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ARMY RESEARCH LABORATORY

Helicopter Performance Evaluation (HELPE) Computer Model

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A HELicopter Performance Evaluation (HELPE) computer model has been developed. The model is empirically based on the energy balance method. For a helicopter at a given mission, the model computes for a helicopter at given weight and flight conditions, the maximum possible level speed, its maneuverability in a turn, and its hover and climb capabilities in the in-ground and out-of-ground effects modes. The code also computes the speeds of maximum endurance in the air and of maximum range for the helicopter.

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1. INTRODUCTION

The Vulnerability/Lethality (V/L) Process Structure (Walbert et al. 1993), as viewed in Figure 1, is the framework in which the Army now conducts V/L analyses. The basis for the taxonomy of the V/L spaces comes from the recognition that V/L analyses pass through distinct levels of information in a precise order. These levels are:

Level 1 - Threat/Target Interaction; Threat/Target encounter conditions,
Level 2 - Target Component Damage States,
Level 3 - Target Capability States, and
Level 4 - Target Combat Utility.

The mappings by which one passes from one level to the next are dependent on different kinds of information at each level. For instance, proceeding from level 1 to level 2, or the O_{12} mapping, describes the physics of the threat/target interaction. Proceeding from level 2 to level 3 (the $O_{2,3}$ mapping) requires the use of engineering measurables/performance models that can be described by fault trees. Basically, fault trees describe how target components interact, in an engineering sense, to achieve a capability. The Degraded States Vulnerability Methodology (DSVM) is one example of an $O_{2,3}$ mapping (Kunkel 1994). In the case of aircraft flight, the capabilities are dependent on such environmental factors as air density and mission configuration. Therefore, to implement the $O_{2,3}$ in general mission independent terms, the capabilities must be expressible in the form of functions relating the capabilities parametrically to these environmental factors. The methodology HELicopter Performance Evaluation (HELPE) presented in this report, provides such functional relationships and form the theoretical foundation for aircraft DSVM. The logic within HELPE and DSVM will assist in the development and evaluation of the time-dependent fault trees that will be incorporated into each analysis. Time-dependent fault trees are the evaluation of damage mechanisms such as fluid leakers (fuel, lubrication, and hydraulic) from tanks and lines, crack propagation of a component or contamination of a component by means of nuclear, biological, and chemical munitions. Eventually, HELPE and DSVM will be incorporated into the new stochastic V/L now known as the Modular Air-System Vulnerability Estimation Network (MAVEN).

MAVEN is a stochastic, point burst model (method) for rotary/fixed wing aircraft and missile systems capable of both vulnerability/lethality and battle damage repair (BDR) analyses. The model is applicable during all phases of the acquisition cycle and will be used in determining predictions for live-fire tests.

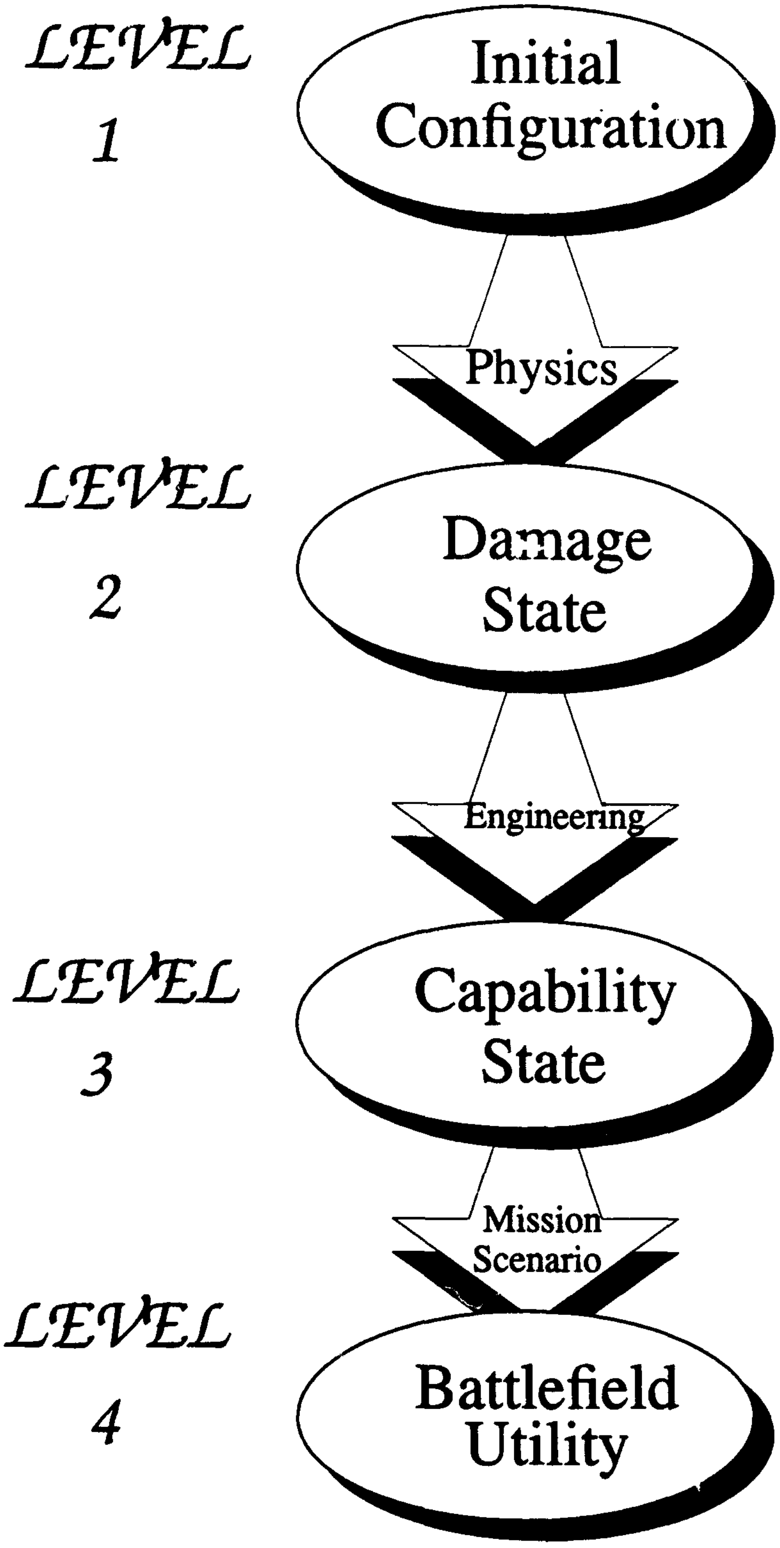


Figure 1. Schematic representations of the vulnerability process, its levels, and mappings.

Finally, MAVEN will fill a void in the current V/L analyses by providing results that are observable and/or measureable (Roach 1994).

Helicopters are widely used by the various armed services to perform many of the unique missions to which they are adapted. Their ability to take off and land vertically, to hover, to fly close to the ground surface, and to land almost anywhere make them ideal to perform many of the functions that cannot be performed by other aircraft. In the military services, helicopters are used for close support of ground combat forces and to quickly transport such forces. Helicopters are also used for various rescue missions and in naval operations. Basically, a helicopter is an aircraft that uses rotating wings to generate lift to support its weight and power to propel it through the air and to control its flight.

Helicopters are designed to perform specific mission objectives. During the design stage, it is desirable to be able to evaluate the performance capabilities of a proposed design. For threat helicopters, one also wishes to assess their performance capabilities on the basis of their known physical characteristics. There are two known methods for evaluating the performance of a helicopter. The first method is called the "force balance method" and the second method is called the "energy balance method." In the force balance method, the forces on the different blade elements of the rotors are integrated to evaluate the net rotor force and the net torque. The helicopter is trimmed to force and moment equilibrium to maintain a specified flight condition. The determination of these forces and moments requires knowledge of the rotor-induced velocity, as well as the rotor blades motion. In the energy balance method of analysis, one evaluates the power required to balance the individual sources of energy losses. Thus, power is required to overcome the profile drag and the induced drag of the rotor. Power is also required to overcome the parasitic drag and to provide power for the helicopter to climb vertically. The energy method is the simpler method to use. Both methods give approximate results. One of the main sources of errors is the difficulty of accurately accounting for the many sources of energy losses such as at the transmission rotor interface, the rotor hub, the tail rotor, the landing gear, and the pods.

Helicopter performance assessment usually addresses the following questions:

- For a given helicopter at given flight conditions and specified mission weight, how fast can the helicopter cruise in level flight conditions?

- Can it hover in the out-of-ground effect mode (OGE) and/or in the in-ground effect (IGE) mode?

- What is its maximum vertical rate of climb from a hover position?

- What is the speed for maximum endurance in the air?

- At what speed must the helicopter fly for a maximum range?

- What is its autorotational descent capability?

The computer model HELPE addresses all the questions posed above except for the autorotational descent capability.

Implementing this model within DSVM will yield capabilities parametrically as a function of energy loss. For example, the parameters include such items as net rotor force and net torque. The questions above will satisfy the $O_{2,3}$ mapping as viewed in the V/L process structure.

2. THE HELPE COMPUTATIONAL MODEL SETUP

HELPE is organized in a main program (called MAIN) and seven subroutines with descriptive names. The program MAIN plays the primary role in the computation. It reads the input and writes it to output, sets up the computation, and calls the various subroutines needed to perform different aspects of the performance evaluation. The principal part of the computation is performed in three nested DO loops. The first loop is indexed to conduct the computation for the first NWT cases of the desired operational mission weights. A one-dimensional weight array (WT) with six elements is defined before entering the DO loop together with various other parameters needed to define the operational conditions of the flight. A one-dimensional speed array VF consisting of 16 elements representing forward level speeds is then defined, which covers the whole range of possible flight speeds. The six elements of WT are defined as the overloaded gross weight, the gross weight, the average of the gross and empty weights, and the one- and two-thirds load weights. The elements of VF start at 30 knots and increase in steps of 10 knots. The subroutine PAVAIL is then called to compute four arrays of available power with elements corresponding to the forward level speeds array. The four arrays correspond to the power available from one or two engines at the maximum continuous power (MCP) or at the intermediate rated power (IRP) settings. A second primary DO loop is then entered in which the power required for each of NFV (<=20) level flight speeds is computed. This computation is basically accomplished by calling the subroutine CQINT. This subroutine computes for a given coefficient of thrust (CT), and advance ratio XMU a torque coefficient CQ0. Subroutine CQINT computes the torque coefficient by means of a two-dimensional interpolation of a table of data consisting of values of CQ corresponding to values of XMU and CT. This table of data is read into the code as a part of the input on tape unit three by subroutine RDATA. Actually, the values of CT in the table are multiplied by 10^4, and the values of CQ are multiplied by 10^5. This table of data is for a base helicopter system. Two corrections are then applied to CQ0 to determine the value of CQ for the candidate helicopter. The first correction DCQ accounts for the additional torque required because of the differences in the frontal drag area between the base and the candidate helicopter. The second correction accounts for the differences in the efficiencies of the rotor system in generating thrust. CQ is then multiplied by an appropriate scaling power factor to determine the power required for the horizontal flight for the corresponding speed and mission weight. Finally, a third DO loop is entered in which the additional power required for vertical climb is computed. The evaluation of this additional power is made for NCR (<=10) different rates of climb which are part of the input. The first rate of climb should always be zero and should correspond to level flight conditions. For the level flight case, subroutine CTINT is called to compute for the available powers, the performance capabilities of the helicopter and its maneuverability. CTINT computes the maximum thrust that can be generated, the load factor, the bank angle, the turn radius, the rate of turn, and the lateral acceleration for the maximum continuous power available and the maximum available power.

Program MAIN also evaluates the possible cruise speeds of a helicopter corresponding to the available power settings. Program MAIN also computes for the candidate helicopter the power required to hover and to do a vertical climb from theoretical considerations. This theoretically computed power takes into consideration the power required by the tail rotor to trim the helicopter. The actual calculations are described later. MAIN finally computes the hover, maneuverability, and vertical climb capability in the OGE mode with two engines and with one engine power. This hover and vertical climb performance is then repeated in the IGE mode. This cycle of calculations is repeated for each of the NWT mission weights desired.

3. SUBROUTINE FUNCTIONS

This section describes the functions performed by each subroutine.

3.1 MAIN. This subroutine reads the input defining the physical characteristics of the candidate helicopter and the desired operational conditions and writes it to output. It calls subroutine RDATA to read and write tables of input data. It sets up the computational flow and calls subroutines CQINT, PAVAIL, CTINT, VINDRA, and GE to compute some aspects of the performance evaluations. This module also evaluates the cruise speeds and the hover and vertical climb capabilities.

