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# NAVAL POSTGRADUATE SCHOOL

Monterey, California

# THESIS

## AN ANALYSIS OF THREE APPROACHES TO THE HELICOPTER PRELIMINARY DESIGN PROBLEM

by

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March 1984

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Three methodologies from which to approach the problem of preliminary helicopter design are explored in this paper. The first is a sensitivity analysis of the basic helicopter performance equations. The purpose here is to ascertain where reasonable simplifications can be made that do not seriously degrade the accuracy of the results. The second is a graphical parametric design method, known as Carpet Plots. In this method a graphical solution is developed to meet the design criteria of the helicopter. In the third, an overview of Boeing Vertol's Helicopter Sizing and Performance Computer Program is given. The computer routines which enable a person to access HESCOMP on the Naval Postgraduate School main frame IBM system are also provided.

# An Analysis of Three Approaches to the Helicopter Preliminary Design Problem

by

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requirements for the degree of

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# ABSTRACT

Three methodologies from which to approach the problem of preliminary helicopter design are explored in this paper. The first is a sensitivity analysis of the basic helicopter performance equations. The purpose here is to ascertain where reasonable simplifications can be made that do not seriously degrade the accuracy of the results. The second is a graphical parametric design method, known as Carpet Plots. In this method a graphical solution is developed to meet the design criteria of the helicopter. In the third, an overview of Boeing Vertol's Helicopter Sizing and Performance Computer Program is given. The computer routines which enable a person to access HESCOMP on the Naval Postgraduate School main frame IBM system are also provided.

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# I. INTRODUCTION

## A. GENERAL

The helicopter design process, the subject of numerous articles and studies is an evolving discipline that borders on being an art. A successful design must balance the user's needs and desires against practical capabilities.

With the introduction of composite materials and new technologies, principally in rotor and engine performance, significant advances have been made in helicopter capabilities. In some instances, the performances of hybrid helicopter designs rivals that of a similarly sized conventional aircraft. For example, the YVX, a joint Boeing-Bell venture, will have the hover and low speed capabilities of a helicopter while being able to cruise at 300 knots.

Viable commercial and military helicopter designs are only thirty years old. The first major use of helicopters occurred during the Korean conflict. To put this in perspective, the first large scale use of conventional type aircraft was in World War I.

Helicopter design can proceed on a number of different levels, ranging from comprehensive computer design programs to preliminary analysis using simplifications of the basic performance equations. Each has its merit and place. Computer-aided design provides a great deal of data.

Generally, these programs integrate aircraft configuration sizing, performance and weight calculations in an iterative process. An example of a computer design program for helicopters is the Helicopter Sizing and Performance Computer Program [HESCOMP], orginally developed by Boeing-Vertol for NASA. This program is currently used as a wide number of institutions conducting studies in helicopter design.

On the opposite end of the spectrum would be sensitivity design studies using the performance equations. Surprisingly accurate simplications of these equations can be made. This provides the designer with an excellent method for doing first cut preliminary helicopter sizing at a low cost.

## B. OBJECTIVE

This report is an investigation of several of the methods employed in the preliminary design of a helicopter. Conceptually, the report can be divided into three parts. In the first section, a sensitivity analysis of the basic performance equations is performed. The purpose here is to ascertain where reasonable simplications can be made that do not seriously degrade the accuracy of the result.

In the second section a graphical method of doing parametric design studies, known as Carpet Plots, is developed. This method allows the user to formulate a graphical solution matrix to meet the design criteria specified for the helicopter. Carpet Plots are particularly instructive since they give visual insight into the interplay of the various design parameters.

In the last section, an overview of HESCOMP is given. Programs are developed which enable a person to access HESCOMP on the Naval Postgraduate School Main Frame IBM system.

# II. SENSITIVITY ANALYSES OF BASIC HELICOPTER EQUATIONS

## A. DESCRIPTION OF PROBLEM

In preliminary helicopter design, there are a number of instances where a quick first cut analysis would be extremely helpful. This is especially true in determining the preliminary size of the helicopter required to meet the specifications.

Historically, there are a number of variables in the performance equations of helicopters which may be treated as constants. This may allow for significant simplifications and aid in the preliminary design process.

In this section, a sensitivity analysis of the performance equations is done. In a sensitivity analysis, each parameter [or variable] is varied in order to determine its effect on the equation. Variables which are shown to have little effect may be treated as constants and the equation simplified accordingly.

## B. SOLIDITY

Solidity, $\sigma$ , is the fraction of the disk area that is composed of blades. It is a function of $b$ , the number of blades, of a constant cord, $c$ , at a radius, $R$:

$$\sigma = \frac{bc}{\pi R} \qquad (2.1)$$

## C. DISK LOADING:

Disk loading is defined as the ratio of the weight to the total area of the rotor disk.

$$DL = \frac{\text{WEIGHT}}{\text{AREA}} = \frac{W}{A} = \frac{W}{\pi R^2} \; [\text{lb/ft}^2] \qquad (2.2)$$

## D. POWER LOADING

Power loading is the ratio of weight to input power.

$$PL = \frac{W}{P_{in}} \; [\text{lb/hp}] \qquad (2.3)$$

In a hover, thrust equals weight; this allows us to rewrite the power loading for the hover condition as

$$PL = \frac{T}{P_{in}} = \frac{\text{ROTOR THRUST}}{\text{ROTOR HORSEPOWER}} \; [\text{lb/hp}] \qquad (2.4)$$

## E. COEFFICIENT OF THRUST AND POWER

The coefficient of thrust, $C_T$ , is a non-dimensional coefficient which facilitates computations and comparisons:

$$C_T = \frac{T}{A\rho V_T^2} = \frac{T}{\pi R^2 \rho (\Omega R)^2} \qquad (2.5)$$

Similarly, a coefficient of power, $C_p$ , has been established as:

$$C_p = \frac{P}{A\rho V_T^3} = \frac{P}{\pi R^2 \rho (\Omega R)^3} \qquad (2.6)$$

No significant simplifications can be made to either of these coefficients. However, it should be observed that the coefficient of thrust is inversely proportional to the square of the rotor tip velocity, while the coefficient of power is inversely proportional to the cube.

