = \frac{(-3 \lambda C_{d_{0}} V_{t}^{3})}{(4f)}
\]

\[
a = -1/3 \times p^2
\]

\[
b = 1/27 \times (2 \times p^2 + 27 \times r)
\]

\[
A = \left[-b/2 + (b^2/2 + a^3/27)^{1/3}\right]^{1/3}
\]

\[
B = \left[-b/2 - (b^2/2 + a^3/27)^{1/3}\right]^{1/3}
\]
d. FLOWCHART

```
start

<table>
<thead>
<tr>
<th>calculate A and B</th>
</tr>
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<tbody>
<tr>
<td>find largest cubic root</td>
</tr>
<tr>
<td>VS1 = A + B</td>
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<tr>
<td>VF = VS1</td>
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A
```

```
A

<table>
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<th>calculate a270</th>
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<td>ΔasΔERRI</td>
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NO

<table>
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<tr>
<td>α &lt; 270</td>
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<table>
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<td>VF = VF + 5</td>
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<table>
<thead>
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</tr>
</thead>
<tbody>
<tr>
<td>VF = VF - 5</td>
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</tbody>
</table>

VS = VF

return
```

e. PROGRAMS AND SUBROUTINES USED

"WBS"
f. PROGRAM LISTING

01 *LBL "VS"
02 FS? 83
03 GTO 10
04 RCL 19
05 RCL 07
06 *
07 PI
08 *
09 RCL 05
10 X^2
11 *
12 4
13 /
14 RCL 26
15 /
16 STO 03
17 RCL 13
18 *
19 4.35
20 *
21 CHS
22 STO 01
23 RCL 13
24 3
25 Y^2
26 RCL 03
27 *
28 CHS
29 STO 02
30 27
31 *
32 RCL 01
33 3
34 Y^2
35 2
36 *
37 *
38 27
39 /
40 STO 31
41 RCL 01
42 X^2
43 -3
44 1/X
45 *
46 STO 30
47 RCL 31
48 X^2
49 4
50 /
51 RCL 38
52 3
53 Y^2
54 27
55 /
56 +
57 sqrt
58 STO 33
59 RCL 31
60 CHS
61 2
62 /
63 +
64 .333334
65 Y^2
66 STO 32
67 RCL 31
68 CHS
69 2
70 /
71 RCL 33
72 -
73 .333334
74 Y^2
75 STO 34
76 RCL 32
77 +
78 STO 32
79 .25
80 *
81 RCL 02
82 +
83 STO 25
84 SF 03
85 GTO "AGN"
86 LBL 10
87 RCL 27
88 RCL 12
89 /
90 STO 31
91 RCL 41
92 -
93 X^2
94 sqrt
95 .001
96 X=0
97 X=Y?
98 GTO 11
99 RCL 31
100 RCL 41
101 X>Y?
102 GTO 12
103 RCL 41
104 RCL 31
105 X>Y?
106 GTO 13
107 LBL 12
108 RCL 25
109 5
110 -
111 STO 25
112 STO "AGN"
113 LBL 13
114 RCL 25
115 5
116 +
117 STO 25
118 GTO "AGN"
119 LBL 11
120 CF 03
121 RCL 41
122 R-D
123 "STALL="
124 ANCL X
125 AVIEW
126 STOP
127 RCL 25
128 1.66894
129 /
130 "VS="
131 ANCL X
132 AVIEW
133 STOP
134 END

34
11. Inflow Ratio

(a) PURPOSE

This subroutine calculates the ratio of the net velocity up through the rotor system to the tip speed.

(b) ASSUMPTIONS

Steady flow through the rotor system.

(c) EQUATIONS

\[
\lambda = -\frac{\sqrt{cT/2}}
\]

\[
\lambda = \frac{-cT}{2 \sqrt{\lambda^2 + \mu^2}} + \mu \tan \lambda
\]

\[
\text{D}_p = \frac{(PP*550)}{V_F}
\]

\[
\lambda_3 = -\tan \left( \frac{D_p}{\mu} \right)
\]
d. FLOWCHART

```
start

calculate initial \( \lambda_0 \)

01

\( \mu \leq 0.1 ? \)

yes

return

no

calculate \( \lambda_3 \)

calculate \( \lambda \)

\( \forall \lambda \leq 5E-5 ? \)

YES

return

NO
```
e. PROGRAMS AND SUBROUTINES USED

f. PROGRAM LISTING

01 LBL "LAMB"
02 RCL 14
03 2
04 SQR
05 SRT
06 CHS
07 STO 03
08 .1
09 RCL 22
10 X=Y?
11 GTO 06
12 RCL 28
13 558
14 *
15 RCL 25
16
17 RCL 10
18
19 STO 23
20 LBL 01
21 RCL 14
22 CHS
23 RCL 03
24 14
25 RCL 24
26 *
27 SQR
28 2
29 *
30 /
31 ENTER
32 RCL 23
33 R-D
34 TAN
35 RCL 22
36 *
37 -
38 STO 08
39 RCL 03
40 -
41 X*2
42 SRT
43 .00005
44 X=Y?
45 GTO 02
46 RCL 08
47 STO 03
48 GTO 01
49 LBL 02
50 RCL 08
51 STO 03
52 LBL 06
53 END
12. **Angle of Attack at 90 Degrees**

a. **PURPOSE**
   This subroutine calculates the angle of attack at the azimuthal position of 90 degrees.

b. **ASSUMPTIONS**
   a. Steady flow through the rotor system.
   b. Blade oscillations are periodic in nature.
   c. Only first harmonics of flapping are necessary for calculating angle of attack.
   d. The thrust vector passes through the C.G.
   e. Only uniform twist of the rotor blade is possible.

c. **EQUATIONS**

\[
\alpha_{90} = \theta_0 + \theta_2 + \theta_4 + \frac{\lambda}{(1 + \mu)}
\]
d. FLOWCHART

- start
- recall collective angle
- recall cyclic angle
- recall linear twist
- calculate α90
- store in R42
- return
e. PROGRAMS AND SUBROUTINES USED

' W8S '
' a90 '

f. PROGRAM LISTING

01 LBL "a90"
02 RCL 33
03 RCL 32
04 +
05 RCL 29
06 +
07 ENTER+
08 RCL 03
09 :*
10 RCL 22
11 +
12 /
13 =
14 STO 42
15 R-P
16 "a90="
17 RCL Y
18 VIEW
19 STOP
20 END
13. Compressibility Power

a. PURPOSE

This subroutine calculates the power required due to compressibility on the main rotor system in forward, straight and level flight in terms of horsepower.