3.2 RDATA. This subroutine reads three tables of data from input and writes them to output. The first two tables consist of values of torque coefficients $CQ \times 10^5$ as functions of thrust coefficients $CT \times 10^4$ and speed ratio XMU. The two tables correspond to two different RPM settings of the rotor for the OGE mode. The third table is for hover in the IGE mode.

3.3 PAVAIL. This subroutine computes the power available as a function of speed. The four arrays of power available, PAC1, PAM1, PAC2, and PAM2, are defined for the available power from one and two engines.

3.4 CQINT. This subroutine computes the power required by the helicopter to fly at a certain speed in level flight for the given mission weight being considered.

3.5 CTINT. This subroutine computes the level flight maneuver capability of the helicopter for the available continuous and maximum power.

3.6 VINDRA. This subroutine calculates the velocity at which the helicopter will have to fly to remain airborne the maximum amount of time. This is the velocity that corresponds to the minimum fuel flow consumption. This subroutine also calculates the velocity that will give maximum flight range.

3.7 GE. This subroutine calculates for the hover mode in IGE, the required CQ for the mission CT. It also calculates for a given CQ, the maximum CT that can be generated.

3.8 LACC. This subroutine calculates for the hover mode in OGE, the maximum thrust that can be generated for the power available.

3.9 GENLSQ. This is a general least squares fit subroutine of data. The subroutine is taken from the system's math library.

3.10 <u>MATINV</u>. This is another subroutine from the system's math library. MATINV is used by GENLSQ for inverting matrices.

3.11 <u>FNEQS</u>. This is another subroutine from the system's math library. FNEQS is used by GENLSQ.

4. THE MATHEMATICAL MODELS

4.1 <u>Mathematical Models and Techniques</u>. This section discusses some of the mathematical models and techniques that were used in this code. The first model discussed is the computation of the availab engine power. Data (see Table 1) of the power output of the T700-GE-700 engine at various altitudes h, International Standard Atmosphere (ISA) conditions, and zero airspeed indicate that the available power output is a linear function of the altitude "h." This data shown in Table 1, and plotted in Figure 2, is derived from General Electric (1976).

Table 1. T700-GE-700 Available Engine Power as a Function of Altitude "h"

	Altitude h (ft)				
	0.0	5,000	10,000	15,000	20,000
IRP (HP)	1,540	1,360	1,164	960	770
MCP (HP)	1,254	1,145	1,000	850	720

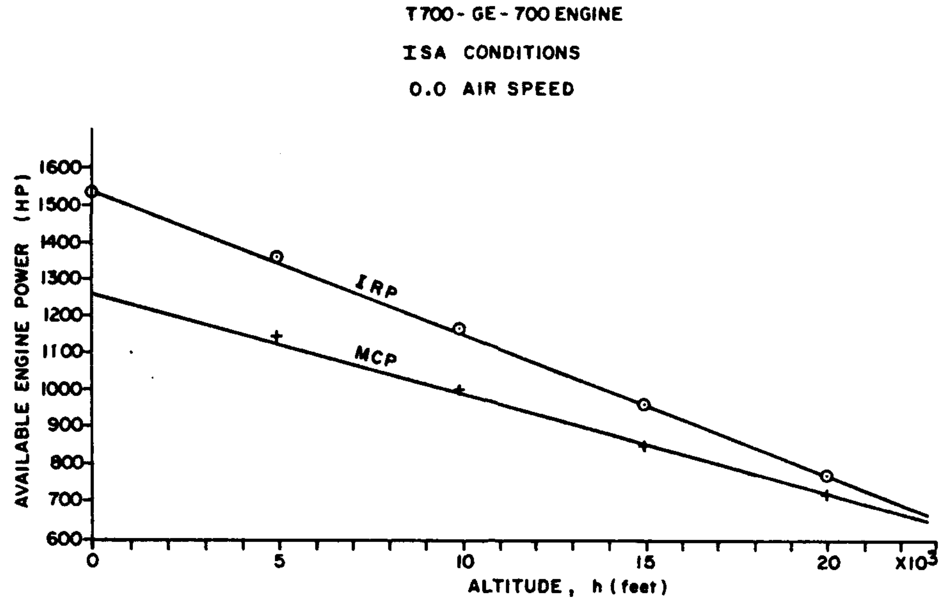
Source: General Electric (1976).

A linear regression fit of this data gives the following equations:

$$\mathrm{IRP}(h) = 1546.8 - 0.0388\ h \tag{1}$$

$$\mathrm{MCP}(h) = 1266 - 0.0273\ h \tag{2}$$

Equations 1 and 2 are only applicable to the T700-GE-700 engine. In program MAIN, the variables HIRP and HMCP represent the intermediate rated power and the maximum continuous power at altitude h and are expressed as linear functions of h. The sea level values of these variables, SIRP and SMCP, as well



Source: General Electric (1976).

Figure 2. Available engine power output as a function of altitude "h."

as the slopes of these lines, DIRPDH and DMCPDH, are therefore part of the required input for an engine. The computed available powers at altitude h are assumed to be at ISA temperatures; hence, a correction must be made if the temperatures were different from standard ISA conditions. Again, the available power is assumed to be a linear function of the temperature; hence; the slopes of the functions with respect to the temperature DIRPDT and DMCPDT need to be given on input for each engine. The resulting available power functions at temperature T, for the engines TIRP and TMCP, are then used by subroutine PAVAIL to define the available power at each speed for the one and two engine operations at the two power settings of IRP and MCP. For speeds exceeding 50 knots, the available power increases slightly. PAVAIL uses the equations:

$$\begin{aligned} PAC1(I) &= TMCP, \\ PAM1(I) &= TIRP, \quad \text{for } VF(I) \leq 50.0\ , \\ PAC1(I) &= TMCP + 0.42\ (VF(I) - 50.0), \quad \text{and} \\ PAM1(I) &= TIRP + 0.62\ (VF(I) - 50.0) \quad \text{For } VF(I) > 50.0\ . \end{aligned} \tag{3}$$

These equations (3) are based on fits of the data for the T700-GE-700 engine and are only valid for it.

The second model discussed is the computation of the power required for a given level flight at speed V and weight W. The speed is represented by the dimensionless advance ratio,

$$\mu = V/V_t, \tag{4}$$

$$V_t = 2 \pi R . N, \tag{5}$$

where V_t is the rotor tip velocity, R its radius, and N is the number of rotor revolutions per second. The initial estimate of scaled power required CQ0 is computed by subroutine CQINT. This computation is achieved by interpolating μ and CT. This computed value CQ0 represents the power required by the base helicopter at the specified CT and μ. Two corrections have to be implemented to determine the power required for the candidate helicopter. The first correction is needed to account for the differences in the frontal drag area between the base helicopter and the candidate helicopter. The power required for a helicopter of weight W to fly at level forward speed V can be written as in McCormick (1967):

$$P = Po + 0.5 W^2/(\rho A V) + 0.5.\rho.f \cdot V^3 \tag{6}$$

$$f = C_d \cdot A_f. \tag{7}$$

The first term on the right-hand side of Equation 6, Po, represents the rotor blades' profile drag; the second term represents the induced drag; and the third term represents the parasitic drag. The profile drag varies very slowly with V^2 but can be considered to remain approximately a constant. The induced drag term dominates at low speeds but becomes negligible in comparison with the parasitic drag at high speeds, or equivalently large values of μ. Thus, for large values of μ (i.e., μ > 0.30),

$$P \approx P_p = 0.5\rho.f. V^3. \tag{8}$$

P_p is the parasitic power lost to drag, ρ is the air density, C_d is the body drag coefficient, and A_f is the frontal body drag area. Let CQ and CP be the coefficients of torque and power then from their usual definitions:

$$CQ = CP = P/\left(\pi R^2 \rho V_t^3\right), \tag{9}$$

where R is the main rotor radius. Using Equation 8, Equation 9 reduces to

$$CQ = CP = 0.5\ C_d\ A_f\ \mu^3/(\pi R^2). \tag{10}$$

Differentiating Equation 10 with respect to μ^3 while holding other parameters constant,

$$\Delta CQ = 0.5\ C_d\ A_f\ \Delta\mu^3/(\pi R^2);$$

hence,

$$C_d = 2\ \pi R^2\ \ \Delta CQ/(A_f\ .\ \Delta\mu^3). \tag{11}$$

Let CQ_1; CQ_2 correspond to the large values μ_1 and μ_2, respectively. Then

$$C_d = \left(2\ \pi R^2\ /A_f\right)\ \left(CQ_2 - CQ_1\right) / \left(\mu_2^3 - \mu_1^3\right). \tag{12}$$

Let $\mu_2 = 0.36$ and $\mu_1 = 0.34$; then we can evaluate C_d from Equation 12 for the base helicopter. To calculate the correction in the value of CQ due to the difference in the frontal drag area between the candidate helicopter and base helicopter, we differentiate Equation 10 with respect to the ratio $A_f/(2\ \pi R^2)$ while holding μ constant and assume that C_d remains constant. Thus,

$$(\Delta CQ)_d = (CQ)_c - (CQ)_b = C_d\ \left[(A_f/2\ \pi\ R^2)_c - (A_f/2\ \pi R^2)_b\ \right]\ .\ \mu^3. \tag{13}$$

The c and b subscripts refer to the candidate and base helicopter, respectively. Thus, $(\Delta CQ)_d$ is the correction that needs to be applied in this case. $(CQ)_b$ is the torque coefficient for the base helicopter which is denoted in the code by CQ0; therefore,

$$(CQ)_c = (CQ)_b + (\Delta CQ)_d. \quad (14)$$

The second correction that needs to be made is to account for the differences in the efficiency of the rotor systems of the candidate and base helicopters in producing thrust. This is accounted for by dividing the computed $(CQ)_c$ by an efficiency factor e (EFF in HELPE) that represents the efficiency of the candidate helicopter system in producing thrust relative to the base helicopter system.

$$CQ = (CQ)_c/e = \left[(CQ)_b + (\Delta CQ)_d \right] /e. \quad (15)$$

The powers required for the horizontal flight denoted by P_h is

$$P_h = CQ \,.\, P_{sc}, \quad (16)$$

$$P_{sc} = \pi R^2 \,.\, \rho \,.\, V_t^3 /550. \quad (17)$$

P_{sc} is the power scale factor and is given in horsepower. The power needed for the helicopter to climb vertically at V_c ft/s is given by

$$P_c = V_c \,(W + 0.5\, C_d \,.\, A_t \,.\, \rho \,.\, V_c^2) /550, \quad (18)$$

where A_t is the top flat plate area, and the total power required for a forward climb is approximately

$$P_t = P_h + P_c. \quad (19)$$

4.2 <u>Level Flight and Maneuverability</u>. For the case of level flight, subroutine CTINT is called to calculate the maximum thrust that can be generated and the ability of the helicopter to turn and maneuver. Thus, if T is the thrust generated, W the operating weight, ℓ_f the load factor in a turn, and ϕ is the bank angle as seen in Figure 3, then according to Saunders (1975),

$$\ell_f = T/W, \quad (20)$$

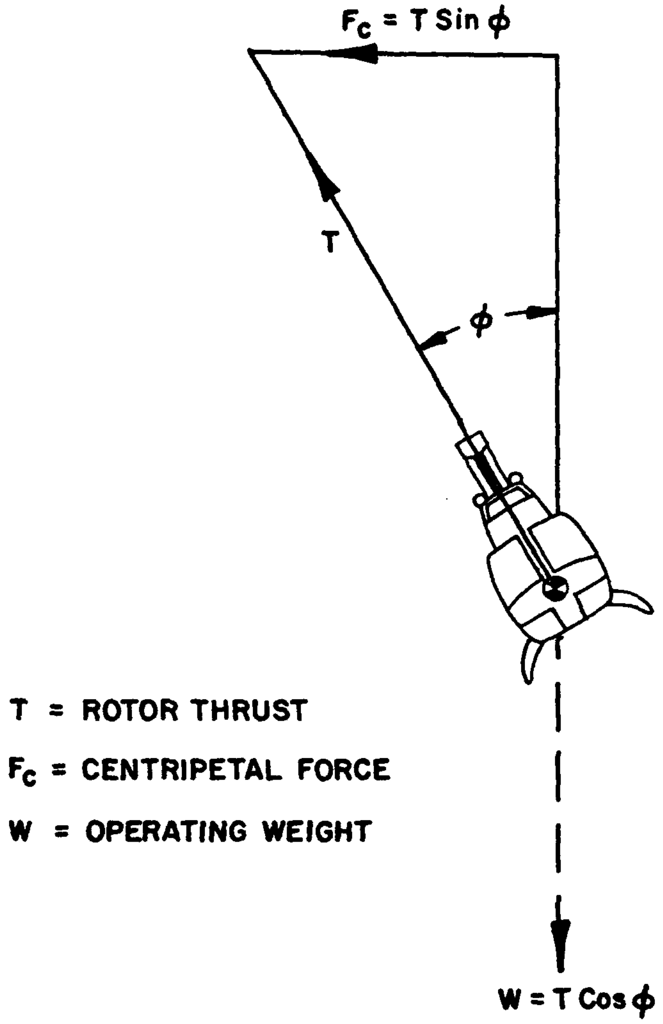


Figure 3. Schematic drawing of the thrust and forces on a helicopter during a turn in level flight.

$$\cos \phi = W/T = 1/\ell_f, \tag{21}$$

$$\tan \phi = \sqrt{\ell_f^2 - 1}. \tag{22}$$

The centrifugal force F_c is given by

$$F_c = (W/g) \;.\; (V^2/R_t); \tag{23}$$

hence,

$$T \sin \phi = (W/g)\,(V^2/R_t), \tag{24}$$

where R_t is the turn radius. Equation 24 reduces to

$$R_t = V_k^2 \;/\; (11.26 \;.\; \tan \phi\;) \text{ feet}, \tag{25}$$

where V_k is the level speed in knots. The rate of turn $\dot{\theta}$ in degrees per second is found to be

$$\dot{\theta} = 1091 \;.\; \tan \phi \;/V_k \text{ deg/sec}, \tag{26}$$

and the horizontal component of acceleration

$$A_h = g \;.\; \tan \phi \;.\; \text{ft/sec}^2 \tag{27}$$

where g is the gravitational acceleration.

