

AD-A284 319



1

ARMY RESEARCH LABORATORY

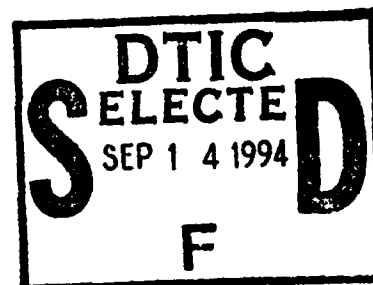


Helicopter Performance Evaluation (HELPE) Computer Model

Abdul R. Kiwan

ARL-TR-489

July 1994



548 94-29742



94 9 13 025

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION IS UNLIMITED.

DTIC QUALITY INSPECTED 3

NOTICES

Destroy this report when it is no longer needed. DO NOT return it to the originator.

Secondary distribution of this report is prohibited.

The findings of this report are not to be construed as an official Department of the Army position, unless so designated by other authorized documents.

The use of trade names or manufacturers' names in this report does not constitute indorsement of any commercial products.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY (Leave blank)

2. REPORT DATE
July 1994

3. REPORT TYPE AND DATES COVERED
Final, Sep 92 - Oct 93

4. TITLE AND SUBTITLE

Helicopter Performance Evaluation (HELPE) Computer Model

5. FUNDING NUMBERS

PR: 1L162618AH80

6. AUTHOR(S)

Abdul R. Kiwan

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

U.S. Army Research Laboratory
ATTN: AMSRL-SL-BA
Aberdeen Proving Ground, MD 21005-5068

8. PERFORMING ORGANIZATION
REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

U.S. Army Research Laboratory
ATTN: AMSRL-OP-AP-L
Aberdeen Proving Ground, MD 21005-5066

10. SPONSORING/MONITORING
AGENCY REPORT NUMBER

ARL-TR-489

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)

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.

DTIC QUALITY INSPECTED 3

14. SUBJECT TERMS

thrust, induced drag, profile drag, tail rotor, parasitic drag, turn radius, rate of turn, vertical rate of climb, maneuverability, bank angle

15. NUMBER OF PAGES

50

16. PRICE CODE

17. SECURITY CLASSIFICATION
OF REPORT
UNCLASSIFIED

18. SECURITY CLASSIFICATION
OF THIS PAGE
UNCLASSIFIED

19. SECURITY CLASSIFICATION
OF ABSTRACT
UNCLASSIFIED

20. LIMITATION OF ABSTRACT
UL

INTENTIONALLY LEFT BLANK.

ACKNOWLEDGMENTS

The author is grateful to Mr. Robert Oehrli, formerly of the Air Systems Branch (ASB) of the Ballistic Vulnerability/Lethality Division (BVL), for his suggestions and to Mr. Stephen Polyak, also of ASB, for many consultations and helpful suggestions.

Accession For	
NTIS	CRA&I
DTIC	REF
Unannounced	
Justification	
By	
Distribution	
Dist	Special
A-1	

INTENTIONALLY LEFT BLANK.

TABLE OF CONTENTS

	<u>Page</u>
ACKNOWLEDGMENTS	iii
LIST OF FIGURES	vii
1. INTRODUCTION	1
2. THE HELPE COMPUTATIONAL MODEL SETUP	4
3. SUBROUTINE FUNCTIONS	5
3.1 MAIN	6
3.2 RDATA	6
3.3 PAVAIL	6
3.4 CQINT	6
3.5 CTINT	6
3.6 VINDRA	6
3.7 GE	6
3.8 LACC	6
3.9 GENLSQ	6
3.10 MATINV	7
3.11 FNEQS	7
4. THE MATHEMATICAL MODELS	7
4.1 Mathematical Models and Techniques	7
4.2 Level Flight and Maneuverability	11
5. INPUT PARAMETERS	15
6. APPLICATION AND COMPARISON OF RESULTS	17
7. REFERENCES	23
APPENDIX A: LISTING OF THE FORTRAN 77 PROGRAM OF THE COMPUTER CODE HELPE	25
APPENDIX B: LISTING OF TORQUE vs. THRUST COEFFICIENTS OF TEST DATA FOR THE UH-60 AND THE AH64 HELICOPTERS	41
LIST OF SYMBOLS	47
DISTRIBUTION LIST	49

INTENTIONALLY LEFT BLANK.

LIST OF FIGURES

<u>Figure</u>	<u>Page</u>
1. Schematic representations of the vulnerability process, its levels, and mappings	2
2. Available engine power output as a function of altitude "h"	8
3. Schematic drawing of the thrust and forces on a helicopter in level flight	12
4. Determination of maximum level flight speeds	14
5. Determination of maximum endurance and maximum range speeds	15
6. Schematic drawing of a UH-60A helicopter	18
7. Computed power vs. speed for the UH-60A helicopter	20
8. Computed maximum speed vs. operating weight for the UH-60A	21

INTENTIONALLY LEFT BLANK.

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 $O_{1,2}$ 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.