2. ASSUMPTIONS

a. Steady flow through the rotor system.

b. The compressibility losses can be expressed as a function of the amount by which the drag divergence Mach number is exceeded at the tip of the advancing blade.

c. EQUATIONS

\[ M_{\text{tip}} = \frac{V_e + V_a}{\alpha} \]

\[ \Delta M_d = M_t - M_{\text{crit}} \ 0.06 \]

\[ M_{\text{crit}} = 0.71 - 2.3 \times \alpha 90 \]

\[ C_{pe} = \left[ 0.012 \times \Delta M_d + 0.1 \times (\Delta M_d)^3 \right] \]

\[ P_a = \frac{C_{pe} \times \rho \times \pi \times R^2 \times V_t^3}{550} \quad \text{(HP)} \]
d. FLOWCHART

1. start
2. calculate tip Mach number
3. calculate ΔMD
4. recall α90
5. calculate critical Mach No
6. calculate compressibility
7. store in R18
8. return
This subroutine estimates the additional power required in forward, straight and level flight due to retreating blade stall. Additionally, this subroutine calculates a stall correction factor, \( k \), that corrects for the special case of inboard stalling.

**ASSUMPTIONS**

a. Steady flow through the rotor system.

b. The section drag coefficient at stall jumps approximately 0.08 at stall onset.

c. The stalled area is symmetric about the 270 degree azimuthal position.

d. For all airfoils considered, the static stall angle is approximately 12.5 degrees.

c. **EQUATIONS**

\[
\frac{-\theta_s}{2 \times \theta_t} \leq 1.0
\]

where,

\[
\theta_s = -\theta \times \theta_t - \Gamma
\]

\[
\Gamma = 0.218166 - \theta + \theta^2
\]

\[
k = -\left( \frac{B_s}{2 \times \theta_t \times X_s} \right)
\]

\[
C_{\text{ps}} = \left[ \frac{C}{24 \times \rho \times (1 - \theta)^2 \times (1 - X_s) \times (1 - X_s^2)} \right]^{1/2}
\]

\[
P_s = C_{\text{ps}} \times \rho \times \rho \times R^2 \times V_t
\]
d. FLOWCHART

```
start

<table>
<thead>
<tr>
<th>NO</th>
<th>-B/2e ≤ 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>k_s = 1.0</td>
<td>calculate stall correction</td>
</tr>
</tbody>
</table>

calculate stall power

apply stall correction

return
```

e. PROGRAMS AND SUBROUTINES USED

* WBS *
* SD *
* CT *
* W *
* PPI *
* LAMB *
f. PROGRAM LISTING

01 LBL "CPS"
02 FS? 01
03 GTO 06
04 RCL 30
05 RCL 08
06 +
07 2
08 /
09 1
10 X<>Y
11 X<=Y?
12 GTO 01
13 1
14 STO 23
15 GTO 02
16 LBL 01
17 RCL 31
18 2
19 /
20 RCL 29
21 /
22 RCL 30
23 +
24 CHS
25 ENTER+
26 1
27 RCL 30
28 -
29 /
30 STO 23
31 LBL 02
32 "KS="
33 ARC L X
34 AVIEW
35 STOP
36 SF 02
37 RCL 19
38 24
39 /
40 PI
41 /
42 ENTER+
43 1
44 RCL 22
45 -
46 X^2
47 *
48 1
49 RCL 30
50 -
51 *
52 .
53 RCL 30
54 X^2
55 -
56 SQRT
57 *
58 RCL 23
59 *
60 STO 23
61 RCL 13
62 3
63 YX
64 RCL 23
65 *
66 PI
67 *
68 RCL 05
69 X^2
70 *
71 RCL 11

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15. **Total Power**

a. **PURPOSE**
   This subroutine calculates the total power required in forward, straight and level flight, to include stall and compressibility power in terms of horsepower.

c. **ASSUMPTIONS**
   Power losses, such as transmission and cooling, can be ignored.

c. **EQUATIONS.**
   \[ P_t = P_t + P_o + P_p + P_s + P_w \]

d. **FLOWCHART**

```
start
  \( \text{recall } P \text{ required} \)
  \( \text{recall } P \text{ required} \)
  \( \text{recall } P \text{ required} \)
  \( \text{recall Stall power} \)
  \( \text{A} \)
```

```
\( \text{recall } P \text{ power} \)
  \( \text{sum all power required} \)
  \( \text{return} \)
```

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e. PROGRAMS AND SUBROUTINES USED

' WBS '  
f. PROGRAM LISTING

01 LBL "PT1"
02 RCL 28
03 RCL 16
04 +
05 RCL 21
06 +
07 RCL 23
08 +
09 RCL 18
10 +
11 "PT="
12 ARCL X
13 AVIEW
14 STOP
15 END
16. **Density/Sonic Velocity**

a. **PURPOSE**
   To generate values of air density and sonic velocity.

b. **ASSUMPTIONS**
   1. Geopotential altitude (H), and geometric altitudes are equal below 20,000 feet (actual ΔH = 29 ft).
   2. In the troposphere the standard temperature lapse rate is -3.57 °F per 1000 feet.