The maximum cruising speed is found by determining the point of intersection of the curve of the power required vs. speed and the curve of the power available vs. speed, as shown in Figure 4. HELPE determines the maximum possible level flight speeds corresponding to available MCP and IRP powers. Figure 5 shows graphically the method of computing the speed of maximum endurance in air V_i, and the speed of maximum range V_r. V_i corresponds to the minimum P_r on the power required curve and V_r corresponds to the point of minimum P/V on the same curve.

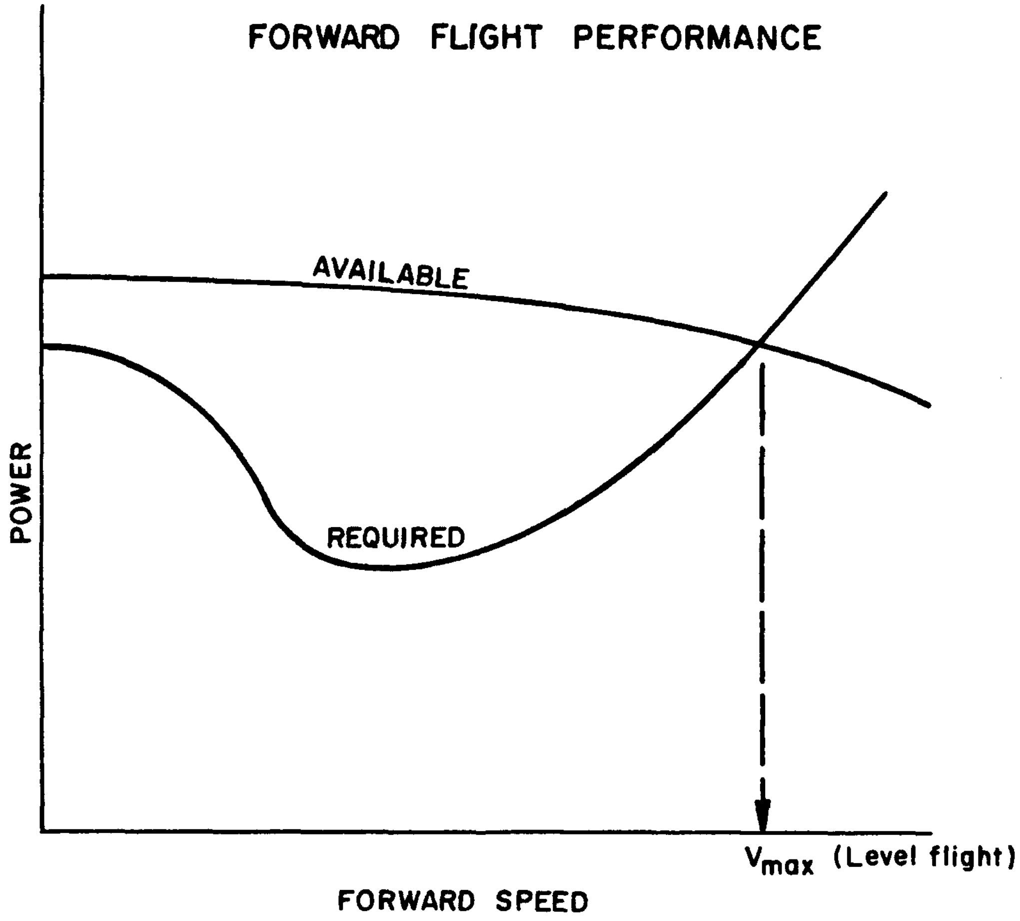


Figure 4. Determination of maximum level flight speeds.

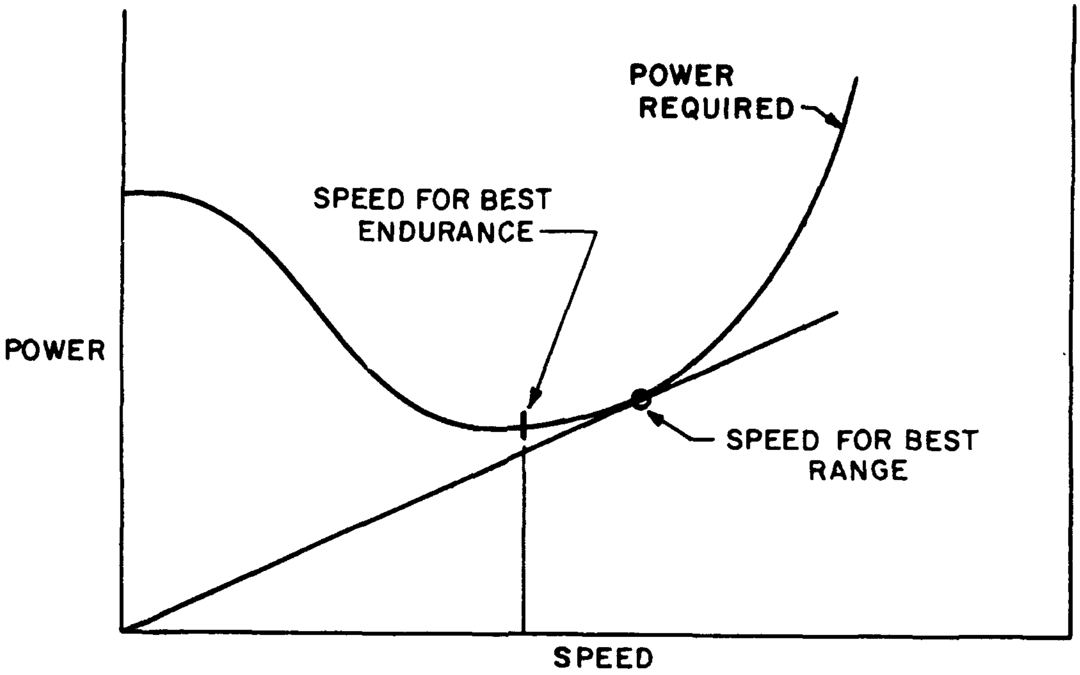


Figure 5. Determination of maximum endurance and maximum range speeds.

5. INPUT PARAMETERS

The following parameters define the required input to run a case. Seven input cards need to be defined as follows with their formats.

Card 1: Format (A10, 3 I 10)

TITLE = Assigned name of aircraft to be evaluated.
NWT = Number of desired mission weights.
NFV = Number of forward speeds.
NCR = Number of climb rates.
NWT <= 6, NFV <= 20, NCR <= 10.

Card 2: Format (8 F 10.4)

WTG = Gross weight of helicopter (pounds).
WTE = Empty weight of helicopter (pounds).
OVLF = Overload weight factor to be used.
FA = Frontal flat plate area of aircraft (feet^2).
TFPA = Top flat plate area of aircraft (feet^2).

SCFAB = Scaled frontal area (FA/$2\pi R^2$) for base aircraft.
DTR = Distance of tail rotor shaft from main rotor shaft (feet).

Card 3: Format (8 F 10.4)

ROTR = Main rotor radius (feet).
TRR = Tail rotor radius (feet).
TRTV = Tail rotor tip speed (ft/sec).
TRA = Tail rotor cant angle (degrees).
SIGMA = Main rotor solidity = ratio of blade's area to rotor disc area.
SIGMATR = Solidity of tail rotor = ratio of blade's area to rotor disc area.
ZNOENG = Number of engines.
RPM = Main rotor rotational speed (rev/min).

Card 4: Format (8 F 10.3)

ROTNO = Number of main rotors.
ALT1 = Desired altitude for performance evaluation (feet).
TEMP1 = Desired temperature for performance evaluation (deg F).
TEMPS = Standard atmosphere (ISA) temperature (deg F) at ALT1.
BNO = Number of blades for main rotor.
BNOTR = Number of blades for tail rotor.
EFF = Efficiency factor of candidate rotor system relative to base rotor system.
DCLS = Parameter representing improvements in technology of blade design.

Card 5: Format (8 F 10.3)

RC(i) = i^{th} rate of vertical climb (feet/min), i=1,2,..NCR.
where RC(1) is recommended to be taken as 0.0.

Card 6: Format (8 F 10.4)

SMCP = Maximum continuous power (HP) of engine at sea level.
SIRP = Intermediate rated power of engine (HP) at sea level.
DMCPDH = The partial derivative ∂ (MCP)/∂h.
DIRPDH = The partial derivative ∂ (IRP)/∂h.
DMCPDT = The partial derivative ∂ (MCP)/∂T.
DIRPDT = The partial derivative ∂ (IRP)/∂T.
CD = Coefficient of drag based on top flat plate area.
T here represents the atmospheric temperature.

Card 7: Format (8 F 10.4)

UTL = Upper transmission limit (HP).
XLTL = Lower transmission limit (HP).
FLAG = A flag, FLAG = 0.0 for base helicopter,
FLAG $\neq$ 0.0 for any other helicopter.
DO = Constant term in the quadratic expression for profile drag coefficient of blade
D1 = Second term coefficient of $\propto$ in the quadratic for profile drag for the blade.

D2 = Coefficient of α^2 in the quadratic for profile drag coefficient for blade.
A = Slope of the curve for coefficient of lift vs. angle of attack α for the main rotor blades.

The profile drag coefficient is $Cdo = D_0 + D1 . \alpha + D2 . \alpha^2$ where α is the angle of attack expressed in radians, as given in Gessow and Myers (1967).

Subroutine RDATA is called to read the $CQ*10^5$ vs. $CT*10^4$ and μ data from tape input. The read data are then written to output. Samples of such data for the UH-60A and the AH64 are given in Appendix B. The input data are read as follows:

Card 1: Format (2 I 5)

NMUD = number of μ data
NCTD = number of CT data

Card 2: Format (15 F 5.2)

DMU(j) = The j^{th} μ data, j=1,....,NMUD.

Card 3: Format (15 F 5.2)

CTD(i) = The i^{th} CT data, i=1,....,NCTD

Card 4: Format (8 F 10.3)

CQD1(i,j) = The $(i,j)^{th}$, CQ data of set 1, i=1,...,NMUD; j=1,...,NCTD.

Card 5: Format (8 F 10.3)

CQD2(i,j) = The $(i,j)^{th}$, CQ data of set 2, i=1,...,NMUD; j=1,...,NCTD.

Card 6: Format (2 F 10.2, F 10.3)

CTIN(k) = the k^{th} CT for IGE data.
CQIN(k) = the k^{th} CQ for IGE data.
DINMU(k) = the k^{th} MU (μ) for IGE data
k = 1,2,.....,8.