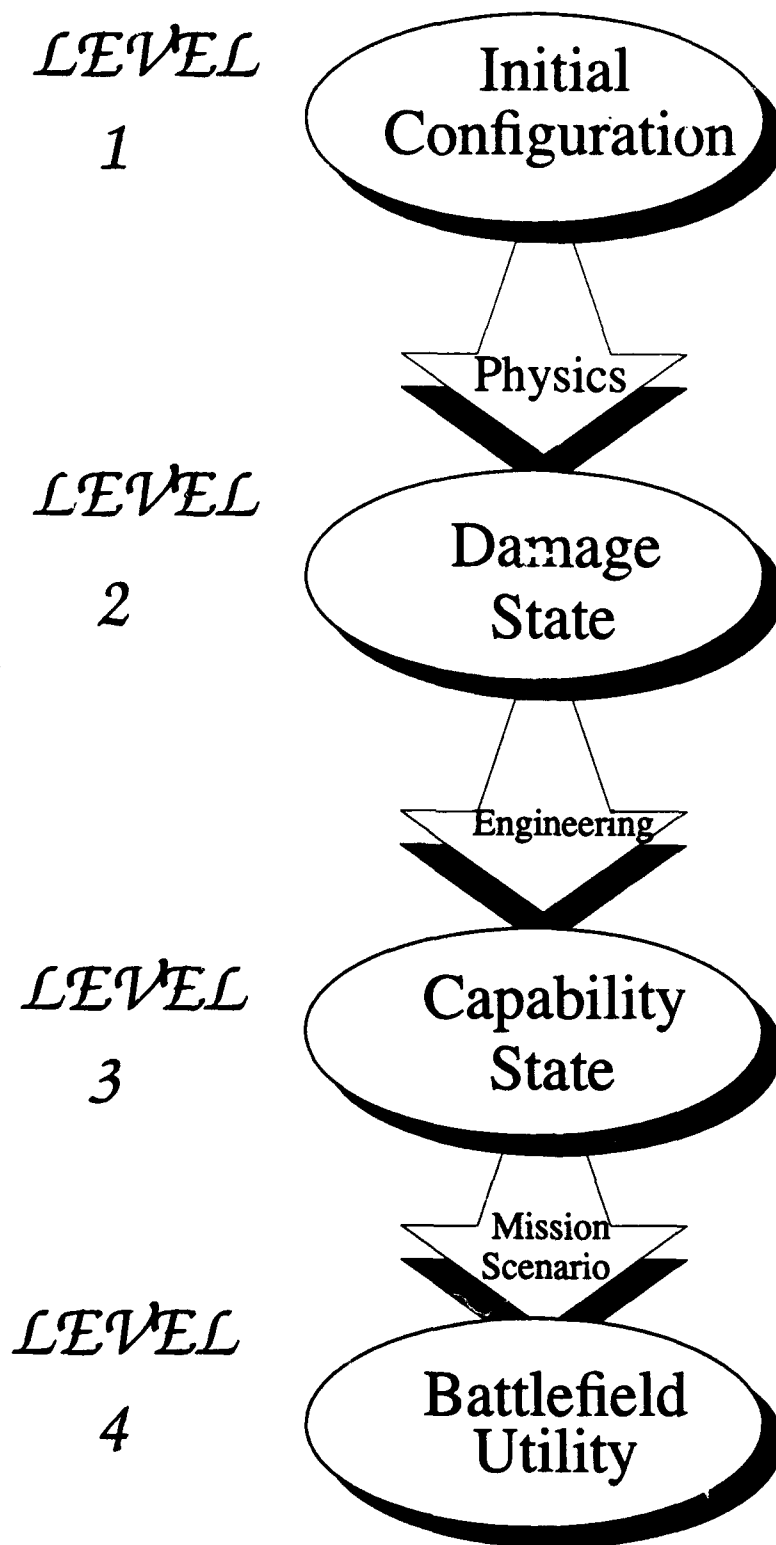


Figure 1. Schematic representations of the vulnerability process, its levels, and mappings.

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 MATINV. This is another subroutine from the system's math library. MATINV is used by GENLSQ for inverting matrices.

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

4. THE MATHEMATICAL MODELS

4.1 Mathematical Models and Techniques. 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 available 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

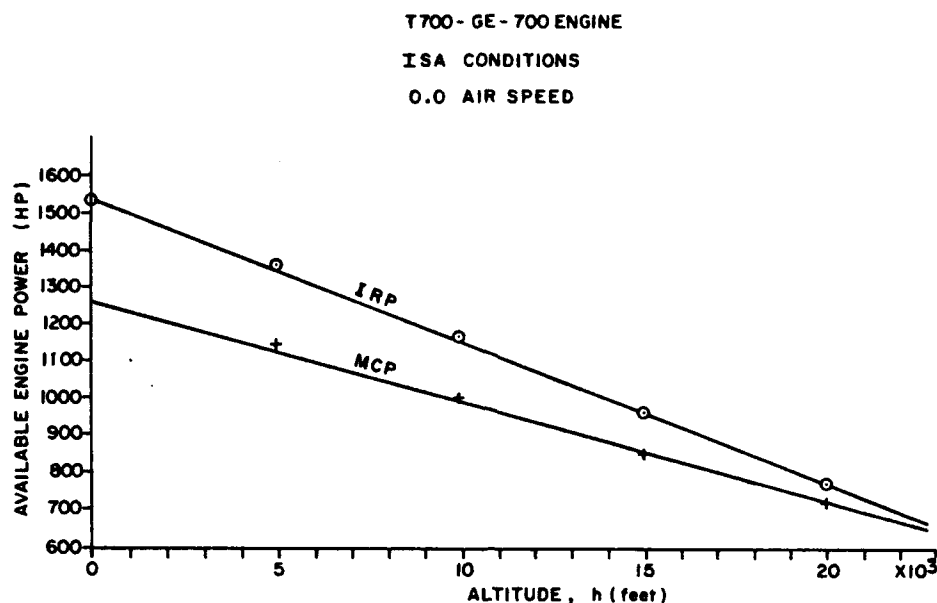
Source: General Electric (1976).