c. **EQUATIONS**
   \[
   \Theta = \frac{T}{T_{SSL}} = (1.0 - 6.8753 \times 10^{-6} \times H)
   \]
   \[
   SVEL = SVEL_{SSL} \times \sqrt{\Theta}
   \]
   \[
   RHO = 0.0023769 \times (1.0 + HTH \times (-0.02875 + 0.000275 \times HTH))
   \]
   where,
   \[
   HTH = DA/1000
   \]

d. **FLOWCHART**

```
start
  calculate sonic velocity
    calculate air density
      return
```
e. PROGRAMS AND SUBROUTINES USED

f. PROGRAM LISTING

\begin{verbatim}
01 LBL "DEN"
02 RCL 45
03 6.875 E-6
04 * 
05 CHS
06 1
07 +
08 SQRT
09 1116.89
10 * 
11 STO 43
12 RCL 45
13 1000
14 /
15 STO 33
16 .000275
17 * 
18 -.02875
19 +
20 RCL 33
21 * 
22 1
23 +
24 .0023769
25 * 
26 STO 11
27 END
\end{verbatim}
17. **Change**

a. **PURPOSE**

This subroutine is used to expedite the changing of up to five of the input parameters whenever a design restraint is exceeded and/or at the end of the main program.

b. **ASSUMPTIONS**

The primary parameters which will require changing are:

a. Forward velocity, $VF$; (Kts)

b. Blade twist, $TW$; (rads)

c. Lift curve slope, $a$; (per rad)

d. Tip velocity, $VT$; (ft/sec)

e. Weight, $W$; (lbs)

c. **EQUATIONS**

$$VF \text{ (ft/sec)} = VF \text{ (Kts)} \times 1.58894$$
d. FLOWCHART

start

clear flag 04

yes = 1
change
data?

no = 0

set flags
04, 27

yes
flag 04
set?

no

STOP

go to IND
R31 *

DISPLAY:
VF(kts)  TW  a  VT  W

prompt: VF(kts)
change Kts to
ft/sec & store
g25

prompt: TWIST =?
store R26

prompt: vt =?
store R

prompt: a =?
store R

prompt: W =?
store R10

NOTE: * returns and
reruns main
program with
new data.
e. PROGRAMS AND SUBROUTINES USED

f. PROGRAM LISTING

01 LBL "CHG"
02 "AGH"
03 ASTO 31
04 CF 04
05 LBL 06
06 "CHANGE?"
07 PROMPT
08 X=0?
09 GTO 07
10 SF 04
11 SF 27
12 "VF TM a VT M"
13 PROMPT
14 LBL A
15 "VF(KTS)=?"
16 PROMPT
17 1.68894
18 *
19 STO 25
20 GTO 95
21 LBL B
22 "TWIST=?"
23 PROMPT
24 STO 29
25 GTO 95
26 LBL C
27 "p=?"
28 PROMPT
29 STO 68
30 GTO 85
31 LBL D
32 "VT=?"
33 PROMPT
34 STO 13
35 GTO 05
36 LBL E
37 "W=?"
38 PROMPT
39 STO 10
40 LBL 05
41 CF 27
42 GTO 06
43 LBL 07
44 FS? 04
45 GTO 101 31
46 END

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D. HP 41-CV SAMPLE OUTPUT

Depending on the value of forward velocity there are three possible types of output that the HP 41-CV computer program is capable of producing. Examples of the three possible cases are listed below.

CASE 1: Forward velocity, \( V_F \), is less than stall onset velocity.

\[
\begin{align*}
P_1 &= 791.751153 \\
P_0 &= 224.584453 \\
P_\infty &= 0.000000 \\
V_\infty &= 137.762848 \\
V_{\text{REX}} &= 76.860750 \\
V_{\text{MDX}} &= 163.448330 \\
C_{\text{CLIC}} &= 0.000000 \\
C_{\text{OLL}} &= 17.896907 \\
\gamma_{270} &= 4.380799 \\
\gamma_{90D} &= 4.380799 \\
\rho_{S} &= 0.000000 \\
\rho_{M} &= 0.000000 \\
PT &= 1.816.255606
\end{align*}
\]
CASE 2: Forward velocity, $V_F$, is greater than stall onset velocity.

$PI=113.87$
$PD=352.43$
$PP=704.24$

$VS=137.76$
$VBEK=75.86$
$VMAX=163.45$

$CYCLIC=-9.39$
$CALL=20.76$

$270=17.75$
$90D=-1.83$

$XS=0.74$
$XD=1.24$

$KS=0.96$
$PS=48.90$

$PM=253.71$

$PT=1.573.16$
CASE 3: Forward velocity, $V_F$, is greater than the maximum forward velocity possible.

$P_I=107.18$
$P_D=368.92$
$P_P=844.72$

$V_S=137.76$
$V_{BEK}=76.86$
$V_{MRK}=163.45$
$V_F > V_{MRK}$

$CYCLIC=-10.55$
$COLL=22.08$

$\Delta 270=19.87$
$\Delta 900=-1.23$

$X_S=0.73$
$X_0=1.53$

$K_S=1.00$
$P_S=156.10$

$P_M=289.23$

$P_T=1.766.15$
APPENDIX C

A. IBM 3033 PROGRAM DOCUMENTATION

This program calculates the power required to fly a helicopter in forward, straight and level high speed flight. In the sections that follow all inputs and implementation requirements are specified. The problem solving methodology used is as described in Chapter II.
B. INPUT DATA REQUIRED

In calculating the performance of a helicopter it is necessary to define a set of force conditions, environmental conditions, and physical conditions. The force conditions required are the aircraft gross weight (W) in pounds, the maximum lift coefficient (C_LMAX), and the coefficient of lift at zero angle of attack (C_L0). The environmental conditions include, forward velocity (V_FK) in knots, speed of sound (SVEL) in feet/sec, rotor height above the ground (H) in feet, and air density (RHO) in lb-ft/sec. For sake of user simplicity, the speed of sound and air density are generated within the program and are comparable to the values found in a standard atmosphere table. Finally, the physical conditions required are the rotor radius (R) in feet, tip velocity (VT) in ft/sec, number of blades (b), main rotor chord (C) in feet, flat plate area (FPA) in ft, geometric twist of the rotor (TWIST) in radians, and airfoil lift curve slope (CLA) in per radians.
C. HELICOPTER SAMPLE DATA

Table C.1 below illustrates the format required when inputing data.