6. APPLICATION AND COMPARISON OF RESULTS

This section sets up the computation of an example and compares the computed results with available test data. Such data are available for the UH-60A Helicopter which is shown in Figure 6. The primary

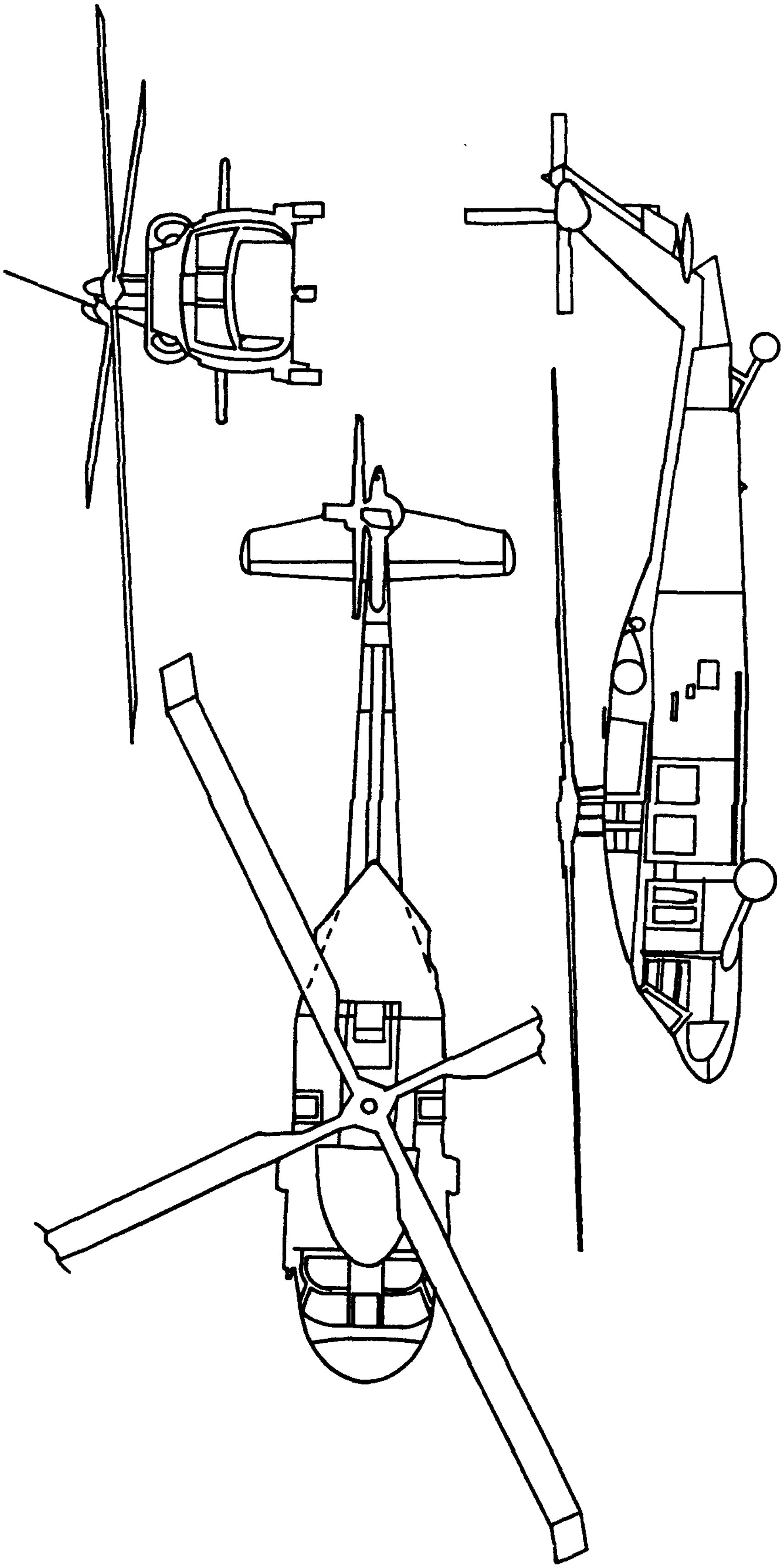


Figure 6. Schematic drawing of a UH-60A helicopter.

operational mission weight for the UH-60A is 16,260 lb. The performance evaluation is desired at 4,000-ft altitude above sea level and at the hot temperature of 95° F. The empty weight was taken to be 13,620 lb. Test data for the UH-60A during these conditions can be found in Nagata (et al. 1981). The input card images used in this case were as follow:

<u>Card 1</u>: TITLE = UH-60A, NWT = 4, NFV = 18, NCR = 6,

<u>Card 2</u>: WTG = 16260.0, WTE = 13620.0, OVLF = 1.245, FA = 74.55,
TFPA = 206.0, SCFAB = 0.0165, DTR = 32.567,

<u>Card 3</u>: ROTR = 26.83, TRR = 5.5, TRTV = 685.28, TRA = 20.0,
SIGMA = 0.0826, SIGMATR = 0.1875, ZNOENG = 2.0, RPM = 257.9,

<u>Card 4</u>: ROTNO = 1.0, ALT1 = 4000.0, TEMP1 = 95.0, TEMPS = 44.7,
BNO = 4.0, BNOTR = 4.0, EFF = 1.0, DCLS = 0.0,

<u>Card 5</u>: RC(1) = 0.0, RC(2) = 450.0, RC(3) = 600.0, RC(4) = 800.0,
RC(5) = 1000.0, RC(6) = 2000.0,

<u>Card 6</u>: SMCP = 1254.0, SIRP = 1540, DMCPDH = -0.0265, DIRPDH = -0.0387,
DMCPDT = -3.9563, DIRPDT = -3.6819, CD = 0.234,

<u>Card 7</u>: UTL = 2828.0, XLTL = 2800.00, FLAG = 0.0, DO = 0.0087,
D1 = -0.0216, D2 = 0.400, A = 5.9244.

Figure 7 shows HELPE computation of the power required at the primary mission weight of 16,260 lb for level flight as a function of the speed. Plots of the maximum continuous power (MCP) and the intermediate rated power (IRP) when both engines are operating are also shown. The plots show that the minimum cruise speed with MCP during these conditions is 19 knots and the maximum cruise speed is 148 knots. HELPE computation shows this speed to be 148.18 knots and the maximum possible speed with IRP power to be 165.11 knots. Test results show the first speed to be 147 knots. HELPE computation shows that the speed for maximum range is 119.5 knots, while the test results give it as 133 knots. HELPE computations and Figure 6 show that the IRP single engine speed is 113.5 knots, while test results place it at 112 knots. HELPE also gives the MCP maximum endurance speed to be 80.6 knots, but no test data are available for comparison. Test results show that the UH-60A cannot fly at any speed on a single engine MCP power. HELPE computation shows this to be the case, and Figure 7 illustrates this graphically. HELPE computation shows that the maximum rate of vertical climb with IRP power at 4,000-ft altitude and 95° F temperature is 572 ft/min while test results give it as 590 ft/min. Figure 8 shows plots of the maximum speed vs. operating weight as computed by HELPE when operating

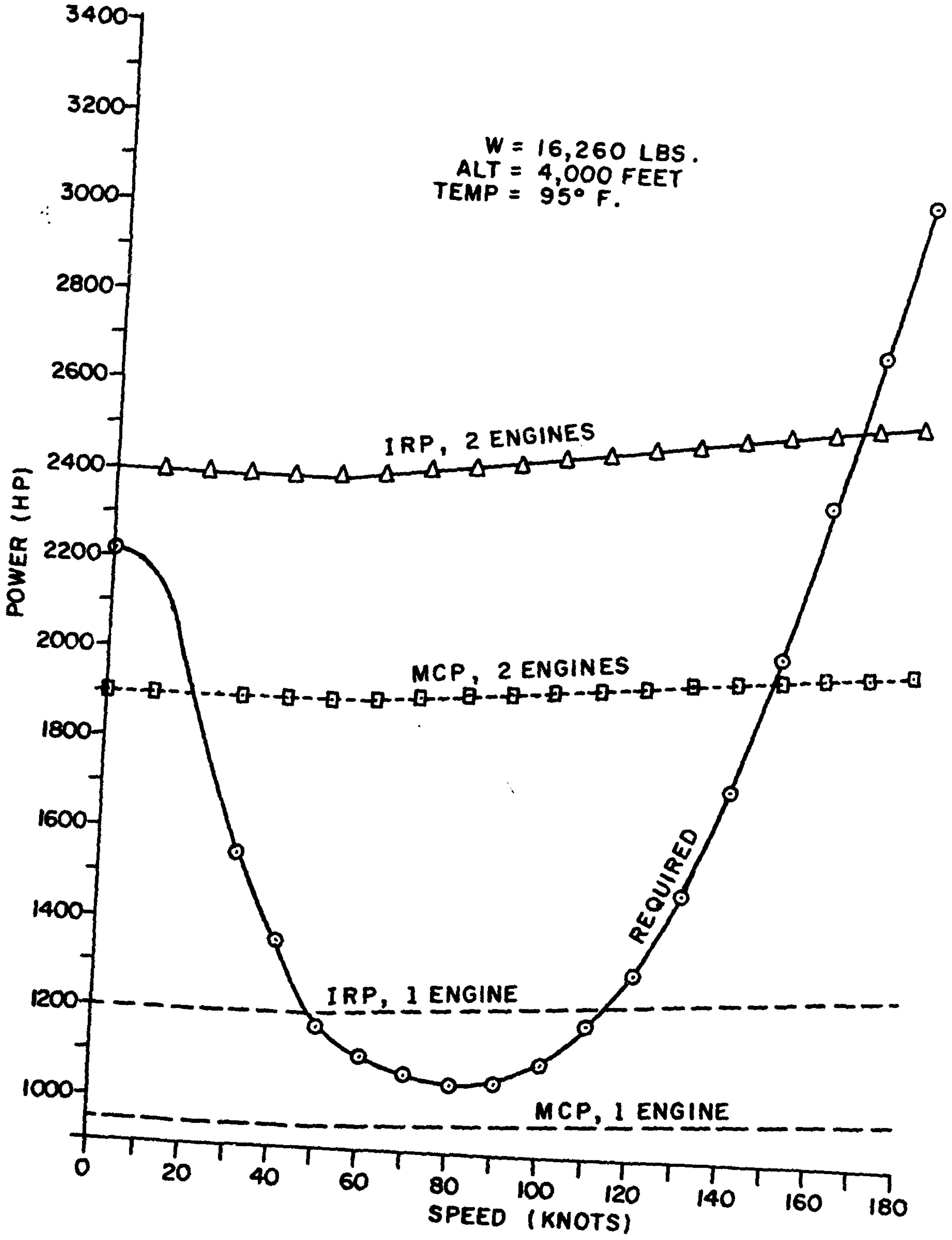


Figure 7. Computed available and required powers vs. speed for the UH-60A helicopter.

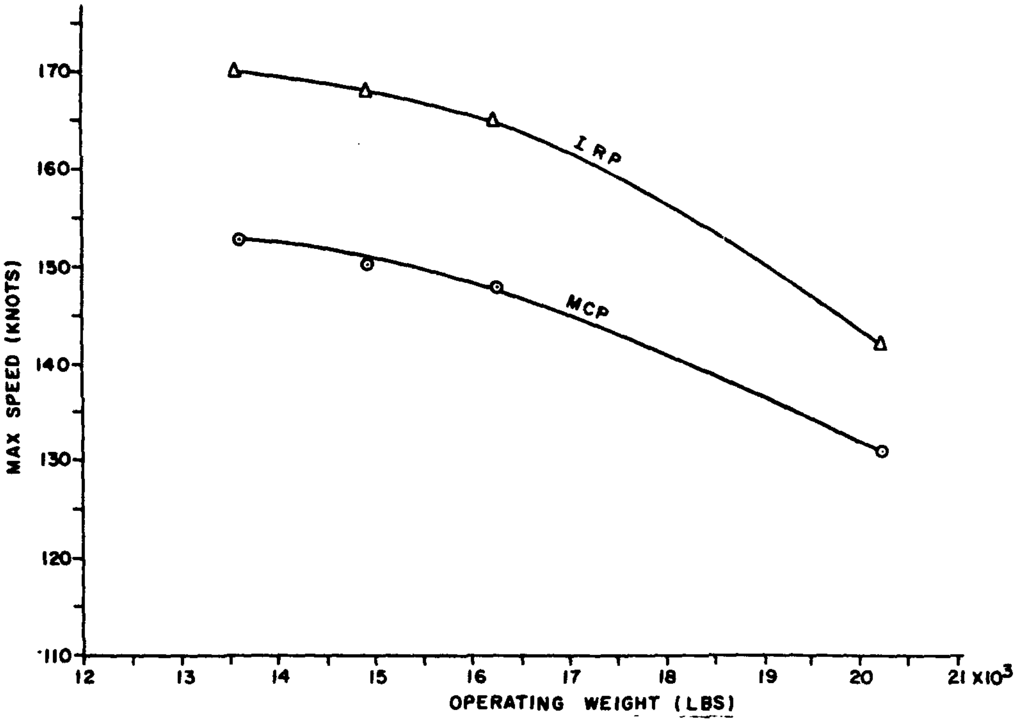


Figure 8. Computed maximum speed vs. operating weight for the UH-60A helicopter.

with MCP, and IRP power at the 4,000-ft altitude and 95° F temperature conditions. Table 2 shows the HELPE computed power required for hover and vertical climb as a function of the climb rate and for the various operational mission weights considered. Appendix A contains the FORTRAN IV listing of the developed code. Appendix B contains a listing of torque vs. thrust coefficients data.