Assuming all other factors being equal, increasing the rotor tip velocity from 600 fps to 700 fps [an increase of 16.7 percent] will have the following result on these coefficients.

$$C_T = \frac{T}{A\rho V_T^2}$$

$$= \frac{T}{A\rho (1.167)^2} \qquad (2.5)$$

$$= \frac{T}{A\rho (1.361)}$$

The coefficient of thrust is reduced by 26.9 percent. Similarly, for the coefficient of power:

$$C_P = \frac{P}{A\rho V_T{}^3}$$

$$= \frac{P}{A\rho(1.167)^3} \qquad (2.6)$$

$$= \frac{P}{A\rho(1.589)}$$

The coefficient of power is reduced by 37.1 percent.

## F. HOVER POWER

The total power in a hover is made up of two terms, profile power, $P_o$ , and induced power, $P_i$ .

Utilizing black element theory the profile power required to hover can be expressed as:

$$P_o = \frac{1}{8} \sigma_r \bar{C}_{do} \rho A(\Omega R)^3 \qquad (2.7)$$

The induced power predicted by momentum theory is:

$$P_i = V_{in} T$$

$$= \frac{T^{3/2}}{\sqrt{2\pi\rho R^2}} \qquad (2.8)$$

The total power required to hover is:

$$P_T = P_i + P_o \qquad (2.9)$$

$$P_T = \frac{T^{3/2}}{\sqrt{2\pi\rho R^2}} + \frac{1}{8}\,\sigma_r\,C_{do}\,\rho\,A(\Omega R)^3 \qquad (2.10)$$

Donald M. Layton in <u>Helicopter Performance</u>, [Ref. 1], found that for the optimum hover power, the induced power is equal to twice the profile power. The analysis was performed in the following manner.

By assuming constant weight, density, solidity, and an average profile drag coefficient, as well as a fixed rotational velocity, equation (2.10) reduces to

$$P = \frac{C_1}{R} + C_2 R^2 \qquad (2.11)$$

where $C_1$ and $C_2$ are constants.

As equation (2.12) shows, profile power increases as the square of the blade radius while the induced power decreases with increasing blade radius.

The optimum hover power with respect to rotor radius can be determined by taking the differential and setting it equal to zero.

$$\frac{dP}{dR} = 0 = -\frac{C_1}{R_2} + 2\,C_2 R \qquad (2.12A)$$

or

$$\frac{C_1}{R} = 2\,C_2 R^2 \qquad (2.12B)$$

which implies

$$P_i = 2\,P_o \qquad (2.12C)$$

## G. HELICOPTER SIZING

A simplified relationship between the total power required, gross weight and rotor radius can be developed in the following manner.

The total power required to hover equation for the main rotor was developed in the preceding section and is repeated here for clarity.

$$P_T = P_i + P_o \tag{2.9}$$

$$P_T = \frac{T^{3/2}}{\sqrt{2\pi\rho}} \cdot \frac{1}{R} + \frac{1}{8} \sigma_r \overline{C}_{do} \rho\pi V_{tip}{}^3 R^2 \tag{2.10}$$

In a hover, thrust equals weight. Solving equation (2.11) for weight one obtains:

$$W^{3/2} = [P_T - \frac{1}{8} \sigma C_{do} \rho\pi V_T{}^3 R^2] \sqrt{\rho A} \tag{2.13}$$

This equation may be further simplified if it is assumed that the density, average profile drag coefficient and tip velocity are constants; these are reasonable assumptions. Historically, the average profile drag coefficient of a helicopter has been approximately 0.01. The operating environment of today's helicopters, especially military, is below 5,000 feet agl. This allows for the use of the standard sea level value for density with little error. Primarily, due to tip mach effects, the upper limit on the rotor tip velocity is in the range of 700 fps.

The resulting equation with these assumptions incorporated into a constant, K , is:

$$W = [47.527\ P_T\ R - K_1\ bc]^{2/3} \qquad (2.13)$$

Equation (2.13) can be further reduced when the order of magnitude of the two terms is considered.

$$47.527\ P_T\ R >> K_1\ bc$$

Thus,

$$W \approx [47.527\ P_T\ R]^{2/3} \qquad (2.14)$$

To determine how accurate this simplification is, the equation is used to approximate the total weight of a number of helicopters for which the parameters are available. As Table 2.1 indicates, the weight approximation formula yields values within six percent of the actual total weight of these helicopters.

## H. FIGURE OF MERIT

A figure of merit, FM , has been defined for the helicopter as the ratio of the ideal rotor induced power to the actual power required to hover, with non-uniform induced velocity, tip losses and profile drag power.