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

$$\text{IRP}(h) = 1546.8 - 0.0388 h \quad (1)$$

$$\text{MCP}(h) = 1266 - 0.0273 h \quad (2)$$

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:

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

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,

$$\mu = V/V_t, \quad (4)$$

$$V_t = 2 \pi R \cdot N, \quad (5)$$

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):

$$P = P_o + 0.5 W^2/(\rho AV) + 0.5 \cdot \rho \cdot f \cdot V^3 \quad (6)$$

$$f = C_d \cdot A_f. \quad (7)$$

The first term on the right-hand side of Equation 6, P_o , 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., $\mu > 0.30$),

$$P \approx P_p = 0.5 \rho \cdot f \cdot V^3. \quad (8)$$

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:

$$CQ = CP = P / (\pi R^2 \rho V_t^3), \quad (9)$$

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

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

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,

$$C_d = 2 \pi R^2 \Delta CQ / (A_f \cdot \Delta \mu^3). \quad (11)$$

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

$$C_d = (2 \pi R^2 / A_f) (CQ_2 - CQ_1) / (\mu_2^3 - \mu_1^3). \quad (12)$$

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,

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

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

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

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

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

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

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 Level Flight and Maneuverability. 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),

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

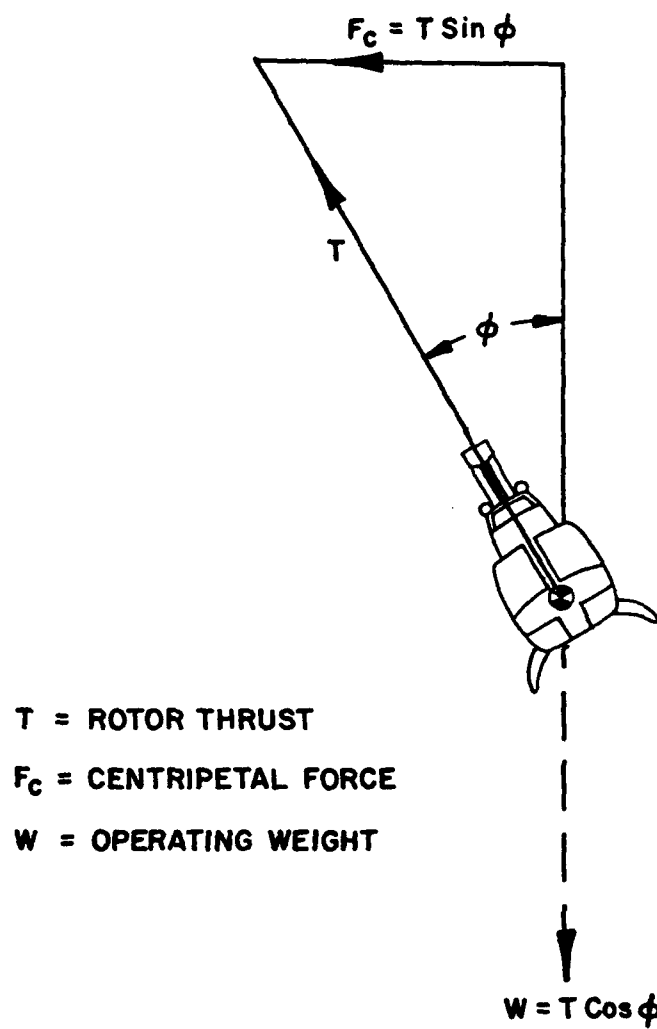


Figure 3. Schematic drawing of the thrust and forces on a helicopter during a turn in level flight.

$$\cos \phi = W/T = 1/\ell_f, \quad (21)$$

$$\tan \phi = \sqrt{\ell_f^2 - 1}. \quad (22)$$

The centrifugal force F_c is given by

$$F_c = (W/g) \cdot (V^2/R_t); \quad (23)$$

hence,

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

where R_t is the turn radius. Equation 24 reduces to

$$R_t = V_k^2 / (11.26 \cdot \tan \phi) \text{ feet}, \quad (25)$$

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

$$\dot{\theta} = 1091 \cdot \tan \phi / V_k \text{ deg/sec}, \quad (26)$$

and the horizontal component of acceleration

$$A_h = g \cdot \tan \phi \cdot \text{ft/sec}^2 \quad (27)$$

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.