<table>
<thead>
<tr>
<th>RADIUS</th>
<th>CPO</th>
<th>W</th>
<th>VI</th>
<th>FPA</th>
</tr>
</thead>
<tbody>
<tr>
<td>22.</td>
<td>.01075</td>
<td>10512.</td>
<td>738.0</td>
<td>17.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>TWIST</th>
<th>NO. BLADES</th>
<th>CHORD</th>
<th>INITIAL VEL</th>
<th>CLA</th>
</tr>
</thead>
<tbody>
<tr>
<td>-.1745</td>
<td>2.</td>
<td>2.25</td>
<td>0.0</td>
<td>5.73</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>H</th>
<th>CLMAX</th>
<th>NO. ENGINES</th>
<th>TYPE AIRFOIL</th>
<th>DA</th>
</tr>
</thead>
<tbody>
<tr>
<td>1000.</td>
<td>1.4</td>
<td>2.</td>
<td>7.</td>
<td>1000.</td>
</tr>
</tbody>
</table>
D. IBM PROGRAM FLOWCHART

start

read input data

calculate disk area

calculate solidity

calculate induced velocity

calculate AMAX

calculate coef of thrust

calculate G.E. ratio

A

A

calculate tip-loss factor

Calculate VMAX

calculate induced power

NO

h/a>1.59?

YES

apply GE ratio

GE = 1.0

correct for tip losses

calculate profile power

B

110
calculate $a_{90}$
calculate $a_{270}$
calculate comp power
calculate total power
calculate $V_{OPT}$
set $V_F = V_{OPT}$

$G$

$E$

calculate $a_{90}$
calculate $a_{270}$
calculate comp power
calculate total power
calculate $V_{OPT}$
set $V_F = V_{OPT}$

$F$
calculate $a_{270}$

$G$

$G$

$a_{270} = A_m a$

$a_{270} > A_m a$

$X2$

$VF = VF + \Delta VF$

$VF = VF - \Delta VF$

go to $F$

stop
2. IBM PROGRAM LISTING

This section contains the listing of the IBM 3033 computer program developed in this report.
THIS PROGRAM CALCULATES THE PERFORMANCE OF A HELICOPTER
FROM HOVER TO FORWARD, STRAIGHT AND LEVEL FLIGHT, HIGH
SPEED FLIGHT.

WRITTEN BY  CPT W. CARMONA (JUN 83)

INTEGER NDEG, IER, O/, CEN'/ O/
REAL LAMBDA, M, K, MCMIT, MT, H, N, LERR, MCRO, LAJB0, HTH, MCRI TO
DATA DERR, U1, NDEG, 37, LERR, 0, 001, MCMIT, O, 725, OVFK/ 10./
READ(5, 2001, CDC, W, VT, FPA, TWIST, B, C, VFK, CLA, H, CMAX, N, TYPE, DA
WRITE(6, 201)
WRITE(6, 201)

***********************************************************************
* CALCULATION OF SONIC VELOCITY AND AIR DENSITY BASE ON STANDARD *
* ATMOSPHERE TABLE *
***********************************************************************

THETA = 1., - 6.8753 E-06 * H
SVEL = 1116.89 * SQRT(THETA)
MT = EA/1000.
RHOM = 0.0023769 * (1. + HTH + - 0.02875 + .000275 * HTH)

***********************************************************************
* SELECTION OF PROPER AIRFOIL DATA FOR TYPE OF AIRFOIL CHOSEN *
***********************************************************************

IF TYPE .EQ. 4160 ID 1
IF TYPE .EQ. 3160 ID 2
IF TYPE .EQ. 4160 ID 5
IF TYPE .EQ. 3160 ID 7

NACA 0015 AIRFOIL CHARACTERISTICS
1 MCRO = 6.64
CMAX = 1.26
CLA = 5.13
GO TO 6

S1095 AIRFOIL CHARACTERISTICS
2 MCRO = 6.73
CMAX = 1.16
CLA = 5.73

GO TO 1000
GO TO 8
NACA 63 A 410.5 AIRFOIL CHARACTERISTICS

MCRO = 0.72
CLMAX = 1.27
CLA = 5.25
GO TO 8

NACA 0012 AIRFOIL CHARACTERISTICS

MCRO = 0.72
CLMAX = 1.22
CLA = 5.28
GO TO 8

NACA 0010 AIRFOIL CHARACTERISTICS

MCRO = 0.74
CLMAX = 1.22
CLA = 5.28
GO TO 8

NACA 0011 AIRFOIL CHARACTERISTICS

MCRO = 0.73
CLMAX = 1.22
CLA = 5.73
GO TO 8

AH1-J CEKA AIRFOIL CHARACTERISTICS

MCRO = 0.72
CLMAX = 1.4
CLA = 5.73

AMAX = CLMAX/CLA

WRITE(6,312)R,C,B,b,VT,FPA,H,DA,H,RHO,SVEL,TWIST,TYPE,CLMAX,AMAX,
>
CLA,CD0,MCRO,VFK

PI = 3.14159
AD = PI * (F**2)
SD = (B * C)/(PI * R)
VI = SQRT(W/2.*RHO*AD)
CT = W/(AD * RHO * (VT**2))
D = 2 * R
GE = -0.1276*(H/D)**4 + .708*(H/D)**3 - 1.4569*(H/D)**2 + 1.3432*(H/D)
>
+ .3167

IF (H/C .GE. 1.55) GE = 1.0
BTL = 1.3 - (SQRT(2.*CT)/B)
LAMBD1 = LABD1A
(REF = &USH)[LAMB]
IF (LREF < GE. 100) GO TO 67
08 LAMBD1 = LABD1

** SOLVING SIMULTANEOUS EQUATIONS FOR CYCLIC AND COLLECTIVE ANGLES **

31 E1 = (2. * CT)/(SC*CLA)
E2 = T2*LAMBD1
E3 = T3*TWIST
D1 = ((2. * CT)/(SU*CLA)) - 11*LAMBD1 - TWIST*T3
D2 = -(X11*LAMBD1) - (TWIST*A13)
CYCLIC = (L2*T2 - (101*A12))/ (T2*A14 - T4*A12)
COLL = (D1 - T4*CYCLIC) / T2
THETA0 = COLL * 57.29578
THETA2 = CYCLIC * 57.29578
WRITE6,2091A11,A12,A13,A14,T1,T2,T3,T4,LAMBD1