## TABLE 2.1

### HELICOPTER WEIGHT COMPARISON

| HELICOPTER | TOTAL GROSS WEIGHT (1000 lbs) | CALCULATED GROSS WEIGHT (1000 lbs) | PERCENT OF ACTUAL GROSS WEIGHT |
|---|---|---|---|
| AH-64 | 14.66 | 14.69 | 101% |
| UH-1N | 14.20 | 13.74 | 97% |
| H-3H | 21.00 | 20.63 | 98% |
| S76 | 10.00 | 9.90 | 99% |
| UH-60A | 20.25 | 19.33 | 95% |
| H-54B | 42.00 | 42.00 | 100% |
| H-53D | 42.00 | 41.00 | 98% |
| H-53E | 73.50 | 69.00 | 84% |

In a hover, the figure of merit may be written as:

$$FM = \frac{1}{\sqrt{2}} \cdot PL \cdot \frac{DL}{\sqrt{\rho}}$$

$$= \frac{CT^{1.5}}{\sqrt{2C_p}} \qquad (2.15)$$

The figure of merit is customarilty plotted against the quantity $CT/\sigma$ . According to Zalesch [Ref. 2], $CT/\sigma$ , is proportional to the average blade angle of attack and can be used as a measure of rotor efficiency. The curve in Figure 2.1 is based on data from Reference 2 for a typical tail rotor helicopter.

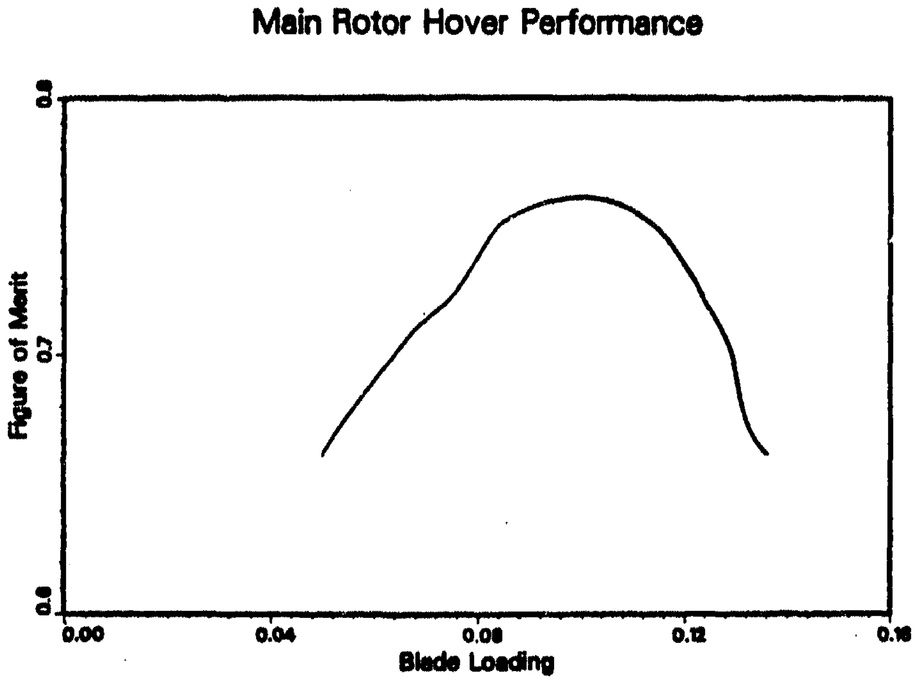

Figure 2.1. FM Versus Blade Loading $CT/\sigma$

Previous studies have shown that a figure of merit between 0.70 and 0.80 is considered average.[Ref. 3] If the induced power is between 70 and 80 percent of the total power, the figure of merit will be approximately 0.75.

With the figure of merit limited to values between 0.70 and 0.80, the following simplification can be made, assuming the hover condition of thrust equaling weight and standard sea level conditions:

$$FM = \frac{W^{3/2}}{67.214\ P_T R} \qquad (2.16)$$

For Navy helicopter design, the rotor radius has been limited by flight deck spotting constraints to less than 30 feet; the exception to this is the H-3, R = 31 feet and the H-53, R = 36 to 38 feet [depending on the model]. However, these two helicopters work almost exclusively from large air dedicated ships such as the LPH, LHA and CV.

If the small deck operating assumption is made, equation (2.16) can be further simplified to [assuming R = 28 feet]:

$$P = \frac{W^{3/2}}{1881.98\ FM} \qquad (2.17)$$

An FM of 0.80 will yield a P to W relationship of:

$$P_T = \frac{W^{3/2}}{1505.58} \qquad (2.18)$$

while an M of 0.70 yields a relationship

$$P = \frac{W^{3/2}}{1317.39} \qquad (2.19)$$

If equation (2.17) is solved utilizing the approximate weight relationship developed earlier of

$$W^{3/2} = 47.527\ P_T R \qquad (2.14)$$

a value for the figure of merit of 0.707 is obtained. This is within the historical range of values.

## I. TAIL ROTOR SIZING

A historical analysis of typical helicopters [Ref. 3), shows the following empirical relationship for the tail rotor radius

$$R_T \simeq 1.3\ \left[\frac{GW}{1000}\right]^{1/2}\ [ft] \qquad (2.20)$$

when comparing the results of this equation with actual tail rotor radius data, it was found that if a multiplication factor of 1.2 is used vice 1.3 a better approximation is obtained. The results are tabulated in Table 2.2.