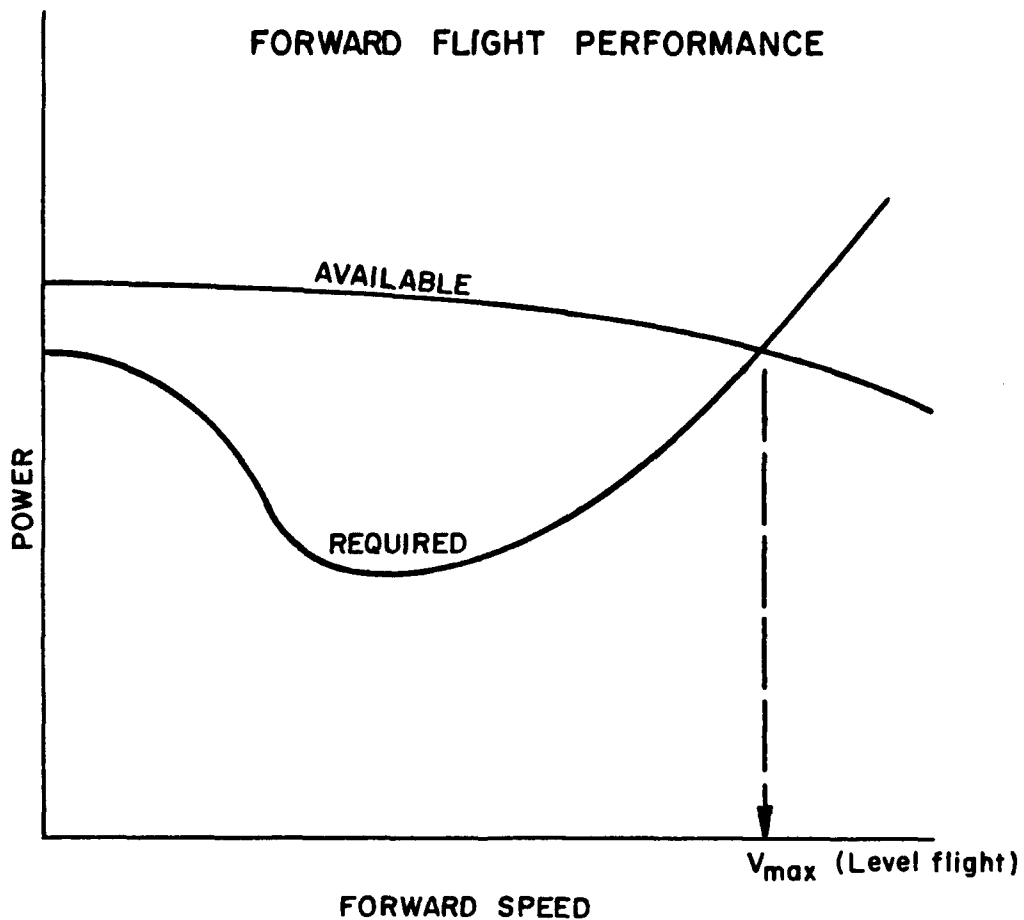


Figure 4. Determination of maximum level flight speeds.

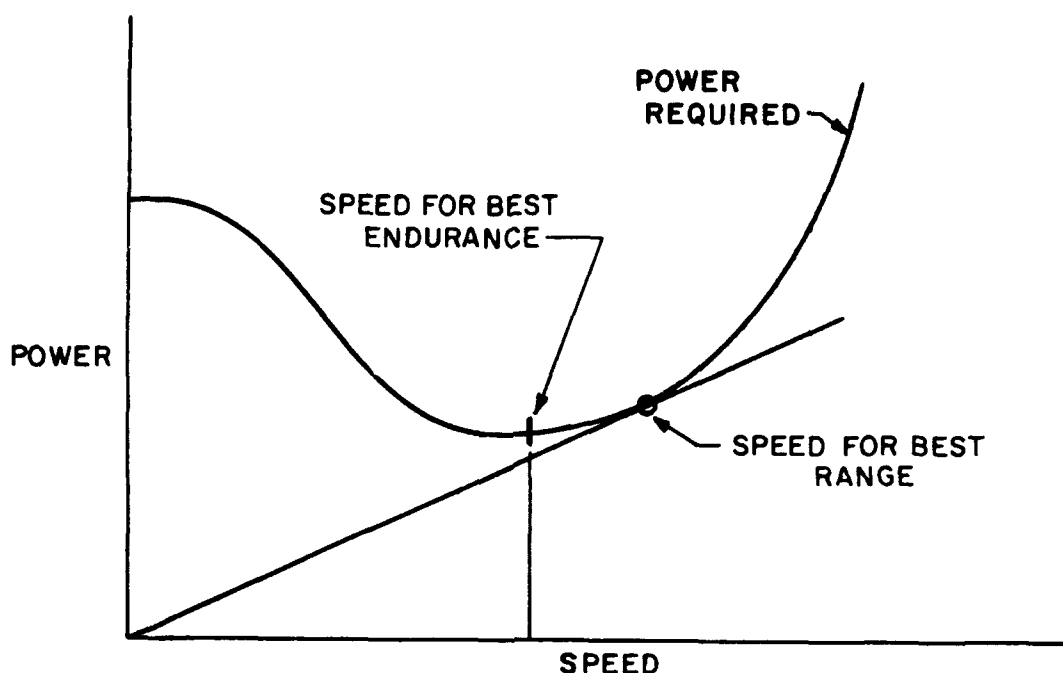


Figure 5. Determination of maximum endurance and maximum range speeds.