** CALCULATION OF STALL DYNAMIC PARAMETERS & STALL CORRECTION FACTOR **

17 GAM = AMAX - COLL + CYCLIC
CS = MU * GAM * LAMBD1
BS = -ML * TWIST - GAM
RT = (BS**2 - 1.0*TWIST*CS)
WRITE6,2291RT
IF(RT > 1.0 )19
19 XS = (1-BS + SQRT(RT))/(1.0*TWIST)
xo = -XS - ES/TWIST
WRITE6,2156GAM,CS,BS,XS,xo
IF (XS = 1.0)17
17 IF(XS>2.0)20

** CALCULATION OF STALL POWER **

21 CPS = (SC / (SQRT(1.0 - MU)**2) * (1.0 - XS)**2 * SQRT(1.0 - XS**2)
IF(XS>2.0)6GAM,BS,xo,xo2
IF (XS<0)2.0,1.0
G0 1D100 TO 24

** CALCULATES INBOARD STALL CORRECTION IF (-BS/TWIST < 1.0) **

117
C
KS = -(ES/(2.*TWIST)+XS)/(1.-XS)
24 CPS = KS * CPS
GO TO 22
20 CPS = 0.0
KS = 0.0
25 PS = CPS*RHC*AD+(VT**3)/550.
WRITE(10,216)KS,CPS
C
**********************************************************************
C* ANGLE GF ATTACK CALCULATIONS
C**********************************************************************
C
A90 = CCLL + CYCLIC + TWIST + LAMBDA/(1.*MU)
A270 = CCLL - CYCLIC + TWIST + LAMBDA/(1.*MU)
A90D = A90 * 57.29278
A270D = A270 * 57.29278
C
WRITE(16,223)CYCLIC,COLL,A90D,A270D
C
**********************************************************************
C* CALCULATION OF COMPRESSION PWER
C**********************************************************************
C
26 MT = (WF+VT)/SVEL
MCRIT = MCR - CLA * A90 * .113
IF (MT < 1.128,27,27
27 WRITE(6,240)
GO TO 32
28 DMD = PT-MCRIT - .06
IF (DMD < 2.33,33,33)
30 CPC = SC*(0.012*DMD+.1*(DMD**3))
GO TO 33
32 CPC = 0.0
DMD = 0.3
33 PM = CPC*RHC*AD*(VT**3)/550.
C
CALCULATION OF TOTAL PWER
C
PT1 = PT+PM+PS
WRITE(6,230)MT,MCRIT,DMD,CPC,PT,PV,PP,FM,PS,PT1
TSHP = 1.13*PT1 + 10.0
VFK = VF / 1.68894
VFK = VFK + DVFK
IF (VFK > LT, VMAX) GO TO 65
CENT = CENT + 1
IF (CENT > G1, 1,GO TO 97
VFK = VMAX
IF (VFK .EQ. VMAXK) GC TO 65
CONTINUE

DETERMINATION OF STALL ONSET VELOCITY

VOPT = SQRT(W/R+0.005*SQRT(ADV/3.0/FPA))
VOPTK = VOPT/1.68894
VSK = VOPTK
WRITE(6,301)VSK
VF = VFK * 1.68894
MU = VF/VT
PP = 1.5 * FHO * FPA * (VF**3) 1/550.
C1 = (BTL**2) + .5 * MU**2
C2 = (BTL**2) + .5 * MU**2
T1 = B(TL**2)/3. + (MU**2 * BTL * .51
T3 = (BTL**2/4.) * (BTL**2 + MU**2)
T4 = (ML/21 * (BTL**2 + MU**2/4))
A11 = ((BTL**2 * MU**2) - (MU**2/8.1)**4.1) / (BTL**2+C2)
A12 = (L*ML*BTL)/(15.*C2)
A13 = (L*ML*BTL)/(C2)
A14 = (BTL**2 + 1.5*MU**2)/C2

CALCULATION OF INFLOW ANGLE LAMBDA

ALPHA = -1PF550.)/VF/w
LAMBDA = -SQRT(C7/2)
IF (MU + LE + 0.11) GO TO 71
LAMBDA = -C1/SQRT(2.*(LAMBDA**2) + MU**2) + MU + TAN(ALPHA)
DLAMB = LAMDA - LAMBDA
IF (DLAMB > LAMBDA) GO TO 72
CONTINUE
IF (MU + LE + 0.11) LAMBDA = LAMBDA

SOLVING SIMULTANEOUS EQUATIONS FOR CYCLIC AND COLLECTIVE ANGLES

E1 = (12.*C1)/(50*CLAE)
E2 = T1*LAMDA
E3 = T3*TWIST
D1 = (12.*C1)/(50*CLAE) - T1*LAMDA - TWIST*T3
D2 = -(A11*LAMDA) - (1*TWIST*A13)
COMPARISON OF ACTUAL A270 TO STATIC STALL ANGLE

DA270 = A27C - AMAX
DREF = ABS(AA27C)
IF (DA270 < DREF) GO TO 85
IF (DREF < AMAX) GO TO 95
VF = VF + 1.0
GO TO 85
VF = VF - 1.0
GO TO 95
VS = VF / 1.64994
WRITE(*,243) DREF, DERR
A270D = A27C + 17.5 * 0.1
WRITE(*,241) A27D, VS, WOS, VMAX
STOP