## J. FORWARD FLIGHT POWER CONSIDERATIONS

The total power in forward flight consists of induced, profile and parasite power. If the helicopter is a single rotor vehicle, the tail rotor power should be taken into

# TABLE 2.2

## TAIL ROTOR SIZING

| HELICOPTER | ACTUAL TAIL ROTOR RADIUS [FT] | APPROXIMATION [FT] [2.20] | [2.21] |
|---|---|---|---|
| AH-64 | 4.6 | 4.98 | 4.59 |
| UH-1N | 4.3 | 4.90 | 4.52 |
| SH-3H | 5.3 | 5.95 | 5.5 |
| S-76 | 4.0 | 4.11 | 3.79 |
| UH-60A | 5.5 | 5.85 | 5.4 |
| CH-53D | 8.0 | 8.42 | 7.78 |
| CH-53E | 10.0 | 11.15 | 10.29 |

account, as well as all mechanical losses [transmission, etc.] for accurate calculations. However, a reasonable approximation can be obtained by considering only the main rotor and increasing this power figure by several percent to account for these losses.

Figure 2.2 is a plot of the induced, profile, parasite and total power curves for typical tail rotor helicopter.

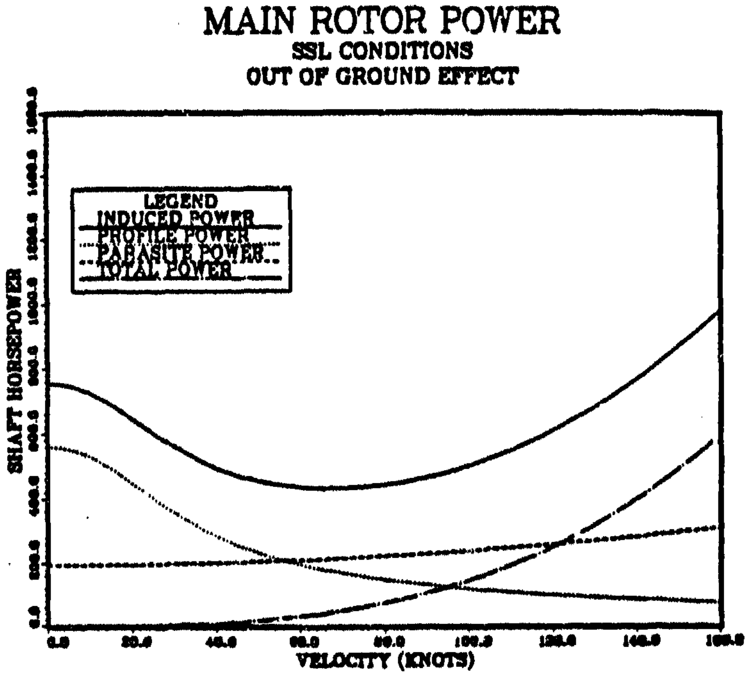

Figure 2.2. Power Required Versus Forward Velocity

The induced power drops off rapidly with increasing forward-velocity, whereas the parasite power increases rapidly.

Parasite power is the power required to overcome the drag forces created by the aircraft's geometry. These drag forces are due to pressure drag and skin friction.

Parasite drag is extremely sensitive to the helicopter's loading. It is generally a minimum for forward flight and increases for sideways flight. Helicopters are generally streamlined for forward flight and the flat plate area is a minimum in this direction. The equation for the parasite power is:

$$P_p = \frac{1}{2} \rho V_f^3 f_f \qquad (2.21)$$

The parasite power is a function of the cube of the forward velocity. As such, with the advent of high speed helicopters a great deal of consideration has been placed on streamlining the geometric shape in order to reduce this power requirement.

Blade element theory is commonly used to develop the profile power equation for forward flight. An excellent development of this equation is given in Reference 1.

The profile power equation in forward flight is:

$$P_{of} = \frac{1}{8} \sigma C_{do} \rho A V_T^3 [1 + 4.3 \mu^2] \qquad (2.22)$$

Equation (2.23) is a function primarily of the main rotor geometry. The variable with the most significance is the rotor tip velocity; increasing the tip velocity from 600 to 700 fps results in a 58.8 percent increase in profile power [assuming other factors are constant].

The induced power is a function of the induced velocity. In a hover, the total flow through the rotor system is induced. As the forward velocity increases, the mass flow rate through the rotor disc increases due to the forward translation of the helicopter. This reduces the induced velocity.

The equation for the induced power requirements at all forward velocities is:

$$P = T \cdot V_{it} \tag{2.23}$$

where

$$V_{it} = \left\{ -\frac{V_f^2/V^2}{2} + \sqrt{\left[V_f^2/2V^2\right]^2 + 1} \right\}^{1/2} .V \tag{2.23a}$$

At high forward velocities, the induced power required can be approximated as:

$$P_i = WV_{it} - \frac{W^2}{2\rho AV_f} \tag{2.24}$$

The total power for forward flight is the sum of the induced, profile and parasite powers.

$$P_T = P_i + P_o + P_p \tag{2.25}$$

$$P_T = T.V_{it} + \frac{1}{8} \sigma C_{do} \rho A V_T{}^3 [1 + 4.3 \mu^2] + \frac{1}{2} \rho f_f V_f{}^3 \qquad (2.25a)$$

At high forward velocities, equation (2.23) can be substituted into equation (2.25), resulting in:

$$P_T = \frac{W^2}{2\rho A V_f} + \frac{1}{8} \sigma C_{do} \rho A V_T{}^3 [1 + 4.3 \frac{V_f}{\Omega R}] + \frac{1}{2} \rho f_f V_f{}^3 \qquad (2.26)$$

If one makes the following assumptions:

$W = \text{const}$ $\quad C_{do} = \text{const}$

$\rho = \text{const}$ $\quad \sigma = \text{const}$

$VT = \text{const}$

Equation (2.26) reduces to

$$P_T = \frac{K_1}{R^2} + K^2 R^2 + P_p \qquad (2.27)$$

The derivative of equation (2.27) with respect to radius is:

$$\frac{dP_T}{dR} = - \frac{2K_1}{R^3} + 2 K_2 R \qquad (2.28)$$

Setting this equal to zero, one obtains:

$$-\frac{2K_1}{R^3} + 2\ K_2\ R = 0 \qquad (2.28a)$$

$$\frac{R}{2} * [-\frac{2K_1}{R^3} + 2\ K_2\ R] = 0 \qquad (2.28b)$$

$$\frac{K_1}{R^2} = K_2\ R^2 \qquad (2.28c)$$

$$P_i = P_o \qquad (2.28d)$$

This defines point of minimum total power required for VMAX range. This corroborates with the results obtained by Waldo Carmona [Ref. 4].

If the total power required is differentiated with respect to forward velocity and is set equal to zero, it can be seen that

$$P_i = 3\ P_o \qquad (2.29)$$

or

$$\frac{W^2}{2\rho AV_f} = \frac{3\rho fV_f^{\ 2}}{2} \qquad (2.30)$$

Solving this equation for velocity results in:

$$V_f = \left[\left(\frac{W}{A}\ \frac{A}{3f_f}\right)^{1/2}\right]^{1/2} \quad \text{ft/sec} \qquad (2.31)$$

According to Carmona [Ref. 4], this corresponds to the best endurance velocity.

## K. DENSITY EFFECTS ON TOTAL POWER

The effect of density on the total power required in forward flight is as follows:

The general operating altitudes of a helicopter are below 10,000 feet. The corresponding ICAO STANDARD ATMOSPHERE range for density is

$$\rho = 0.0023769\ [\text{lb sec}^2/\text{ft}^4] \quad \text{SSL}$$

$$\rho = 0.0017553\ [\text{lb sec}^2/\text{ft}^4] \quad \text{at 10,000 feet}$$

$\rho/\rho SSL$ varies from 1 to .7385.

The effect on the components of $P_T$ are as follows:

Induced Power:

$$1/\rho/\rho SSL \Rightarrow 1 \text{ to } \frac{1}{.7385}$$

This translates to a 35 percent increase in the induced power.

Parasite and Profile Power:

Both parasite and profile powers are directly proportional to the density ratio. Therefore, as you go up in altitude both $P_o$ and $P_p$ are reduced.

# III. CARPET PLOT DESIGN STUDY

## A. DESCRIPTION OF PROBLEM

Preliminary helicopter design involves one with a wide range of choices. For any given payload and performance specifications, there a number of helicopter designs that satisfy the requirements. The problem in the preliminary design process is narrowing these possibilities and selecting the design which will provide the best helicopter for the mission.

Obviously, the operating environmental constraints help to define the basic configuration. These constraints are usually specified in the Request for Proposal [RFP], in the case of a military helicopter. For example, typical constraints placed on the design of a Navy helicopter are the size of the ship deck and hangar from which it will be operating, the requirement for a blade fold system, dual engine configuration and IFR capability.

Even with these design constraints, there is still a great deal of leeway. In order to insure that the best helicopter design is selected, an appropriate number of solutions satisfying the specifications should be investigated. Since each solution is generally characterized by a different combination of design parameters, the selection, according to Greenfield [Ref. 5], can best be made through a parametric study which allows for the optimization of many design parameters.

One method of parametric analysis used is Carpet Plots. This method is based on the simultaneous graphical solution of the weight and hover performance equations. To this solution set is added to the environmental constraints to the helicopters size. This effectively brackets the area of acceptable design solutions.

This method assumes that minimum gross weight is the criterion by which the best [or optimum] design parameters are selected.

## B. ASSUMPTIONS

1. Airfoil used is a derivative of the NACA 0012 with the following mean approximate values from Reference 5.

$a$ = slope of airfoil section lift curve, $dC_t/d\alpha$, per rad.

$a = 5.73$

$\delta$ = blade section drag coefficient

$\delta_0 = .009$

$\delta_2 = .3$

2. a) The tail rotor radius is assumed to be .16 times the main rotor radius [Ref. 5].

b) The distance between the rotors, or tail rotor moment arm, $\ell_{TR}$ is 1.19R [Ref. 5]. These ratios reflect the values of maximum rotor diameter and overall length specified as size limitations.

3. B = .97. Historical approximation [Ref. 7].

## C. METHODOLOGY

In order to properly develop the weight and performance equations required for a carpet plot design study, the payload and performance specifications of the helicopter are needed. This data is used to tailor the equations for the design.

The equations will be developed here for a four-place light helicopter. The equation development procedure is applicable to other size helicopters; the development for a medium helicopter, 20,000 lb weight class, is to be found in Appendix B.

The following specification requirements which are similar to those in Reference 5 will apply to this design:

1. The rotor diameter should be less than 35.2 feet.
2. The overall length should be less than 41.4 feet.
3. The gross weight of the helicopter should not exceed 2,450 lbs.
4. The helicopter should be capable of hovering, out of ground effect at 6,000 feet with an ambient air temperature of $95^{o}$F.

5. The useful load at hover shall consist of, as a minimum, 200 lbs for the pilot, 400 lbs of payload and sufficient fuel to give the helicopter up to three hours endurance at sea level conditions.