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 $\leq$ 6, NFV $\leq$ 20, NCR $\leq$ 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 (feet²).

TFPA = Top flat plate area of aircraft (feet²).

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)

where RC(i) = i^{th} rate of vertical climb (feet/min), $i=1,2,\dots,NCR$.
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 $\partial (MCP)/\partial h$.
DIRPDH = The partial derivative $\partial (IRP)/\partial h$.
DMCPDT = The partial derivative $\partial (MCP)/\partial T$.
DIRPDT = The partial derivative $\partial (IRP)/\partial T$.
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 $C_{do} = D_0 + D1 \cdot \alpha + D2 \cdot \alpha^2$ where α is the angle of attack expressed in radians, as given in Gessow and Myers (1967).

Subroutine RDATA is called to read the $CQ \cdot 10^5$ vs. $CT \cdot 10^4$ 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, $j=1, \dots, \text{NMUD}$.

Card 3: Format (15 F 5.2)

CTD(i) = The i^{th} CT data, $i=1, \dots, \text{NCTD}$

Card 4: Format (8 F 10.3)

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

Card 5: Format (8 F 10.3)

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

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

$k = 1, 2, \dots, 8.$

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

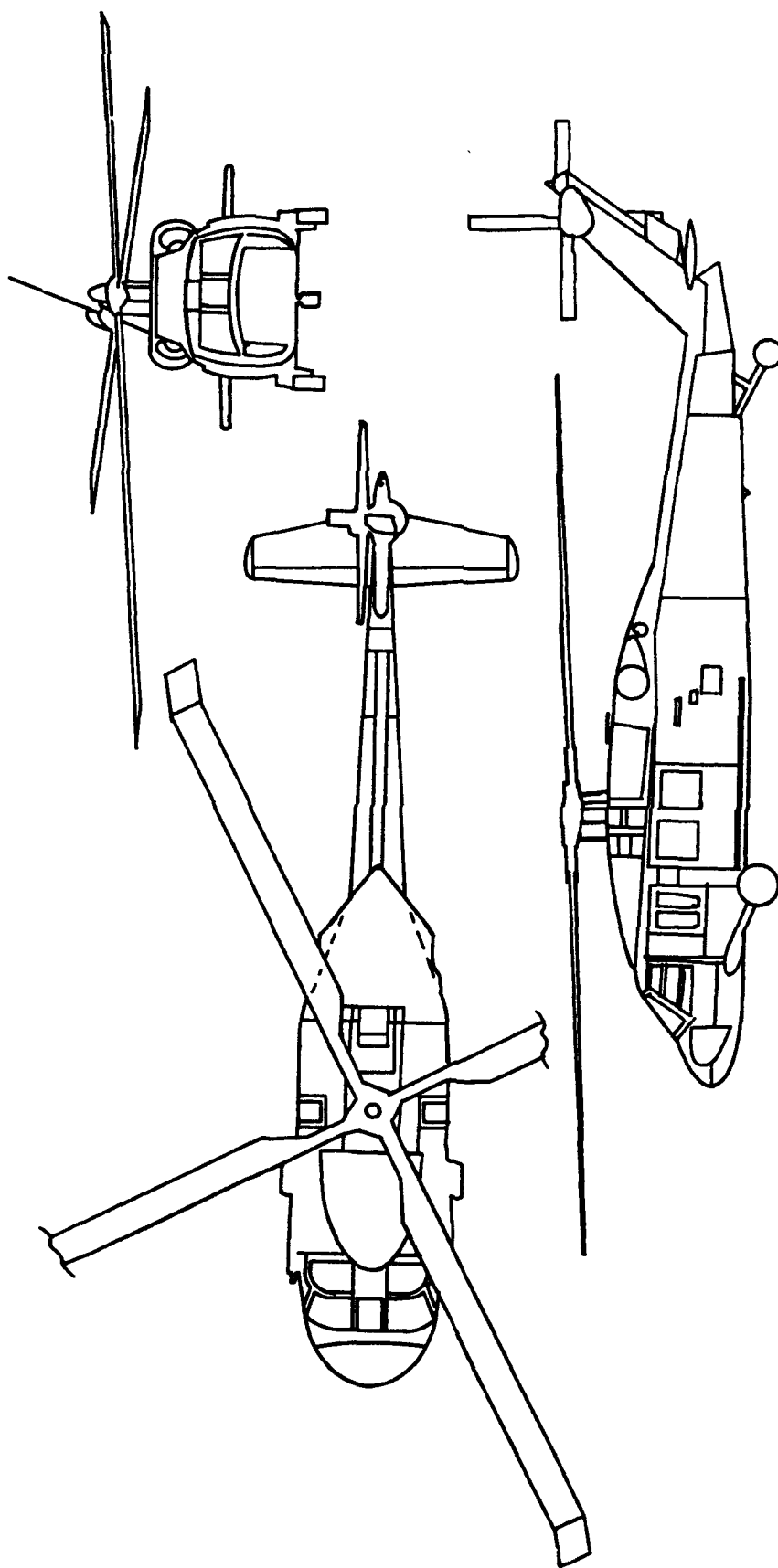


Figure 6. Schematic drawing of a UH-60A helicopter.