100 FORMAT(5G12.6,5G12.6,5G12.6)
101 FORMAT(21X, 'INPUT DATA',//)
102 FORMAT(//,15X, 'HIGH SPEED FORWARD FLIGHT ANALYSIS',//)
109 FORMAT(//10X, 'DYNAMIC PARAMETERS',//)
110 A11 ........................................... *F10.6/,
111 A12 ........................................... *F10.6/,
112 A13 ........................................... *F10.6/,
113 A14 ........................................... *F10.6/,
114 T1 ........................................... *F10.6/,
115 T2 ........................................... *F10.6/,
116 T3 ........................................... *F10.6/,
117 T4 ........................................... *F10.6/,
118 T5 ........................................... *F10.6/
119 INFLATION RATIO (LAMBDA) ................... *F10.6/
215 FORMAT(//10X, 'VALUES FOR DETERMINING STALL COEFFICIENT',//)
216 GIAMMA ....................................... *F14.8/,
217 CX ........................................... *F14.8/
218 CX ........................................... *F14.8/
219 GIAMMA ....................................... *F10.7/
220 GIAMMA ....................................... *F10.7/
221 FORMAT(5X, 'INBOARD STALL CORRECTION FACTOR ................ *G16.9/',
222 //5X, 'ANGLE OF ATTACK CALCULATIONS',//)
223 AX ........................................... *F10.6/
224 AX ........................................... *F10.6/
225 AX ........................................... *F10.6/
226 AX ........................................... *F10.6/
**ALPHA = 270° (DEG)**

229 FORMAT('//10x,'STALL POWER CALCULATIONS'//'  
5x,'POWER REQUIRED'//'  
5x,'INDUCED POWER = *6X,G12.6//'  
5x,'PROFILE POWER = *6X,G12.6//'  
5x,'PARASITE POWER = *5X,G12.6//'  
5x,'COMPRESSION POWER COEFF = *G12.6//'  
5x,'TOTAL POWER REQUIRED = *G12.6//'  
5x,'FWD VELOCITY IN KNOTS = *G12.6//'  
5x,'TIP MACH NUMBER GREATER THAN OR EQUALL TO 1.0'//'  
5x,'ANGLE AT STALL ONSET = *3X,G12.6//'  
5x,'STALL ONSET VELOCITY = *3X,G12.6//'  
5x,'VELOCITY MAX ENDURANCE = *2X,G12.6//'  
5x,'MAXIMUM FORWARD VELOCITY = *G12.6//'  
5x,'DIFFERENCE BETWEEN A270 AND AMAX = *G12.6//'  
5x,'ACCEPTABLE ERROR = *G12.6//'  
5x,'PARASITE DRAG = *G12.6//'  
5x,'DISK PLANE ANGLE OF ATTACK = *G12.6//'  
5x,'INITIAL STALL ONSET VELOICITY APPROXIMATION (KTS) = *G12.6//'  
5x,'COEFFICIENT OF THRUST'  
5x,'INDUCED VELOCITY'  
5x,'DISC AREA'  
5x,'SOLIDITY'  
5x,'TIP-LOSS FACTOR'  
5x,'GROUND EFFECT RATIO'  
5x,'RADIUS'  
5x,'MAIN ROTOR CHORD'  
5x,'NUMBER OF MAIN ROTOR BLADES'  
5x,'AIRCRAFT GROSS WEIGHT'  
5x,'ROTOR TIP VELOCITY'  
5x,'HORIZONTAL FLAT PLATE AREA'  
5x,'NUMBER OF ENGINES IN HELICOPTER'  
5x,'DENSITY ALTITUDE'
MAIN ROTOR HEIGHT ABOVE GROUND: 12.0/
AIR DENSITY (RNG): 12.9/
SONIC VELOCITY: 12.0/
BLADE GEOMETRIC TWIST: 12.0/
TYPE AIRFOIL: 12.0/
MAXIMUM 2-D LIFT COEFFICIENT: 12.0/
2-D STATIC STALL ANGLE (A_MAX): 12.0/
LIFT CURVE SLOPE (/RAD): 12.0/
ZERO-LIFT DRAG COEFFICIENT: 12.0/
CRITICAL MACH NO. (FCR_CL = 3): 12.0/
INITIAL FORWARD VELOCITY (KT): 12.0/
SAMPLE OF IBM COMPUTER OUTPUT

This section contains an example run of the IBM computer program, utilizing AH-1 Cobra data, starting at a forward velocity of 120 knots and terminating at VMAX.
# High Speed Forward Flight Analysis

**Input Data**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radius</td>
<td>22,000003</td>
</tr>
<tr>
<td>Main Rotor Mcg</td>
<td>22,250003</td>
</tr>
<tr>
<td>Number of Main Rotor Blades</td>
<td>24,000000</td>
</tr>
<tr>
<td>Aircraft Gross Weight</td>
<td>10612.0</td>
</tr>
<tr>
<td>Rotor Tip Velocity</td>
<td>728,000</td>
</tr>
<tr>
<td>Horizontal Flat Plate Area</td>
<td>11,00000</td>
</tr>
<tr>
<td>Number of Engines in Helicopter</td>
<td>3,00000</td>
</tr>
<tr>
<td>Density Altitude</td>
<td>1000.00</td>
</tr>
<tr>
<td>Main Rotor Height Above Ground</td>
<td>100/00</td>
</tr>
<tr>
<td>Air Density (Rmc)</td>
<td>0.302390</td>
</tr>
<tr>
<td>Sonic Velocity</td>
<td>1113.34</td>
</tr>
<tr>
<td>Blade Geometric Twist</td>
<td>-174500</td>
</tr>
<tr>
<td>Type Airfoil</td>
<td>7.000000</td>
</tr>
<tr>
<td>Maximum 2-D Lift Coefficient</td>
<td>1.400000</td>
</tr>
<tr>
<td>2-D Static Stall Angle ((\alpha_{max}))</td>
<td>24.3320</td>
</tr>
<tr>
<td>Lift Curve Slope (/rad)</td>
<td>5.73600</td>
</tr>
<tr>
<td>Zero-Lift Drag Coefficient</td>
<td>0.910730</td>
</tr>
<tr>
<td>Critical Mach NC (for (\alpha_{c} = 0))</td>
<td>0.720000</td>
</tr>
<tr>
<td>Initial Forward Velocity (Kt)</td>
<td>120.0000</td>
</tr>
<tr>
<td>Coefficient of Thrust</td>
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<td>Tip-Loss Factor</td>
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<td>Ground Effect Ratio</td>
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**Parasite Drag = 804.258**