Table 2. Power Required for the UH-60A Helicopter for Hover and Vertical Climb (OGE)

Altitude = 4,000 ft, Temperature = 95° F Available Power: MCP = 1,898 HP, IRP = 2,400 HP				
Climb rate	WT (lb)			
(ft/min)	13,620	14,940	16,260	20,244
0	1,667	1,892	2,118	2,851
450	1,852	2,096	2,340	3,127
600	1,914	2,164	2,414	3,219
800	1,997	2,255	2,513	3,342
1,000	2,080	2,346	2,611	3,465
2,000	2,495	2,801	3,107	4,081

The HELPE-computed results compare very favorably with the test measured data. Most of the computed results are within 10% of flight test measured data. HELPE is easy to run, and the computation is very economical. A considerable amount of information is obtained in output, which has not been described or compared here because of the lack of test values. The code can be particularly useful in the design stage for parametric study or in threat systems for threat evaluation. Future code improvements and extensions might follow in the future, but this report documents the current status of the code.

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APPENDIX A:

LISTING OF THE FORTRAN 77 PROGRAM OF THE COMPUTER CODE HELPE

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```
                           PROGRAM MAIN
      DIMENSION RC(10),WT(6),PRCLD(10),PREMR(10),PRTTH(10)
      COMMON DMU(15),CTD(12),CQD1(14,7),CQD2(14,7),NMUD,NCTD
      COMMON /BCT/XMU,PSFAC,SIGMA,VTIP,CT,CLSTL,VFTS,RHO1
      COMMON/PAVA/PAC1E,PAM1E,VF(20),PAC1(20),PAM1(20),PAC2(20),PAM2(20)
      COMMON /BCT1/CTCP,CTMP,IX,PRHF(20),PCLF(20),PMLF(20),EFF
      COMMON/IGE/CTIN(10),CQIN(10),XINMU(10)
C     READ INPUT FROM TAPE5 OR (INPUT DATA FILE) AND WRITE IT
C     FLAG=0.0 FOR BASE A/C,FLAG NOT  0.0 OTHERWISE ,SCFA=FA/(2.0*AD)
C     SCFAB IS THE SCALED FRONTAL AREA FOR THE BASE A/C(UH60 OR AH64)
C     PAC1E,AND PAM1E ARE MAX CONT AVAILABLE POWER,AND MAXPOWER FOR ONE
C     ENGINE AT  ALT1,AND TEMP1 CONDITIONS,AND 0.0 AIRSPEED
C     DTR IS DISTANCE OF TAIL ROTOR FROM MAIN ROTOR SHAFT.
C     SLMCP,SLIRP ARE CONT. AND MAX POWER AT SEA LEVEL AND STANDARD COND.
C     DMCPDH,DIRPDH,DMCPDT,DIRPDT ARE THE PARTIAL DERIVATIVES OF THE POWER
C     WITH RESPECT TO ALTITUDE AND TEMPERATURE.
      CHARACTER TITLE *10
      READ(*,130)TITLE,NWT,NFV,NCR
      READ(*,113)WTG,WTE,OVLF,FA,TFPA,SCFAB,DTR
      READ(*,113)ROTR,TRR,TRTV,TRA,SIGMA,SIGMATR,ZNOENG,RPM
      READ(*,110)ROTNO,ALT1,TEMP1,TEMPS,BNO,BNOTR,EFF,DCLS
      READ(*,110)RC(1),RC(2),RC(3),RC(4),RC(5),RC(6)
      READ(*,113)SLMCP,SLIRP,DMCPDH,DIRPDH,DMCPDT,DIRPDT,CD
      READ(*,113)UTL,XLTL,FLAG,D0,D1,D2,A
  100 FORMAT(//)
  110 FORMAT(8F10.3)
  111 FORMAT(8F15.4)
  112 FORMAT(2F10.2,2X,F10.2)
  113 FORMAT(8F10.4)
  115 FORMAT(8F15.4)
  120 FORMAT(’CONTS POWER MAX VEL=’,F8.2,10X,’MAX POWER MAX VEL=’,F8.2)
  130 FORMAT(A10,3I10)
  140 FORMAT(’*******PERFORMANCE CALCULATION FOR THE ’,A8,’******’)
  141 FORMAT(’AIRCRAFT=’,A8,5X,’NWT=’,I5,5X,’NFV=’,I5,5X,’NCR=’,I5)
   60 FORMAT(’ALT1=’,F8.0,4X,’TEMP1=’,F8.1,4X,’WEIGHT=’,F8.0)
   65 FORMAT(1H ,6X,’VHS’,6X,’CLM RT’,4X,’REQ HP’,6X,’AVAI HP’,7X,’LO FA
     *C’,6X,’BK ANG’,6X,’TUR R’,6X,’RT TUR’,4X,’LAT ACCEL’)
   66 FORMAT(1H ,5X,’KNOTS’,5X,’FT/MIN’,6X,’HP’,10X,’HP’,10X,’RATIO’,7X,
     *’DEGREES’,5X,’FEET’,6X,’DEG/SEC’,5X,’FT/SEC2’)
   70 FORMAT(1H ,10X,’HOVER,VERTICAL CLIMB RATE, AND LAT ACCEL CAP O.G.E
     *. TWO ENGINES’)
   71 FORMAT(10X,’HOVER,VERTICAL CLIMB RATE,AND LAT ACCEL CAP ONE ENGINE
     * O.G.E.’)
   72 FORMAT(10X,’HOVER,VERT. CLIMB RATE,AND LAT ACCEL CAP I.G.E.,TWO EN
     *GINES’)
   73 FORMAT(1H0,10X,’HOVER,VERT.CLIMB RATE,AND LAT ACCEL CAP I.G.E.,ONE
     * ENGINE’)
   75 FORMAT(1H0,’AVAIL CONT POWER=’,E12.5,3X,’AVAIL MAX POWER=’,E12.5,5
     *X,’PREQ. HOV.=’,E12.5)
   80 FORMAT(1H0,4X,’CLIMB RATE’,5X,’REQ. PCLD.’,5X,’REQ. TOT. POWER’,3
     *X,’REQ. TH. H.P.’,5X,’LAT CONT ACCEL’,5X,’LAT MAX ACCEL’,4X,’CONT
     *VEL’,4X,’MAX VEL’)
```

```
 81 FORMAT(1H0,7X,'FT/MIN',9X,'H.P.',13X,'H.P.',14X,'H.P.',11X,'FT/SEC
   *2',12X,'FT/SEC2',9X,'FT/MIN',5X,'FT/MIN')
 84 FORMAT(1H0,3E15.5,3X,E15.5,4X,E15.5,5X,E15.5,2X,F8.2,5X,F8.2)
 82 FORMAT(1H0,'CTCP=',E12.5,5X,'CTMP=',E12.5,5X,'CT=',E12.5,5X,'THRCP
   *=',E12.5,5X,'THRMP=',E12.5)
 83 FORMAT(1H0,'CTCI=',E12.5,5X,'CTMI=',E12.5,5X,'CT=',E12.5,5X,'THRCP
   *I=',E12.5,5X,'THRMPI=',E12.5)
    WRITE(*,140)TITLE
    WRITE(*,141)TITLE,NWT,NFV,NCR
    WRITE(*,111)WTG,WTE,OVLF,FA,TFPA,SCFAB,DTR
    WRITE(*,115)ROTR,TRR,TRTV,TRA,SIGMA,SIGMATR,ZNOENG,RPM
    WRITE(*,115)ROTNO,ALT1,TEMP1,TEMPS,BNO,BNOTR,EFF,DCLS
    WRITE(*,115)RC(1),RC(2),RC(3),RC(4),RC(5),RC(6)
    WRITE(*,115)SLMCP,SLIRP,DMCPDH,DIRPDH,DMCPDT,DIRPDT,CD
    WRITE(*,115)UTL,XLTL,FLAG,D0,D1,D2,A
C   SUBROUTINE RDATA IS CALLED TO READ CQ VS CT DATA FOR CONSTANT MU
    CALL  RDATA
C   DEFINE WEIGHTS OF INTEREST,PRESSURE,TEMP,DENSITY,THRUST AND POWER
C   SCALE FACTORS
    PI=3.1416
    AD=PI*ROTR*ROTR
    WT(1)=WTG*OVLF
    WT(2)=WTG
    WT(3)=0.5*(WTG+WTE)
    WT(4)=WTE
    DW=WTG-WTE
    WT(5)=WTE + DW / 3.0
    WT(6)=WTE + 2.0 * DW / 3.0
    PRESS1=2117.-(0.1312*ALT1**0.9278)
    TRA1=459.7+TEMP1
    THETA=TRA1/518.7
    SCN=RPM/SQRT(THETA)
    RHO1=PRESS1/(32.17*53.34*TRA1)
    VTIP=6.283*ROTR*RPM/60.
    TSFAC=3.1416*ROTR*ROTR*RHO1*VTIP*VTIP*ROTNO
    PSFAC=TSFAC*VTIP/550.
    HIRP=SLIRP+DIRPDH*ALT1
    HMCP=SLMCP+DMCPDH*ALT1
    DT=TEMP1-TEMPS
    TIRP=HIRP+DIRPDT*DT
    TMCP=HMCP+DMCPDT*DT
    PAC1E=TMCP
    PAM1E=TIRP
C   BEGINING OF THE WEIGHTS LOOP
    DO 600 IW=1,NWT
    WRITE(*,100)
    WRITE(*,60)ALT1,TEMP1,WT(IW)
    CT=WT(IW)/TSFAC
    CTOS=CT/SIGMA
    CALL CQINT(0.34,CT,VTIP,CQ1)
    CALL CQINT(0.36,CT,VTIP,CQ2)
    CDX=8948.35*(CQ2-CQ1)
    F=CDX*FA
    SCFA=FA/(2.0*AD)
```

```
      DSCFA=SCFA-SCFAB
      WRITE(*,65)
      WRITE(*,66)
      VF(1)=30.00
C     BEGINING OF THE HORIZONTAL SPEEDS LOOP
      DO 150 IV=1,NFV
      XIV=IV-1
      VF(IV)=VF(1) + XIV*10.0
  150 CONTINUE
      CALL PAVAIL(NFV,ZNOENG,UTL,XLTL)
      DO 500 IV=1,NFV
      IX=IV
      VFTS=VF(IV)*1.689
      XMU=VFTS/VTIP
      CLSTL=0.15-0.07*XMU+DCLS
C     CALCULATE CQ REQUIRED FOR HORIZONTAL FLIGHT
      IF(FLAG .EQ. 0.0)GOTO 200
      DCQ=CDX*DSCFA*XMU**3
  200 CALL CQINT(XMU,CT,VTIP,CQ0)
      IF(FLAG .EQ. 0.0)DCQ=0.0
      CQ=(CQ0+DCQ)/EFF
      PRHF(IV)=CQ*PSFAC
C     BEGINING OF THE VERTICAL CLIMBS RATE LOOP
      DO 400 IC=1,NCR
      RCS=RC(IC)/60.0
      PRCL=RCS*(WT(IW)+0.5*CD*TFPA*RHO1*RCS*RCS)/550.0
      PRTOT=PRHF(IV)+PRCL
      PRCLD(IC)=PRCL
      IF(RCS .EQ. 0.0)GOTO 300
      WRITE(*,112)VF(IV),RC(IC),PRTOT
      GOTO 400
C     CALCULATE THE CTS CORRESPONDING TO PAC AND PAM
  300 CALL CTINT
  400 CONTINUE
  500 CONTINUE
C     CALCULATION OF MAX VELOCITIES FOR EACH FLIGHT WEIGHT
      DO 505 J=1,NFV
      IF(PCLF(J) .GT. 1.0)GOTO 505
      IF(J .LE. 2)GOTO 505
      GOTO 507
  505 CONTINUE
  507 SLC=(VF(J)-VF(J-1))/(PRHF(J)-PRHF(J-1))
      VFCP=VF(J-1)+SLC*(PAC2(J)-PRHF(J-1))
      DO 510 JJ=1,NFV
      IF(PMLF(JJ) .GT. 1.0)GOTO 510
      IF(JJ .LE. 2)GOTO 510
      GOTO 512
  510 CONTINUE
  512 SLM=(VF(JJ)-VF(JJ-1))/(PRHF(JJ)-PRHF(JJ-1))
      VFMP=VF(JJ-1)+SLM*(PAM2(JJ)-PRHF(JJ-1))
      WRITE(*,120)VFCP,VFMP
      CALL VINDRA(NFV,VF,PRHF)
C     THEORETICAL ESTIMATE OF POWER REQUIRED TO HOVER AND TO CLIMB
      B=1.0-SQRT(2.0*CT)/BNO
```