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:

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

Card 2: WTG = 16260.0, WTE = 13620.0, OVLf = 1.245, FA = 74.55,
TFPA = 206.0, SCFAB = 0.0165, DTR = 32.567,

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

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

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

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

Card 7: 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

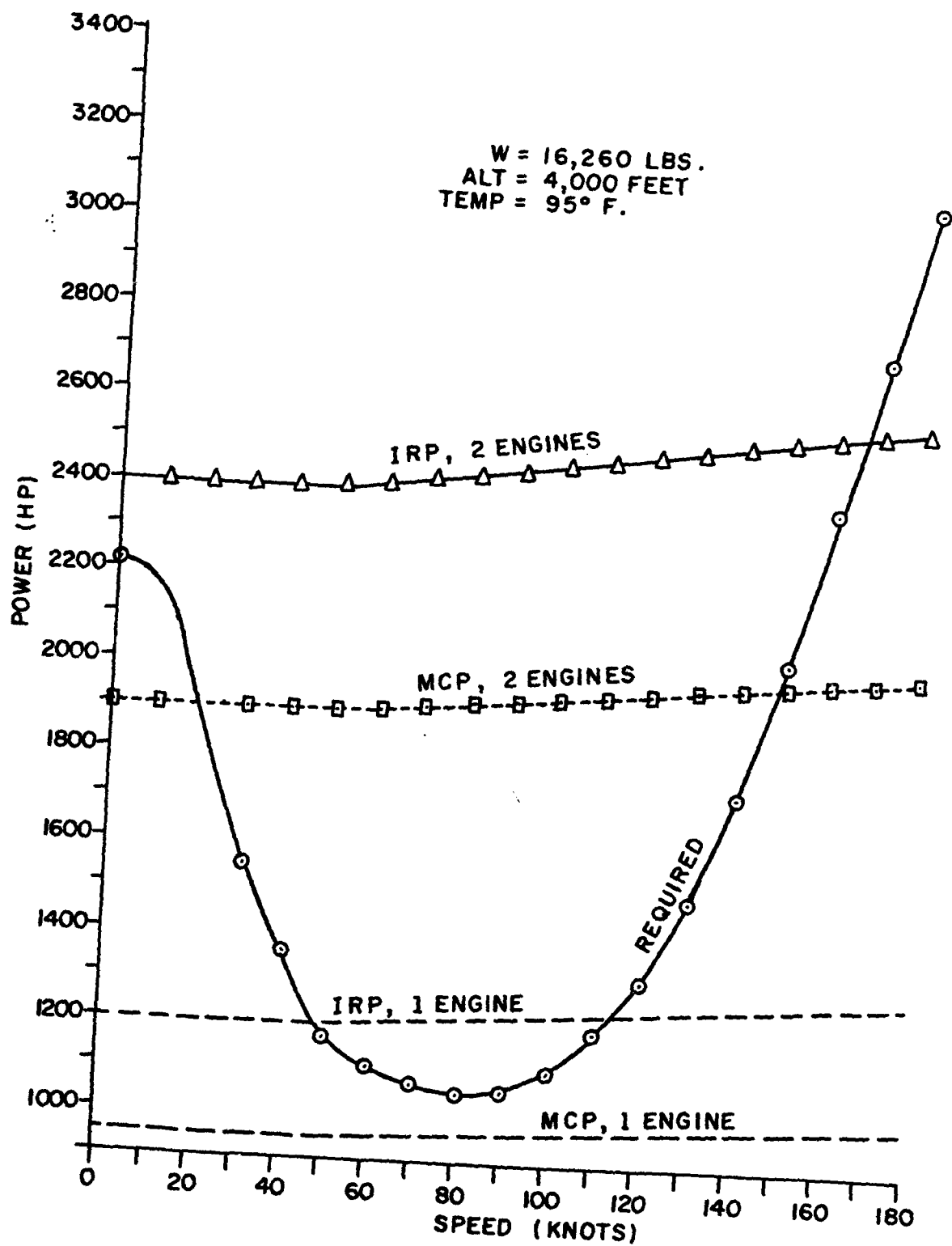


Figure 7. Computed available and required powers vs. speed for the UH-60A helicopter.