6. Maximum speed of at least 110 knots using Normal Rated Power, at sea level.

7. Total Power Required at 6,000 feet and 95°F shall be not more than 206.

## D. HOVER EQUATIONS

1. The main rotor power required to hover out of ground effect is

Total Main Rotor Power [Hover] = Rotor Profile Power + Rotor Induced Power

$$\begin{aligned} P_T &= \frac{1.13W}{550B\sqrt{2\rho_o}} \sqrt{\frac{DL}{\rho/\rho_o}} \\ &+ \frac{6WV_T}{4400} \frac{\rho/\rho_o}{C_{LRo}} \left[ \delta_0 + \delta_2 \left[ \frac{C_{LRo}}{\alpha\rho/\rho_o} \right]^2 \right] \end{aligned} \tag{3.1}$$

At an altitude of 6,000 feet and a temperature of 95° , $\rho/\rho_o = .749395$ . Therefore, equation (1) can be simplified to:

$$\begin{aligned} P_{T6000/95^oF} &= .035479W[DL]^{1/2} \\ &+ \frac{.91971}{C_{LRo}} [10]^{-5}(1 + 1.80779\ C_{LRo}{}^2)W\ V_T \end{aligned} \tag{3.2}$$

The tail rotor thrust required to counterbalance the main rotor torque is:

$$T_{TR} = \frac{550\ P_T R}{\ell_{TR}\ V_T} = \frac{550\ P_T}{1.19 V_T} \qquad (3.3)$$

where $\ell_{TR}$ has been defined as 1.19R . With $R_{TR}$ defined as .16R , the tail rotor disk loading can be written, using equation (3) as:

$$DL_{TR} = \frac{T_{TR}}{A_{TR}} = \frac{550\ P_T}{1.19 V_T} \frac{1}{\pi(.16R)^2}$$

$$= \frac{550\ P_T}{1.19(.0256)V_T} \frac{DL}{W} \qquad (3.4)$$

Greenfield [Ref. 5], in his development, assumes that the tail rotor tip speed is equal to the main rotor tip speed and that $\delta_{TR} = .02$ and $\beta_{TR} = .90$ . With these assumptions the equation for the tail rotor power required to hover can be written as:

$$P_{T_{TR_{Hover}}} = 2055.7 \left[\frac{DL}{W\ \rho/\rho_o}\right]^{1/2} \left[\frac{P_{T_{Hover}}}{V_T}\right]^{3/2}$$

$$+ \frac{.012605\ P_{T_{Hover}}}{C_{LRTR}} \qquad (3.5)$$

The equation for the tail rotor mean blade lift coefficient can be written as

$$C_{LRTR} = \frac{P_T}{562.5(\rho/\rho_o)} \qquad (3.6)$$

if it is assumed that the tail rotor is designed to counterbalance a sea level main rotor torque equivalent to 90 percent of the installed power.

Substituting equation (3.6) into equation (3.5) one obtains the following expression for hover tail rotor power:

$$P_{T_{TR6000/950}} = 2374.7 \left[ \frac{DL}{W} \right]^{1/2} \left[ \frac{P_{T_H}}{V_T} \right]^{3/2} + 5.3134 \qquad (3.7)$$

It is assumed that the gear losses amount to 3 percent and that there is a 1 percent cooling power loss, the total brake horsepower required to hover becomes:

$$P_T = \frac{P_{Tm} + P_{TTR}}{96} \qquad (3.8)$$

Empirical studies have shown that the tail rotor power required to hover can be approximated by

$$P_{T_{AC}} \sim .8 \text{ [total horsepower to hover]}$$

This allows one to write the main rotor power required to hover as:

$$P_{Tm} = (.88)(P_{Tm}) \qquad (3.9)$$

Following Greenfield's [Ref. 5] development further, if equations (3.2) and (3.7) are substituted in equation (3.8), one obtains

$$P_{T_{H6000/95^\circ}} = .036757\ W\ \sqrt{DL} + \frac{.95803}{C_{LRo}} (10)^{-5} [1 + 1.80779\ C_{LRo}^{2}]\ W\ V_T + 2473.6 \sqrt{\frac{DL}{W}} \left[\frac{P_{Tm}}{V_T}\right]^{3/2} + 5.5348 \qquad (3.10)$$

Utilizing the approximation for tail rotor power, equation (3.9), equation (3.10) can be solved for W (gross weight) as a function of variables $V_T$ (tip speed), DL (rotor disk loading), $C_{LRo}$ (rotor mean lift coefficient) and $P_{T_H}$ (total power to hover).

$$W = \frac{K_1 \left[1 - 411.51 \frac{DL^{3/4}}{V_T^{3/2}} \left(1 + K_2 \frac{V_T}{\sqrt{DL}}\right)^{1/2}\right] - K_3}{V_T + K_4 \sqrt{DL}} \qquad (3.11)$$

where:

$$K_1 = P_{T6000/90^\circ} \frac{(10)^5}{K_5} \qquad (3.11a)$$

$$K_2 = \frac{.00025929}{C_{LRo}} (1 + 1.80779\ C_{LRo}^{2}) \qquad (3.11b)$$

$$K_3 = \frac{553480}{K_5} \qquad (3.11c)$$

$$K_4 = \frac{3695.7}{K_5} \qquad (3.11d)$$

$$K_5 = \frac{.95803}{C_{LRo}} (1 + 1.80779\ C_{LRo}{}^2) \qquad (3.11e)$$

Equation (3.11) has been programmed in Appendix B and solved for tip speeds from 600 to 700 cps and $C_{LR}$ of .3 to .7.