```
      X=CT/(B*B)
C     CALCULATE CQ REQUIRED BECAUSE OF PROFILE DRAG
      CQPRO=SIGMA*D0/8.0+0.6667*D1*X/A+4.0*D2*X*X/(SIGMA*A*A)
C     CALCULATE THE CQ REQUIRED FOR INDUCED DRAG AND TO CLIMB
      DO 513 J=1,NCR
      VV=RC(J)/60.
      VOVT=VV/VTIP
      CQICL=0.5*CT*SQRT(VOVT*VOVT+2.0*X)+0.5*VOVT*CT
      CQDR=0.5*CD*TFPA*VV**3/(550.0*PSFAC)
      CQTMR=CQICL+CQPRO+CQDR
      THTR=CQTMR*TSFAC*ROTR/DTR
      TSCFTR=PI*RHO1*TRR*TRR*TRTV*TRTV
      CTTR=THTR/TSCFTR
      BTR=1.0-SQRT(2.0*CTTR)/BNOTR
      XTR=CTTR/(BTR*BTR)
      CQPRTR=SIGMATR*D0/8.0+0.6667*D1*XTR/A+4.0*D2*XTR*XTR/(SIGMATR*A*A)
      CQITR=0.5*CTTR*SQRT(2.0*XTR)
      CQTTR=CQPRTR+CQITR
      PRTTR=CQTTR*TSCFTR*TRTV/550.0
      PREMR(J)=CQTMR*PSFAC
  513 PRTTH(J)=PREMR(J)+PRTTR
C     END OF SECTION OF THEORETICAL ESTIMATES OF POWER REQUIRED
C     BEGINNING OF HOVER,AND VERTICAL CLIMB CALCULATIONS
C     COMPUTATION OF POWER REQUIRED TO HOVER AND TO CLIMB ON BASIS OF DATA
      CALL CQINT(0.0,CT,VTIP,CQHO)
      PRHO=CQHO*PSFAC/EFF
C     NEXT DO LOOP IS FOR FULL AND REDUCED POWER CALCULATION
      DO 550 K=1,2
      PAC=PAC1E*ZNOENG
      PAM=PAM1E*ZNOENG
      PAC=AMIN1(PAC,UTL)
      PAM=AMIN1(PAM,UTL)
      IF(K .EQ. 2)PAC=AMIN1(PAC1E,XLTL)
      IF(K .EQ. 2)PAM=AMIN1(PAM1E,XLTL)
      WRITE(*,100)
      IF(K .EQ. 1)WRITE(*,70)
      IF(K .EQ. 2)WRITE(*,71)
      WRITE(*,75)PAC,PAM,PRHO
      CPCE5=PAC*EFF*1.0E+5/PSFAC
      CPME5=PAM*EFF*1.0E+5/PSFAC
      CALL LACC(CPCE5,CPME5,VTIP,CTCP,CTMP)
      THRCP=CTCP*TSFAC
      THRMP=CTMP*TSFAC
      WRITE(*,82)CTCP,CTMP,CT,THRCP,THRMP
      WRITE(*,80)
      WRITE(*,81)
      DO 522 J=1,NCR
      PRDAT=PRHO+PRCLD(J)
      X1LF=CTCP/CT
      IF(X1LF .LE. 1.0)ACCEL1=0.0
      IF(X1LF .LE. 1.0)GOTO 515
      TANA1=SQRT(X1LF*X1LF-1.0)
      DELPAC=PAC-PRDAT
      VCMAX=DELPAC*550.0/WT(IW)
```

```
      VCL60=VCMAX*60.0
      ACCEL1=32.17*TANA1
  515 X2LF=CTMP/CT
      IF(X2LF .LE. 1.0)ACCEL2=0.0
      IF(X2LF .LE. 1.0)GOTO 520
      TANA2=SQRT(X2LF*X2LF-1.0)
      DELPAM=PAM-PRDAT
      VMMAX=DELPAM*550.0/WT(IW)
      VML60=VMMAX*60.0
      ACCEL2=32.17*TANA2
  520 WRITE(*,84)RC(J),PRCLD(J),PRDAT,PRTTH(J),ACCEL1,ACCEL2,VCL60,VML60
C     NEXT FOUR STATEMENTS ARE TO RETURN TO FULL POWER CALCULATIONS.
  522 CONTINUE
  550 CONTINUE
C     IN THIS SECTION WE CALCULATE THE IN GROUND EFFECT PERFORMANCE
      CALL GE(CT,CQI,0.0,CPCE5,CPME5,CTCI,CTMI)
      PRHOIG=CQI*PSFAC/EFF
      DO 590 I=1,2
      PAC=PAC1E*ZNOENG
      PAM=PAM1E*ZNOENG
      PAC=AMIN1(PAC,UTL)
      PAM=AMIN1(PAM,UTL)
      IF(I .EQ. 2)PAC=AMIN1(PAC1E,XLTL)
      IF(I .EQ. 2)PAM=AMIN1(PAM1E,XLTL)
      WRITE(*,100)
      CPCE5=PAC*EFF*1.0E+5/PSFAC
      CPME5=PAM*EFF*1.0E+5/PSFAC
      IF(I .EQ. 1)WRITE(*,72)
      IF(I .EQ. 2)WRITE(*,73)
      WRITE(*,75)PAC,PAM,PRHOIG
      CALL GE(CT,CQI,1.0,CPCE5,CPME5,CTCI,CTMI)
      THRCPI=CTCI*TSFAC
      THRMPI=CTMI*TSFAC
      WRITE(*,83)CTCI,CTMI,CT,THRCPI,THRMPI
      WRITE(*,80)
      WRITE(*,81)
      DO 580 J=1,NCR
      PRDIG=PRHOIG+PRCLD(J)
      XLF1=CTCI/CT
      IF(XLF1 .LE. 1.0)ACCL1=0.0
      IF(XLF1 .LE. 1.0)GOTO 560
      TANA1=SQRT(XLF1*XLF1-1.0)
      ACCL1=32.17*TANA1
      DPAC=PAC-PRDIG
      VCM=DPAC*550.0/WT(IW)
      VCM60=VCM*60.0
  560 XLF2=CTMI/CT
      IF(XLF2 .LE. 1.0)ACCL2=0.0
      IF(XLF2 .LE. 1.0)GOTO 580
      TANA2=SQRT(XLF2*XLF2-1.0)
      ACCL2=32.17*TANA2
      DPAM=PAM-PRDIG
      VMM=DPAM*550.0/WT(IW)
      VMM60=VMM*60.0
```

```
  580 WRITE(*,84)RC(J),PRCLD(J),PRDIG,PRTTH(J),ACCL1,ACCL2,VCM60,VMM60
  590 CONTINUE
  600 CONTINUE
      STOP
      END

               SUBROUTINE RDATA
      COMMON DMU(15),CTD(12),CQD1(14,7),CQD2(14,7),NMUD,NCTD
C     THIS SUBROUTINE READS THE CQ VS. CT DATA FOR A GIVEN VALUE
C     OF MU FROM TAPE 5 AND WRITES IT.
      COMMON/IGE/ CTIN(10),CQIN(10),XINMU(10)
      READ(*,10)NMUD,NCTD
      READ(*,15) (DMU(J),J=1,NMUD)
      READ(*,15) (CTD(I),I=1,NCTD)
      WRITE(*,30)
      WRITE(*,11) NMUD,NCTD
      WRITE(*,12) (CTD(J),J=1,NCTD)
      DO 101 I=1,NMUD
      READ(*,20) (CQD1(I,J),J=1,NCTD)
  101 WRITE(*,50) DMU(I),(CQD1(I,J),J=1,NCTD)
      WRITE(*,100)
      WRITE(*,40)
      WRITE(*,12) (CTD(J),J=1,NCTD)
      DO 102 I=1,NMUD
      READ(*,20) (CQD2(I,J),J=1,NCTD)
  102 WRITE(*,50) DMU(I),(CQD2(I,J),J=1,NCTD)
      WRITE(*,60)
      DO 200 K=1,8
      READ(*,70)CTIN(K),CQIN(K),XINMU(K)
  200 WRITE(*,75)CTIN(K),CQIN(K),XINMU(K)
   10 FORMAT(2I5)
   11 FORMAT(1H0,10X,'NMUD=',I5,10X,'NCTD=',I5)
   12 FORMAT(1H0,8X,10F10.3)
   15 FORMAT(15F5.2)
   20 FORMAT(8F10.3)
   30 FORMAT(1H0,'OUT OF GROUND EFFECT TORQUE COEFFICIENTS,CQ*1.0E5 VS C
     *T*1.0E4')
   40 FORMAT(1H0,'OUT OF GROUND EFFECT SECOND SET OF TORQUE COEFFS')
   50 FORMAT(1H0,F8.3,10F10.3)
   60 FORMAT(1H0,'IN GROUND EFFECTS TORQUE COEFF, CT*1.0E4 VS CQ*1.0E5')
   70 FORMAT(3F10.1)
   75 FORMAT(1H0,2F10.2,F10.3)
  100 FORMAT(//)
      RETURN
      END

           SUBROUTINE CQINT(XMU,CT,VTIP,CQ)
      COMMON DMU(15),CTD(12),CQD1(14,7),CQD2(14,7),NMUD,NCTD
C     THIS SUBROUTINE INTERPOLATES FOR THE VALUE OF CQ CORR. TO CT,MU
      CTE4=CT*1.0E4
      DO 30 I=1,NMUD
      IF(XMU .GT. DMU(I))GOTO 30
      GOTO 35
   30 CONTINUE
```

```
      I=I-1
   35 DO 40 J=1,NCTD
      IF(CTE4 .GT. CTD(J))GOTO 40
      GOTO 45
   40 CONTINUE
      J=J-1
   45 IF(J .EQ. 1)J=J+1
C     INTERPOL FOR CQ ALONG I=CONST LINE(MU=COST); J AND CT VARY
      DCTJ1J=CTD(J)-CTD(J-1)
      DCTJ1X=CTE4-CTD(J-1)
      SLOI1=(CQD1(I,J)-CQD1(I,J-1))/DCTJ1J
      CQI1=CQD1(I,J-1)+SLOI1*DCTJ1X
      SLOI2=(CQD2(I,J)-CQD2(I,J-1))/DCTJ1J
      CQI2=CQD2(I,J-1)+SLOI2*DCTJ1X
      IF(I .EQ. 1)I=I+1
C     INTERPOL FOR CQ ALONG I-1=CONST LINE
      SLOI11=(CQD1(I-1,J)-CQD1(I-1,J-1))/DCTJ1J
      CQI11=CQD1(I-1,J-1)+SLOI11*DCTJ1X
      SLOI12=(CQD2(I-1,J)-CQD2(I-1,J-1))/DCTJ1J
      CQI12=CQD2(I-1,J-1)+SLOI12*DCTJ1X
C     INTERPOL FOR CQ1,CQ2 W.R.T. MU, CT=CONST
      DMUI1I=DMU(I)-DMU(I-1)
      DMUI1X=XMU-DMU(I-1)
      SLCQ1=(CQI1-CQI11)/DMUI1I
      CQ1=CQI11+SLCQ1*DMUI1X
C     INTERPOL FOR CQ2 W.R.T. MU, CT=CONST
      SLCQ2=(CQI2-CQI12)/DMUI1I
      CQ2=CQI12+SLCQ2*DMUI1X
C     CQE5=CQ1+(CQ2-CQ1)*(SCN-245.6)/12.4
      VTIP1=713.65
      VTIP2=749.61
      CQE5=CQ1+(CQ2-CQ1)*(VTIP-VTIP1)/(VTIP2-VTIP1)
      CQ=CQE5*1.0E-5
      RETURN
      END