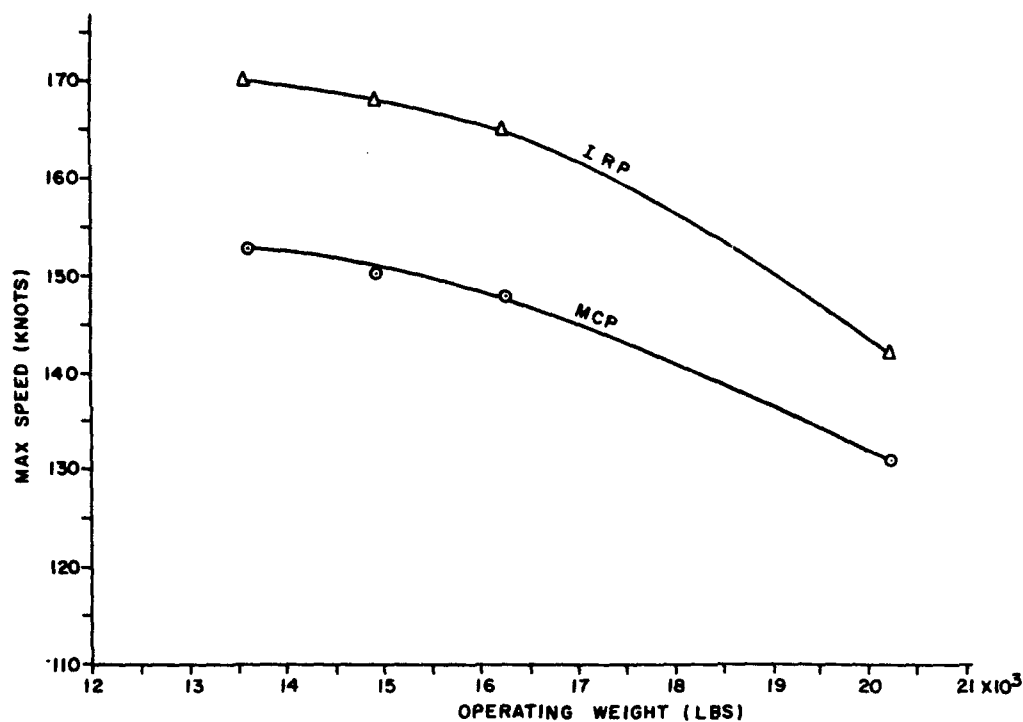


Figure 8. Computed maximum speed vs. operating weight for the UH-60A helicopter.

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 (ft/min)	WT (lb)			
	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.

7. REFERENCES

- General Electric. Specification for T700-GE-700 Turbo Engine, DARCOM-CP-2222-02000B, Part 1, 2 December 1976.
- Gessow, A., and G. C. Myers, Jr. Aerodynamics of the Helicopter. Frederick Ungar Publishing Co., p. 81, 1967.
- Kunkel, R. W. "Degraded States Capability Categories and Levels of Rotary Wing Aircraft." U.S. Army Research Laboratory report in process, Aberdeen Proving Ground, MD, 1994.
- McCormick, Jr., B. W. Aerodynamic of V/STOL Flight. Academic Press, p. 154, 1967.
- Nagata, J. I., et al. "Airworthiness and Flight Characteristics Evaluation UH-60A (Black Hawk) Helicopter." USAAEFA, Project No. 77-17, pp. 8-9, September 1981.
- Roach, L. K. "A Rational for the Modular Air-Systems Vulnerability Estimation Network (MAVEN) Methodology." U.S. Army Research Laboratory report in process, Aberdeen Proving Ground, MD, 1994.
- Saunders, G. H. Dynamics of Helicopter Flight. NY: John Wiley & Sons, Inc., pp. 140-142, 1975.
- Walbert, J. N., L. K. Roach, M. D. Burdeshaw. "Current Directions in the Vulnerability/Lethality Process Structure." ARL-TR-296, U.S. Army Research Laboratory, Aberdeen Proving Ground, MD, October 1993.

INTENTIONALLY LEFT BLANK.

APPENDIX A:
LISTING OF THE FORTRAN 77 PROGRAM
OF THE COMPUTER CODE HELPE

INTENTIONALLY LEFT BLANK.

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 TAPES 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,TFFA,SCFAB,DTR
  WRITE(*,115)ROTR,TRR,TRTV,TRA,SIGMA,SIGMATR,ZNOENG,RPM
  WRITE(*,115)ROTN,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*ROTN
  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 PRTH(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)
THRCF=CTCP*TSFAC
THRMP=CTMP*TSFAC
WRITE(*,82) CTCP,CTMP,CT,THRCF,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,PRTH(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
      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 SUBROUTINE CALCULATES LOAD FACTOR, BANK ANGLE, TURN RADIUS, AND RA
C   OF TURN, AND LATERAL ACCELERATION FOR THE HORIZONTAL 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=X/SIGMA
      IF (C .GT. CLSTL) CTX=CLSTL*SIGMA
      IF (K .EQ. 2) GOTO 80
C    IN THIS PART WE CALCULATE THE 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) - CQD2(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),
1 SA(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

```

```

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 * 10⁵ vs. CT * 10⁴ 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 * 10⁵ vs. CT * 10⁴

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 * 10⁴ vs. CQ * 10⁵

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 * 10⁵ vs. CT * 10⁴ 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 * 10⁵ vs. CT * 10⁴

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 COEFFICIENTS,
CT * 10⁴ vs. CQ * 10⁵

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

<u>VARIABLE</u>		<u>HELPE PROGRAM</u>
<u>SYMBOL</u>		<u>NAME</u>
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
V_t	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).	TTPA
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

INTENTIONALLY LEFT BLANK.