**Disk Plane Angle of Attack = -0.759760E-01**

**Dynamic Parameters**

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<td>A13</td>
<td>0.572130</td>
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<td>A14</td>
<td>1.123432</td>
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<tr>
<td>T1</td>
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<td>0.2450381</td>
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<td>Inflow Ratio ((\lambda_{BL}))</td>
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STALL POWER CALCULATIONS

INBOARD STALL CORRECTION FACTOR........... 0.0
STALL POWER COEFFICIENT..................... 0.5

ANGLE OF ATTACK CALCULATIONS

LONGITUDINAL CYCLIC ANGLE........... -0.109013
LONGITUDINAL COLLECTIVE ANGLE........... 0.314954
ALPHA(90) (JEG)........................ -0.048086
ALPHA(270) (DEC)...................... 12.311994

HIGH SPEED MACH EFFECTS

ADVANCING BLADE TIP MACH NUMBER...... 0.845366
CRITICAL MACH NUMBER.................. 0.723433
DRAG DIVERGENCE MACH NUMBER........... 0.649159E-01
COMPRSIBILITY POWER COEF.............. 0.521491E-04

****************************************************

POWER REQUIRED

****************************************************

INDUCED POWER = 151.545
PROFILE POWER = 2964.464
PARASITE POWER = 297.103
COMPRSIBILITY POWER = 134.301
STALL POWER = 0.0

TOTAL POWER REQUIRED = 879.112

****************************************************

FORWARD VELOCITY IN KNOTS = 130.000

****************************************************

PARASITE DRAG = 946.234
DISK PLANE ANGLE OF ATTACK = -.891604E-01

DYNAMIC PARAMETERS

A11................................. 0.680172
A12................................ 0.880877
A13................................. 0.623882
A14................................ 1.207472
T1................................ 0.470875
T2................................ 0.325344
T3................................ 0.221234
T4................................ 0.136796
INFLOW RATIO (LAMBDAA)............... -0.046428

125
STALL POWER CALCULATIONS

\[ R_T = 7.984 \times 10^{-2} \]

INBOARD STALL CORRECTION FACTOR........ 0
STALL POWER COEFFICIENT................. 0

ANGLE OF ATTACK CALCULATIONS

\[ \alpha (90^\circ) = 0.123 \]
\[ \alpha (120^\circ) = 0.294 \]

HIGH SPEED MACH EFFECTS

ADVANCING BLADE TIP MACH NUMBER........ 8.603
CRITICAL MACH NUMBER.................. 7.233
CRITICAL DIVERGENCE MACH NUMBER......... 7.791
COMPRESSION POWER COEFFICIENT........... 0.240

------------------------------
PWRER REQUIRED
------------------------------

INDUCED POWER = 1.399
PROFILE POWER = 3.989
PARASITE POWER = 3.771
COMPRESSIBILITY POWER = 1.620
STALL POWER = 0
TOTAL POWER REQUIRED = 9.864

------------------------------
FORWARD VELOCITY IN KNOTS = 140.0
------------------------------

PARASITE DRAG = 1.097
DISK PLANE ANGLE OF ATTACK = -0.1034

DYNAMIC PARAMETERS

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<th>A1</th>
<th>A2</th>
<th>A3</th>
<th>A4</th>
<th>T1</th>
<th>T2</th>
<th>T3</th>
<th>T4</th>
<th>LAMBDA</th>
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<td>0.679</td>
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<td>0.474</td>
<td>0.320</td>
<td>0.249</td>
<td>0.147</td>
<td>0.350</td>
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126
STALL POWER CALCULATIONS

RT .......................................................... -3.8970E-02
INBOARD STALL CORRECTION FACTOR .......... 0
STALL POWER COEFFICIENT ...................... 0

ANGLE OF ATTACK CALCULATIONS

LONGITUDINAL CYCLIC ANGLE ............. -0.136576
LONGITUDINAL COLLECTIVE ANGLE ........ -0.339933
ALPHA(90) (DEG) .............................. -0.520492
ALPHA(270) (DEG) ............................. 13.12913

HIGH SPEED MACH EFFECTS

ADVANCING BLADE TIP MACH NUMBER .... 0.875484
CRITICAL MACH NUMBER ..................... 0.75882
DRAG DIVERGENCE MACH NUMBER .......... 0.86012E-01
COMPRESSIBILITY POWER COEFF .......... 7.45873E-04

********************************************

PCWER REQUIRED

********************************************

INDUCED POWER = 129.913
PROFILE POWER = 322.449
PARASITE POWER = 471.789
COMPRESSIBILITY POWER = 151.657
STALL POWER = 0
TOTAL POWER REQUIRED = 1115.81

********************************************

FORWARD VELOCITY IN KNOTS = 150.000

********************************************

PARASITE DRAG = 1259.78
DISK PLANE ANGLE OF ATTACK = -0.118713

DYNAMIC PARAMETERS

A11 ................................................. 0.751849
A12 ................................................. 1.934476
A13 ................................................. 1.734801
A14 ................................................. 1.281061
A1 .................................................. 0.5782098
A2 .................................................. 0.3298187
A3 .................................................. 0.4278153
A4 .................................................. 0.349103
INFLOW RATIO (LAMBDA) ..................... 0.3956720

127
STALL POWER CALCULATIONS

RT.................... 230777E-02

VALUES FOR DETERMINING STALL COEFFICIENT

\[
\begin{align*}
\text{GAMMA} & = -6.26459390 \\
\text{C} & = -6.141355927 \\
\text{S} & = 0.32449627 \\
x & = 0.7921403 \\
x & = 1.66749362
\end{align*}
\]

INBOARD STALL CORRECTION FACTOR........... 0.62218694
STALL POWER COEFFICIENT.................... 1.1202595E-04

ANGLE OF ATTACK CALCULATIONS

LONGITUDINAL CYCLIC ANGLE ........... -0.152545
LONGITUDINAL COLLECTIVE ANGLE ....... 0.356377
ALPHA (90) (DEG) .................. -0.738687
ALPHA (270) (DEG) .................. 16.740753