         SUBROUTINE PAVAIL(NFV,ZNOENG,UTL,XLTL)
      COMMON/PAVA/PAC1E,PAM1E,VF(20),PAC1(20),PAM1(20),PAC2(20),PAM2(20)
      DO 100 I=1,NFV
      PAC1(I)=PAC1E
      PAM1(I)=PAM1E
      IF(VF(I) .GE. 50.0)PAC1(I)=PAC1(I)+0.42*(VF(I)-50.0)
      IF(VF(I) .GE. 50.0)PAM1(I)=PAM1(I)+0.62*(VF(I)-50.0)
      PAC2(I)=ZNOENG*PAC1(I)
      PAM2(I)=ZNOENG*PAM1(I)
      PAC1(I)=AMIN1(PAC1(I),XLTL)
      PAM1(I)=AMIN1(PAM1(I),XLTL)
      PAC2(I)=AMIN1(PAC2(I),UTL)
      PAM2(I)=AMIN1(PAM2(I),UTL)
  100 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE CTINT
C      THIS SUBRROUTINE CALCULATES LOAD FACTOR,BANK ANGLE,TURN RADIUS,AND RA
C     OF TURN,AND LATERAL ACCELERATION FOR THE HORIZENTAL FLIGHT MODE ONLY.
C     THIS SUBROUTINE INTERPOLATES ON MU AND CQ TO FIND THE CT CORRES. TO PA
      COMMON DMU(15),CTD(12),CQD1(14,7),CQD2(14,7),NMUD,NCTD
      COMMON/PAVA/PAC1E,PAM1E,VF(20),PAC1(20),PAM1(20),PAC2(20),PAM2(20)
      COMMON /BCT/XMU,PSFAC,SIGMA,VTIP,CT,CLSTL,VFTS,RHO1
      COMMON /BCT1/CTCP,CTMP,IX,PRHF(20),PCLF(20),PMLF(20),EFF
  120 FORMAT(1H0,2F10.2,4F12.2,2X,E12.4,3F11.2)
      TSFAC=PSFAC*XMU*550.0/VFTS
      WTT=CT*TSFAC
      VFKN=VFTS/1.689
      RCS=0.0
      CPCE5=PAC2(IX)*1.0E+5/PSFAC
      CPME5=PAM2(IX)*1.0E+5/PSFAC
      XCP=CPCE5*EFF
C     FOR K=1,PAV=PAC2(IX),FOR K=2,PAV=PAM2(IX).
      DO 90 K=1,2
      IF(K .EQ. 2)XCP=CPME5*EFF
   10 DO 20 I=1,14
      IF(XMU .GT. DMU(I))GOTO 20
      GOTO 30
   20 CONTINUE
      I=I-1
   30 DO 50 J=1,7
      IF(XCP .GT. CQD1(I,J))GOTO 50
      GOTO 60
   50 CONTINUE
      J=J-1
   60 IF(J .EQ. 1)J=J+1
      SLOPI1=(CTD(J)-CTD(J-1))/(CQD1(I,J)-CQD1(I,J-1))
      CTI1=CTD(J-1)+SLOPI1*(XCP-CQD1(I,J-1))
      IF(I .EQ. 1)I=I+1
      DO 65 JJ=1,7
      IF(XCP .GT. CQD1(I-1,JJ))GOTO 65
      GOTO 68
   65 CONTINUE
      JJ=JJ-1
   68 IF(JJ .EQ. 1)JJ=JJ+1
      SLOPI11=(CTD(JJ)-CTD(JJ-1))/(CQD1(I-1,JJ)-CQD1(I-1,JJ-1))
      CTI11=CTD(JJ-1)+SLOPI11*(XCP-CQD1(I-1,JJ-1))
      CT1=CTI11+(CTI1-CTI11)*(XMU-DMU(I-1))/(DMU(I)-DMU(I-1))
      DO 70 J=1,7
      IF(XCP .GT. CQD2(I,J))GOTO 70
      GOTO 75
   70 CONTINUE
      J=J-1
   75 IF(J .EQ. 1)J=J+1
      SLOPI2=(CTD(J)-CTD(J-1))/(CQD2(I,J)-CQD2(I,J-1))
      CTI2=CTD(J-1)+SLOPI2*(XCP-CQD2(I,J-1))
      DO 76 JJ=1,7
      IF(XCP .GT. CQD2(I-1,JJ))GOTO 76
      GOTO 77
   76 CONTINUE
```

```
      JJ=JJ-1
   77 IF(JJ .EQ. 1)JJ=JJ+1
      SLOPI12=(CTD(JJ)-CTD(JJ-1))/(CQD2(I-1,JJ)-CQD2(I-1,JJ-1))
      CTI12=CTD(JJ-1)+SLOPI12*(XCP-CQD2(I-1,JJ-1))
      CT2=CTI12+(CTI2-CTI12)*(XMU-DMU(I-1))/(DMU(I)-DMU(I-1))
C     CTE4=CT1+(SCN-245.6)*(CT2-CT1)/12.4
      VTIP1=713.65
      VTIP2=749.61
      CTE4=CT1+(CT2-CT1)*(VTIP-VTIP1)/(VTIP2-VTIP1)
      CTX=CTE4* 1.0E-4
      CTXOS [illegible] X/SIGMA
      IF(C [illegible] .GT. CLSTL)CTX=CLSTL*SIGMA
      IF(K .EQ. 2)GOTO 80
C     IN THIS PART WE CALCULATETHE LOAD FACTOR,BANK ANGLE,TURN RADIUS,
C     RATE OF TURN AND LATERAL ACCELERATION.
      PCLF(IX)=CTX/CT
      IF(PCLF(IX) .LT. 1.0)GOTO 81
      TANPHI=SQRT(PCLF(IX) *PCLF(IX) -1.0)
      ACCEL=32.17*TANPHI
      GOTO 83
   81 TANPHI=-1.0E-5
      ACCEL=32.17*TANPHI
   83 PHIR=ATAN(TANPHI)
      PHID=PHIR*57.29578
      IF(TANPHI .EQ. 0.0)GOTO 78
      TURRFT=VFKN*VFKN/(11.26*TANPHI)
      GOTO 79
   78 TURRFT=1000000.
   79 ROTDS=1091.*TANPHI/VFKN
      WRITE(*,120)VFKN,RCS,PRHF(IX),PAC2(IX),PCLF(IX),PHID,TURRFT,ROTDS,
     *ACCEL
      GOTO 90
   80 PMLF(IX)=CTX/CT
      IF(PMLF(IX) .LT. 1.0)GOTO 86
      TANPHI=SQRT(PMLF(IX)*PMLF(IX)-1.0)
      ACCEL=32.17*TANPHI
      GOTO 87
   86 TANPHI=-1.0E-5
      ACCEL=32.17*TANPHI
   87 PHIR=ATAN(TANPHI)
      PHID=PHIR*57.29578
      IF(TANPHI .EQ. 0.0)GOTO 85
      TURRFT=VFKN*VFKN/(11.26*TANPHI)
      GOTO 82
   85 TURRFT=1000000.
   82 ROTDS=1091.0*TANPHI/VFKN
      WRITE(*,120)VFKN,RCS,PRHF(IX),PAM2(IX),PMLF(IX),PHID,TURRFT,ROTDS,
     *ACCEL
      GOTO 90
   90 CONTINUE
      RETURN
      END
```

```
           SUBROUTINE VINDRA(NFV,VF,PRHF)
      DIMENSION XD(5),X(5,3),Y(5),AF(5),A(4,4),C(3),SIG(3),T(3),R(5),
     *XC(2),YC(2),VF(1),PRHF(1)
C     THIS SUBROUTINE CALCULATES THE INDURANCE VELOCITY AND THE VELOCITY
C     CORRESPONDING TO MAXIMUM RANGE.THE COMPUTATION IS PERFORMED WITH A
C     LEAST SQUARE FIT OF FIVE DATA POINTS OF THE POWER VS VELOCITY CURVE
      IC=0
      N=3
      M=5
      NRX=5
      NRA=4
      IND=NFV-1
      DO 50 J=1,IND
      IF(PRHF(J+1) .LT. PRHF(J))GOTO 50
      GOTO 60
   50 CONTINUE
   60 XD(1)=VF(J-2)
      XD(2)=VF(J-1)
      XD(3)=VF(J)
      XD(4)=VF(J+1)
      XD(5)=VF(J+2)
      Y(1)=PRHF(J-2)
      Y(2)=PRHF(J-1)
      Y(3)=PRHF(J)
      Y(4)=PRHF(J+1)
      Y(5)=PRHF(J+2)
      DO 100 I=1,M
      X(I,1)=1
      X(I,2)=XD(I)
      X(I,3)=XD(I)*XD(I)
  100 CONTINUE
      CALL GENLSQ(X,NRX,Y,M,A,NRA,N,C,R,AF,ERMS,SIG,T,DET,IC)
      WRITE(*,2)
      WRITE(*,1)C
      WRITE(*,2)
      WRITE(*,3)(XD(I),Y(I),AF(I),R(I),I=1,M)
      WRITE(*,2)
      XC(1)=-C(2)/(2.0*C(3))
      XM=C(2)+2.0*SQRT(C(1)*C(3))
      XC(2)=(XM-C(2))/(2.0*C(3))
      DO 200 K=1,2
  200 YC(K)=C(1)+C(2)*XC(K)+C(3)*XC(K)*XC(K)
    1 FORMAT(1H0,'C(1)=',F10.5,5X,'C(2)=',F10.5,5X,'C(3)=',F10.5)
    2 FORMAT(//)
    3 FORMAT(15X,4F10.5)
    4 FORMAT(1H0,'VMAXIND=',F10.5,5X,'PRMIN=',F10.5,5X,'VMAXRA=',F10.5,
     *5X,'PRMAXRA=',F10.5)
      WRITE(*,4)  (XC(I),YC(I),I=1,2)
      RETURN
      END

      SUBROUTINE LACC(CPCE5,CPME5,VTIP,CTCP,CTMP)
      COMMON DMU(15),CTD(12),CQD1(14,7),CQD2(14,7),NMUD,NCTD
C     THIS SUBROUTINE CALCULATES THE MAX AMOUNT OF THRUST THAT CAN
```

```
C     BE GENERATED IN HOVER FOR THE POWERS PAC,AND PAM.
      CQX=CPCE5
      DO 90 K=1,2
      IF(K .EQ. 2)CQX=CPME5
      DO 50 J=1,7
      IF(CQX .GT. CQD1(1,J))GOTO 50
      GOTO 60
   50 CONTINUE
   60 IF(J .EQ. 1)J=J+1
      CT1=CTD(J-1)+(CTD(J)-CTD(J-1))*(CQX-CQD1(1,J-1))/(CQD1(1,J)-CQD1(1
     *,J-1))
      DO 70 JJ=1,7
      IF(CQX .GT. CQD2(1,JJ))GOTO 70
      GOTO 80
   70 CONTINUE
   80 IF(JJ .EQ. 1)JJ=JJ+1
      CT2=CTD(JJ-1)+(CTD(JJ)-CTD(JJ-1))*(CQX-CQD2(1,JJ-1))/(CQD2(1,JJ)-C
     *QD2(1,JJ-1))
C      CTXE4=CT1+(CT2-CT1)*(SCN-245.6)/12.4
      VTIP1=713.65
      VTIP2=749.61
      CTXE4=CT1+(CT2-CT1)*(VTIP-VTIP1)/(VTIP2-VTIP1)
      CTX=CTXE4*1.0E-4
      IF(K .EQ. 1)CTCP=CTX
      IF(K .EQ. 2)CTMP=CTX
   90 CONTINUE
      RETURN
      END

      SUBROUTINE  GE(CT,CQI,FL,CPCE5,CPME5,CTCI,CTMI)
      COMMON/IGE/CTIN(10),CQIN(10),XINMU(10)
      IF(FL .EQ. 1.0)GOTO 40
C     THIS SUBROUTINE CALCULATES IN THIS PART THE CQ REQUIRED FOR HOVER IN I
      CTE4=CT*1.0E+4
      DO 20 I=1,8
      IF(CTE4 .GT. CTIN(I))GOTO 20
      GOTO 30
   20 CONTINUE
      I=I-1
   30 IF(I .EQ. 1)I=I+1
      CQE5=CQIN(I-1)+(CQIN(I)-CQIN(I-1))*(CTE4-CTIN(I-1))/(CTIN(I)-CTIN(
     *I-1))
      CQI=CQE5*1.0E-5
      GOTO 100
C     THIS SUBROUTINE CALCULATES IN THIS PART THE THRUST IT CAN GENERATE IN
C     THE I.G.E. CORRESPONDING TO PAC AND PAM.
   40 CQX=CPCE5
      DO 90 K=1,2
      IF(K .EQ. 2)CQX=CPME5
      DO 60 J=1,8
      IF(CQX .GT. CQIN(J))GOTO 60
      GOTO 70
   60 CONTINUE
      J=J-1
```

```
 70 IF(J .EQ. 1)J=J+1
    CTX4=CTIN(J-1)+(CTIN(J)-CTIN(J-1))*(CQX-CQIN(J-1))/(CQIN(J)-CQIN(J
   *-1))
    CTX=CTX4*1.0E-4
    IF(K .EQ. 1)CTCI=CTX
    IF(K .EQ. 2)CTMI=CTX
 90 CONTINUE
100 RETURN
    END