<u>No. of Copies</u>	<u>Organization</u>
2	Administrator Defense Technical Info Center ATTN: DTIC-DDA Cameron Station Alexandria, VA 22304-6145
1	Commander U.S. Army Materiel Command ATTN: AMCAM 5001 Eisenhower Ave. Alexandria, VA 22333-0001
1	Director U.S. Army Research Laboratory ATTN: AMSRL-OP-CI-AD, Tech Publishing 2800 Powder Mill Rd. Adelphi, MD 20783-1145
1	Director U.S. Army Research Laboratory ATTN: AMSRL-OP-CI-AD, Records Management 2800 Powder Mill Rd. Adelphi, MD 20783-1145
2	Commander U.S. Army Armament Research, Development, and Engineering Center ATTN: SMCAR-TDC Picatinny Arsenal, NJ 07806-5000
1	Director Benet Weapons Laboratory U.S. Army Armament Research, Development, and Engineering Center ATTN: SMCAR-CCB-TL Watervliet, NY 12189-4050
1	Director U.S. Army Advanced Systems Research and Analysis Office (ATCOM) ATTN: AMSAT-R-NR, M/S 219-1 Ames Research Center Moffett Field, CA 94035-1000

<u>No. of Copies</u>	<u>Organization</u>
1	Commander U.S. Army Missile Command ATTN: AMSMI-RD-CS-R (DOC) Redstone Arsenal, AL 35898-5010
1	Commander U.S. Army Tank-Automotive Command ATTN: AMSTA-JSK (Armor Eng. Br.) Warren, MI 48397-5000
1	Director U.S. Army TRADOC Analysis Command ATTN: ATRC-WSR White Sands Missile Range, NM 88002-5502
(Class. only) 1	Commandant U.S. Army Infantry School ATTN: ATSH-CD (Security Mgr.) Fort Benning, GA 31905-5660
(Unclass. only) 1	Commandant U.S. Army Infantry School ATTN: ATSH-WCB-O Fort Benning, GA 31905-5000
	<u>Aberdeen Proving Ground</u>
2	Dir, USAMSAA ATTN: AMXSY-D AMXSY-MP, H. Cohen
1	Cdr, USATECOM ATTN: AMSTE-TC
1	Dir, USAERDEC ATTN: SCBRD-RT
1	Cdr, USACBDCOM ATTN: AMSCB-CII
1	Dir, USARL ATTN: AMSRL-SL-I
5	Dir, USARL ATTN: AMSRL-OP-AP-L

No. of
Copies Organization

1 Commander
Dahlgren Division
Naval Surface Warfare Center
ATTN: Code G29, Mr. Thomas Wasmund
Dahlgren, VA 22448-5000

1 ASC/XREWA
ATTN: Dr. Kevin T. McArdle
Eglin AFB, FL 32542-5600

Aberdeen Proving Ground

10 Dir, USARL
ATTN: AMSRL-I, D. Haskell (433)
AMSRL-SL-BA,
A. Kiwan (1065)
J. Walbert (1065)
S. Polyak (1065)
D. Ten Broeck (1065)
W. Thompson (1052)
R. Walther (1065)
J. Fries (1065)
K. Kim (1065)
AMSRL-SL-C, W. Hughes (E3331)

USER EVALUATION SHEET/CHANGE OF ADDRESS

This Laboratory undertakes a continuing effort to improve the quality of the reports it publishes. Your comments/answers to the items/questions below will aid us in our efforts.

1. ARL Report Number ARL-TR-489 Date of Report July 1994

2. Date Report Received _____

3. Does this report satisfy a need? (Comment on purpose, related project, or other area of interest for which the report will be used.) _____

4. Specifically, how is the report being used? (Information source, design data, procedure, source of ideas, etc.) _____

5. Has the information in this report led to any quantitative savings as far as man-hours or dollars saved, operating costs avoided, or efficiencies achieved, etc? If so, please elaborate. _____

6. General Comments. What do you think should be changed to improve future reports? (Indicate changes to organization, technical content, format, etc.) _____

CURRENT ADDRESS

Organization

Name

Street or P.O. Box No.

City, State, Zip Code

7. If indicating a Change of Address or Address Correction, please provide the Current or Correct address above and the Old or Incorrect address below.

OLD ADDRESS

Organization

Name

Street or P.O. Box No.

City, State, Zip Code

(Remove this sheet, fold as indicated, tape closed, and mail.)
(DO NOT STAPLE)

DEPARTMENT OF THE ARMY

OFFICIAL BUSINESS



**NO POSTAGE
NECESSARY
IF MAILED
IN THE
UNITED STATES**

BUSINESS REPLY MAIL
FIRST CLASS PERMIT NO 0001, APG, MD

Postage will be paid by addressee

Director
U.S. Army Research Laboratory
ATTN: AMSRL-OP-AP-L
Aberdeen Proving Ground, MD 21005-5066