HIGH SPEED MACH EFFECTS

ADVANCING BLADE TIP MACH NUMBER .... 0.890658
CRITICAL MACH NUMBER ........... 0.728348
DRAG DIVERGENCE MACH NUMBER ...... 0.102339
COMPRESSIBILITY POWER COEFF .......... 0.867833E-04

****************************************************

POWER REQUIRED

****************************************************

INDUCED POWER = 121.281
PROFILE POWER = 336.941
PARASITE POWER = 580.279
COMPRESSIBILITY POWER = 228.099
STALL POWER = 80.1774
TOTAL POWER REQUIRED = 1341.69

****************************************************

FORWARD VELOCITY IN KNOTS = 160.000
****************************************************

PARASITE DRAG = 1433.35
DISK PLANE ANGLE OF ATTACK = -0.135048
### DYNAMIC PARAMETERS

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<td>( A_{13} )</td>
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<td>( A_{15} )</td>
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<td>( T_1 )</td>
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<td>( \text{INFLOW RATIO (LAMBDA)} )</td>
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### STALL POWER CALCULATIONS

RT: 1158.52E-01

### VALUES FOR DETERMINING STALL COEFFICIENT

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<td>-C.3019456</td>
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<td>( C_B )</td>
<td>-C.1751545</td>
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<td>( B_S )</td>
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<td>( X_S )</td>
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<td>( X_D )</td>
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\( \text{INBOARD STALL CORRECTION FACTOR} \): 1.0000000

\( \text{STALL POWER COEFFICIENT} \): 0.6934921E-04

### ANGLE OF ATTACK CALCULATIONS

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<td>( \text{LONGITUDINAL COLLECTIVE ANGLE} )</td>
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<td>( \text{ALPHA (90) (DEG)} )</td>
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<td>( \text{ALPHA (270) (DEG)} )</td>
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### HIGH SPEED MACH EFFECTS

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<td>73.723</td>
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<td>( \text{DRAG DIVERGENCE MACH NUMBER} )</td>
<td>115133</td>
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<td>( \text{COMPRESSIBILITY POWER COEFF.} )</td>
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**POWER REQUIRED**

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<td>( \text{PARASITE POWER} )</td>
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<td>( \text{COMPRESSIBILITY POWER} )</td>
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<td>( \text{STALL POWER} )</td>
<td>155.386</td>
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<td>( \text{TOTAL POWER REQUIRED} )</td>
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129
FORWARD VELOCITY IN KNOTS = 165.359

PARASITE DRAG = 1494.4
DISK PLANE ANGLE OF ATTACK = -140.799

DYNAMIC PARAMETERS

\[
\begin{align*}
A_{11} &= 0.868277 \\
A_{12} &= 1.141191 \\
A_{13} &= 0.810842 \\
A_{14} &= 1.337756 \\
T_1 &= 0.482689 \\
T_2 &= 0.349822 \\
T_3 &= 0.232734 \\
I_n &= 0.174297 \\
\text{INFLOW RATIO (LAMBDA)} &= 0.027526
\end{align*}
\]

STALL POWER CALCULATIONS

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<th>(155987)E-01</th>
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VALUES FOR DETERMINING STALL COEFFICIENT

\[
\begin{align*}
\text{GAMMA} &= -C.31570089 \\
\text{CS} &= -C.18585188 \\
\text{BS} &= 0.36093623 \\
X_S &= 0.7336488 \\
X_0 &= 1.4493771
\end{align*}
\]

INBOARD STALL CORRECTION FACTOR \(\ast\) \(1.00000000\)
STALL POWER COEFFICIENT \(\ast\) \(61189760\)E-04

ANGLE OF ATTACK CALCULATIONS

\[
\begin{align*}
\text{LONGITUDINAL CYCLIC ANGLE} &= -3.177004 \\
\text{LONGITUDINAL COLLECTIVE ANGLE} &= 0.382947 \\
\text{ALPHA(90) (DEG)} &= -1.019017 \\
\text{ALPHA(270) (DEG)} &= 19.272048
\end{align*}
\]

HIGH SPEE MACH EFFECTS

\[
\begin{align*}
\text{ADVANCING BLADE TIP MACH NUMBER} &= 913929 \\
\text{CRITICAL MACH NUMBER} &= 731516 \\
\text{DRAG DIVERGENCE MACH NUMBER} &= 119.12 \\
\text{COMPRRESSIBILITY POWER COEFF} &= 1.04241E-03
\end{align*}
\]

130
***************

POWER REQUIRED

***************

INDUCED POWER = 111.388
PROFILE POWER = 337.861
PARASITE POWER = 79.536
COMPRESSIBILITY POWER = 267.985
STALL POWER = 157.023
TOTAL POWER REQUIRED = 1643.66

INITIAL STALL ONSET VELOCITY APPROXIMATION (KTS) = 76.

DIFFERENCE BETWEEN A270 AND A MAX = 0.299871E-03
ACCEPTABLE ERROR = .100000E-02

***************

ANGLE AT STALL ONSET= 13.9811
STALL ONSET VELOCITY = 131.913
VELOCITY MAX ENDURANCE = 76.0347
MAXIMUM FORWARD VELOCITY = 103.359

***************
G. COMPARISON OF PROGRAM OUTPUT VS TEST DATA

This section compares the output of the HP41-CV and IBM 3033 computer programs to actual flight test data gathered at the Naval Weapons System Center.
Figure C.1. Power Curves Generated by HP41-CV Program.
POWER REQUIRED VS VELOCITY FOR THE AH1-J USING THE IBM 3033

Figure C.2. Power Curves Generated by the IBM 3033 Program.
Figure C.3. Comparison Between Computer Data and Actual Test Flight Data.
LIST OF REFERENCES


3. NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS TN 2655; A BLADE ELEMENT ANALYSIS FOR VERTICAL TAKEDOWN. NAVAL POSTGRADUATE SCHOOL, 1952.


5. NAVAL SURFACE WEAPONS CENTER NSWC/DR-TE-3823; A COMPUTER MODEL FOR DETERMINING AERONAUTICS EFFECTS ON A NON-AERODYNAMIC EFFECTS RESPONSE. BY MANNIS, P. P., AND McCORMICK, B. W., OCTOBER 1978.


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