Equation (3.11) is one of the two primary equations used to obtain the data required for a carpet plot design analysis. Generally, the variables $V_T$ , DL, $C_{LRo}$ and $P_T$ , that are required for solution have specific ranges of values, depending on the weight class of the helicopter being designed. The graphical results of equation (3.11) for tip speeds of 600 to 700 fps and mean lift coefficients between .3 and .7 are illustrated in Figure 3.1.

Both the Fortran and Disspla programs, as well as a decision making flow chart are provided in Appendix C to aid in using this method for a design solution.

## E. WEIGHT EQUATIONS

Weight equations need to be developed that realistically reflect the sizing class of the helicopter being designed. The evolution is greatly simplified if a specific engine

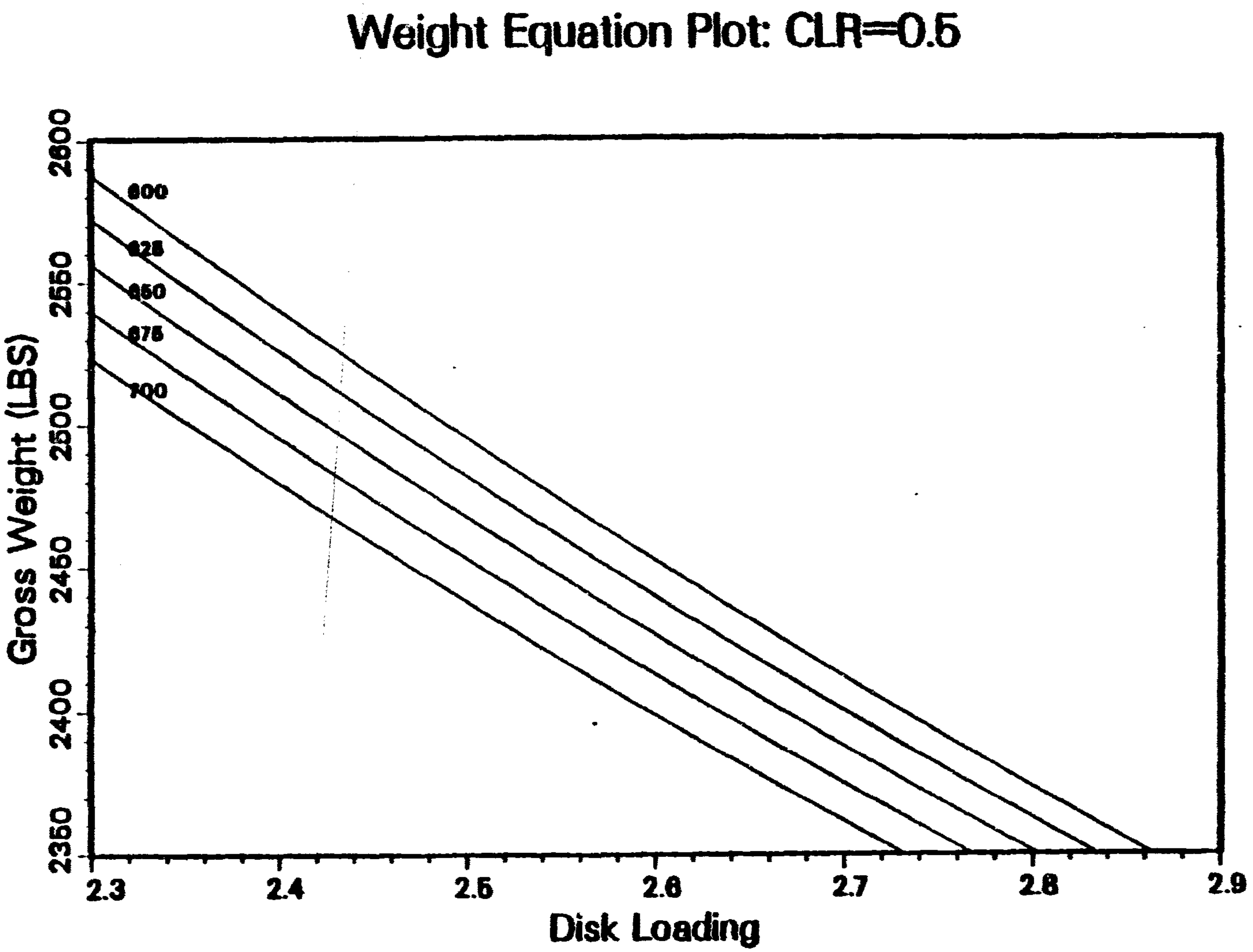

Figure 3.1. Weight Equation Plot: $C_{LR} = 0.5$

installation [# and horsepower] is assumed, since the weight of a number of components depend only on the installed power; this would include such terms as the engine controls and accessories. Another category would be those components whose weights depend on either the gross weight on two or more of the following in combination: rotor tip speed ($V_T$), rotor diameter (R), rotor solidity ($\sigma$).

The equations developed here are taken from the Hiller Aircraft Corporation Performance Data Report. [Ref. 5] In this report they assumed a specific engine installation, the Allison T-63 with a military power rating at sea level of 250 horsepower.

There is a possible problem of the validity of these weight relationships when applied to different helicopter design categories. However, assuming a specific engine determines a number of the component weights, and thus minimizes the inaccuracies. Using the weight estimation relationships developed in the Helicopter Design Manual [Ref. 2], the engine, control and accessory weight can be calculated and the weight formulas developed here applied to give a representative useful load and empty weight formula for preliminary design analysis. This is done in Appendix C, for a 20,000 pound class helicopter.