    SUBROUTINE GENLSQ(X,NRX,F,M,A,NRA,N,C,R,AF,ERMS,SIG,T,DET,IC)
    DIMENSION X(NRX,N),F(NRX),A(NRA,N),C(N),R(M),AF(M),SIG(N),T(N),
   1SA(100)
    NN=N
    MM=M
    NP1=NN+1
    DO 9 IJ=1,NN
    DO 9 IK=1,NP1
    A(IJ,IK)=0.0
    RSQAR=0.
 10 DO 12 K=1,MM
    J=1
    DO 11 I=1,NN
    SA(J)=X(K,I)
 11 J=J+1
    SA(J)=F(K)
    W=1.
 12 CALL FNEQS(A,NN,SA,NRA,W)
    CALL MATINV(A,NN,C,NRA,2,DET)
    DO 125 I=1,NN
125 C(I)=A(I,NN+1)
    IF(IC.EQ.1)GO TO 18
    DO 14 K=1,MM
    APP=0.
    DO 13 I=1,NN
 13 APP=APP+X(K,I)*C(I)
    TE=F(K)-APP
    RSQAR=RSQAR+TE*TE
    IF(IC.EQ.2)GO TO 14
    R(K)=TE
    IF(IC.EQ.3)GO TO 14
    AF(K)=APP
 14 CONTINUE
    IF(M.LE.N) GO TO 19
    FM=MM
    FN=NN
    ERMS=SQRT(RSQAR/(FM-FN))
    DO 17 I=1,NN
    IF(A(I,I).LE.0.)GO TO 16
    SIG(I)=ERMS*SQRT(A(I,I))
    T(I)=C(I)/SIG(I)
    GO TO 17
 16 SIG(I)=A(I,I)
    T(I)=0.
```

```
 17 CONTINUE
 18 RETURN
 19 PRINT   20,MM,NN
    ERMS=0.
    DO 30 I=1,NN
    SIG(I)=0.
 30 T(I)=0.
    GOTO 18
 20 FORMAT(23H ERROR-GENLSQ M.LE.N M=,I5,3H N=,I5)
    END

    SUBROUTINE MATINV(A,N,C,NMAX,K,DET)
    DIMENSION A(NMAX,N), C(N)
    NN=N
    KK=K
    ZERO=0.
    ASSIGN 30 TO N6
    IF(1-KK) 24,23,23
 23 N3=NN
    IF(KK) 25,28,25
 28 ASSIGN 40 TO N6
    GO TO 26
 25 ASSIGN 8 TO N5
    ASSIGN 16 TO N7
    ASSIGN 10 TO N8
    GO TO 27
 24 N3=KK+NN-1
    ASSIGN 2 TO N8
 26 ASSIGN 9 TO N5
    ASSIGN 17 TO N7
 27 T3=1.0
    T2=1.0
    DO 21 I=1,NN
    IF(ABS(A(I,I))-ZERO) 29,29,2
 29 GO TO N6,(40,30)
 40 PRINT   4
    DET = 0.0
    RETURN
  4 FORMAT(16H SINGULAR MATRIX)
  2 T1=1.0/A(I,I)
    T3=T3*A(I,I)
    A(I,I)=1.0
    DO 6 J=1,N3
  6 A(I,J)=A(I,J)*T1
  7 GO TO N5,(8,9)
  8 C(I)=C(I)*T1
  9 DO 17 J=1,NN
    IF(I-J) 11,17,11
 11 T1=A(J,I)
    A(J,I)=0.0
    DO 14 L=1,N3
 14 A(J,L)=A(J,L)-T1*A(I,L)
 15 GO TO N7,(16,17)
 16 C(J)=C(J)-T1*C(I)
```

```
   17 CONTINUE
   21 CONTINUE
      IF(T3) 22,50,22
   50 T3=1.0E-150
   22 DET=T3*T2
      RETURN
   30 IF(I-NN) 31,40,31
   31 J=I+1
      DO 39 L=J,NN
      IF(ABS(A(L,I))-ZERO) 39,39,42
   39 CONTINUE
      GO TO 40
   42 DO 41 J=1,N3
      T1=A(I,J)
      A(I,J)=A(L,J)
   41 A(L,J)=T1
      T2=-T2
      GO TO N8,(10,2)
   10 T1=C(I)
      C(I)=C(L)
      C(L)=T1
      GO TO 2
      END

      SUBROUTINE  FNEQS(A,N,C,NMAX,W)
      DIMENSION A(NMAX,N),C(N)
      JA=N+1
      L=1
      DO 10 I=1,N
      M=L
      K=I
      T=  C(I)*W
      IF  (T)5,10,5
5     DO 14 J=1,JA
      IF  (J-I)9,8,8
    8 A(K,1)=A(K,1)+T*C(J)
   14 K=  K+NMAX
   10 L=  L+NMAX
      RETURN
    9 A(K ,1)=A(M,1)
      M=M+1
      GOTO14
      END
```

APPENDIX B:

LISTING OF TORQUE VS. THRUST COEFFICIENTS OF TEST DATA FOR THE UH-60 AND THE AH64 HELICOPTERS

INTENTIONALLY LEFT BLANK.

UH60 Data
OUT OF GROUND EFFECT TORQUE COEFFICIENTS,
$CQ * 10^5$ vs. $CT * 10^4$ and μ

NUMUD = 14				NCTD = 7			
μ/CT	66.0	72.0	78.0	84.0	90.0	96.0	102.0
0.00	63.2	70.9	79.0	87.3	95.9	104.9	114.1
0.12	34.5	38.5	43.5	48.4	54.0	60.2	68.2
0.14	34.0	37.2	41.5	46.0	50.7	56.5	63.5
0.16	33.0	36.2	39.7	43.8	48.2	53.5	60.0
0.18	32.6	35.5	38.5	42.5	46.7	51.5	57.8
0.20	32.7	35.2	38.4	42.4	46.5	51.4	57.1
0.22	33.5	36.0	39.2	43.0	47.2	52.0	58.0
0.24	35.2	37.8	41.0	45.0	49.2	54.2	60.5
0.26	38.3	40.7	44.0	48.0	52.6	58.0	65.5
0.28	41.7	44.5	48.5	52.5	57.7	64.2	73.0
0.30	47.0	49.6	54.0	59.0	65.0	73.0	86.0
0.32	54.0	56.1	61.0	66.3	74.2	85.0	102.5
0.34	62.0	64.2	69.5	76.1	85.3	99.0	130.0
0.36	71.5	74.0	80.0	87.5	100.1	118.5	155.0

UH60 Data (continued)
OUT OF GROUND EFFECT, SECOND SET OF TORQUE COEFFICIENTS,
CQ * 10^5 vs. CT * 10^4

μ/CT	66.0	72.0	78.0	84.0	90.0	96.0	102.0
0.00	64.6	72.6	80.9	89.5	98.5	107.7	117.3
0.12	35.0	38.5	43.5	49.0	54.5	61.5	70.5
0.14	34.2	37.5	41.7	45.7	50.5	56.0	63.0
0.16	33.0	36.0	39.5	43.5	48.0	53.5	59.0
0.18	32.5	35.5	38.5	42.5	46.5	51.0	56.0
0.20	32.6	35.6	39.0	41.8	45.5	50.0	54.7
0.22	33.5	35.8	39.0	42.2	36.0	50.2	55.0
0.24	35.2	37.7	40.5	43.8	47.6	52.0	57.5
0.26	37.7	40.2	43.0	46.5	51.0	56.0	62.0
0.28	41.1	43.5	46.5	50.5	55.5	62.0	69.5
0.30	46.0	48.0	51.0	55.5	62.0	70.0	80.0
0.32	52.0	54.0	57.5	63.0	70.5	80.5	92.5
0.34	59.7	61.5	65.5	72.0	81.0	95.0	112.5
0.36	68.8	71.0	75.5	82.5	94.0	115.0	130.0

UH60 Data (continued)
INGROUND EFFECTS TORQUE COEFFICIENTS,
CT * 10^4 vs. CQ * 10^5

CT * 10^4	CQ * 10^5	μ
60.0	45.0	0.0
66.0	50.2	0.0
72.0	56.0	0.0
78.0	62.5	0.0
90.0	76.5	0.0
96.0	84.0	0.0
102.0	92.5	0.0

AH64 Data
OUT OF GROUND EFFECT TORQUE COEFFICIENTS, CQ * 10^5 vs. CT * 10^4 AND

NMUD = 14				NCTD = 7			
μ/CT	50.0	59.0	68.0	77.0	86.0	95.0	104.0
0.00	46.0	58.0	71.1	84.6	98.8	113.8	129.6
0.12	32.3	36.2	41.4	48.0	56.0	64.5	74.9
0.14	30.0	33.9	38.8	45.1	52.6	60.8	70.2
0.16	28.4	32.3	37.1	43.5	50.8	58.7	67.8
0.18	27.6	31.5	36.3	42.5	49.6	57.5	66.7
0.20	30.0	33.8	38.1	43.6	50.1	57.9	67.9
0.22	32.4	35.9	40.4	46.1	52.6	60.4	70.2
0.24	34.9	38.7	43.1	48.6	55.5	63.7	74.5
0.26	39.6	43.0	47.2	52.9	59.7	68.3	79.8
0.28	44.8	48.2	52.9	58.7	65.7	75.0	88.3
0.30	51.8	55.8	60.5	66.2	73.6	83.3	99.6
0.32	60.6	64.9	70.2	77.0	85.5	96.4	116.4
0.34	71.3	76.1	82.0	89.4	99.0	112.4	137.0
0.36	81.6	89.0	95.9	104.9	116.9	133.7	163.3

AH64 Data (continued)
OUT OF GROUND EFFECT, SECOND SET OF TORQUE COEFFICIENTS, $CQ * 10^5$ vs. $CT * 10^4$

μ/CT	50.0	59.0	68.0	77.0	86.0	95.0	104.0
0.00	46.9	58.5	71.1	84.6	98.8	113.8	129.6
0.12	32.3	36.2	41.4	48.0	56.0	64.5	74.9
0.14	30.0	33.9	38.8	45.1	52.6	60.8	70.2
0.16	28.4	32.3	37.1	43.5	50.8	58.7	67.8
0.18	27.6	31.5	36.3	42.5	49.6	57.5	66.7
0.20	30.0	33.8	38.1	43.6	50.1	57.9	67.9
0.22	32.4	35.9	40.4	46.1	52.6	60.4	70.2
0.24	34.9	38.7	43.1	48.6	55.5	63.7	74.5
0.20	39.6	43.0	47.2	52.9	59.7	68.3	79.8
0.28	44.8	48.2	52.9	58.7	65.7	75.0	88.3
0.30	51.8	55.8	60.5	66.2	73.6	83.3	99.6
0.32	60.6	64.9	70.2	77.0	85.5	96.4	116.4
0.34	71.3	76.1	82.0	89.4	99.0	112.4	137.0
0.36	81.6	89.0	95.9	104.9	116.9	133.7	163.3

AH64 Data (continued)
INGROUND EFFECTS TORQUE COEFFIEIENTS, $CT * 10^4$ vs. $CQ * 10^5$

$CT * 10^4$	$CQ * 10^5$	μ
41.0	30.7	0.0
50.0	39.4	0.0
59.0	49.0	0.0
68.0	59.3	0.0
77.0	70.3	0.0
86.0	82.0	0.0
95.0	94.3	0.0
104.0	107.2	0.0

LIST OF SYMBOLS

VARIABLE SYMBOL		HELPE PROGRAM NAME
h	Operating altitude in feet.	ALT1
IRP	Intermediate rated power in horsepower.	TIRP, PAM
MCP	Maximum continuous power in horsepower.	TMCP, PAC
V_k	Forward speed (knots).	
V	Forward speed (ft/sec).	VFTS
Vt	Rotor tip speed in ft/sec.	VTIP
μ	Ratio of forward speed to rotor tip speed (ND).	VV, DMU, XMU
W	Operating weight (in pounds).	WT
R	Main rotor radius (feet).	ROTR
N	Number of rotor revolutions per second.	N
Po	Power loss due to blade's profile drag.	
A	Rotor disk area (ft^2).	AD
Af	Frontal drag area of a helicopter (ft^2).	FA
A_t	Top flat plate area of a helicopter (ft^2).	TFPA
Cd	Coefficient of drag.	CD, CDX
f	Equivalent frontal drag area ($C_d \cdot A_f$).	F
ρ	Air density.	RHOI
CQ	Coefficient of torque (ND).	
DCQ	Incremental torque coefficient due to drag.	DCQ
CP	Coefficient of power (ND).	
CT	Coefficient of thrust (ND).	CT
Psc	Power scale factor (lbs ft/sec).	PSFAC
Tsc	Thrust scale factor (lbs).	TSFAC
P_h	Power required for horizontal flight (HP).	PRHF
P_c	Power required for vertical climb (HP).	PRCL
P_t	Total power required (HP).	PRTOT
ℓf	Load factor (ND).	XKF1, XLF2
ϕ	Bank angle in a turn.	PHIr, PHID
T	Rotor thrust (lbs).	
R_t	Turn radius (ft).	TURRFT
$\dot{\theta}$	Rate of turn in deg/sec.	ROTDS
F_c	Centripetal force (ft/sec^2).	
	Number of mission weights to compute.	NWT
	Number of level flight speed considered.	NFV
	Number of vertical climb rates.	NCR
	Level speed array name (knots).	VF
PAC1	Continuous engine power available (HP).	PAC1
PAM1	Maximum engine power available (HP).	PAM1
e	Rotor system efficiency factor (ND).	EFF
	Rate of climb (sec^{-1}).	RCS

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