The following relations are used to reduce the component weight formulas for the specification helicopter:

$$W/DL = A = \pi R^2 \tag{3.12}$$

$$W/PL = MHP = 250 \tag{3.13}$$

(Military rating for Allison T-63 at sea level.) (PL = Power Loading.)

$$P = \sqrt{A}/V_T \tag{3.14}$$

Using these equations the component weight for the specified helicopter empty weight may be reduced to the following:

Engine, Controls and Accessories = 617.5 lbs.

Engine Section Group $$.053[W/PL]^{1.07} = 19.5 \text{ lbs.} \tag{3.15}$$

Main Transmission $$10.43 \frac{W^{1.295}}{(PL\ V_T)^{.863}} = 1221\ p^{.803} \tag{3.16}$$

Rotor Drive Shaft $$5.56 \frac{W^{1.05}}{(PL\ V_T)^{.7}(DL)^{.35}} = 266\ p^{.7} \tag{3.17}$$

Tail Rotor $$32.22 \frac{W^{1.14}}{(PL\ V_T)^{1.7}} = \frac{17449}{V_T^{1.14}} \tag{3.18}$$

The engine, controls and accessories category includes such items as lubrication and oil cooling system, engines, communications, engine controls, engine accessories, instruments starting system, furnishing, flight controls, electrical system and stabilization. These are considered fixed weight items determined from specification of the engine and weight class of the helicopter.

Tail Rotor
Gear Box

$$3.7\ \frac{W^{.75}}{(PL\ V_T^{.5}(DL)^{.25}} = 59.47\sqrt{P} \tag{3.19}$$

Tail Rotor
Drive
Shaft

$$.124\ \frac{W^{1.355}}{(PL\ V_T)^{.57}(DL)^{.785}} = 2.886\ P^{.57}\sqrt{A} \tag{3.20}$$

Body and.
Gear
Landing

$$= 1.91\ W^{.916} + .0294\ W^{.99}$$

Rotor
Blade
Teetering

$$35.15\ \frac{W^{1.185}\sigma^{.33}}{V_T(DL)^{.185}} = 35.15\ \frac{W}{V_T}\ A^{.185}\sigma^{.33} \tag{3.21}$$

Rotor Blade
Artic-
ulated

$$19.77\ \frac{W^{1.205}\sigma^{.33}}{V_T(DL)^{.205}} = 19.77\ \frac{W}{V_T}\ A^{.205}\sigma^{.33} \tag{3.22}$$

Rotor Hub
Teetering

$$.0088\ \frac{W^{1.21}}{DL^{.21}} = .0088\ WA^{.21} \tag{3.23}$$

Rotor Hub
Artic-
ulated

$$.00975\ \frac{W^{1.21}}{DL^{.21}} = 00975\ WA^{.21} \tag{3.24}$$

Fuel System $\quad$ .416 per gallon capacity $= .0615\ W_F$ $\quad$ (3.25)

where $W_F$ = fuel weight.

The individual component weights may now be combined into a single expression for the helicopter empty weight.

$$W_e = 617.5 + .0617W_F = 1221P^{.863} + 266P^{.7} + \frac{17449}{V_T^{1.14}} \tag{3.26}$$

$$+\ 58.47\sqrt{P} + 2.886P^{.57}\sqrt{A} + .191W^{.916} + .0294W^{.99}$$

+ appropriate rotor blade and hub weights.

As stated earlier, the design specifications called for a useful load consisting of a pilot (200 lbs), payload (400 lbs) and the required fuel weight ($W_F$). The fuel weight is calculated for the Allison T-63 in the following manner: endurance of three hours at 85 percent of normal rated powered for the T-63 is 180.2 HP and the specific fuel consumption at this power is .783 lbs fuel/BHP HR. Including an allowance for a three-minute warm-up at NRP and using a 5 percent correction factor on SFC, as specified in Reference 5, the fuel weight becomes:

$$W_F = 3(180.2)(.822) + \frac{3}{60}(212)(777) \tag{3.27}$$

An allowance should also be made for oil plus trapped fuel. This is estimated at 20 lbs.

The total useful load is the sum of the useful load items.

$$W_u = 200 + 400 + 452.6 + 20 = 1072.6 \text{ lbs} \qquad (3.28)$$

A new variable, $W_{BAR}$ , is defined as the sum of the emply weight plus useful load. It is the of equations (3.26) and (3.28).

$$W_{BAR} = 1717.9 + 1221P^{.863} = 266P^{.7} + \frac{17449}{V_T^{1.14}} + 58.47\sqrt{P}$$
$$+ 2.886P^{.57}\sqrt{A} + .191W^{.916} + .0294W^{.99} \qquad (3.29)$$
$$+ \text{ appropriate rotor blade and hub weights.}$$

Equation (3.11) together with equation (3.29) form the basis of a carpet plot design study. These equations are solved simultaneously for $W_{BAR}$ . This solution is best illustrated graphically, as in Figure 3.2. The graph in Figure 3.2 was generated for a specific value of $C_{LR}$ over a range of tip speeds [600 to 700].

## F. GRAPHICAL ANALYSIS

Graphs similar to Figure 3.1 are generated for several value of $C_{LR}$ , and are then cross plotted to form Figure 3.2.

The mean lift coefficient, $C_{LR}$ , values are selected based on what is considered the historical average range of

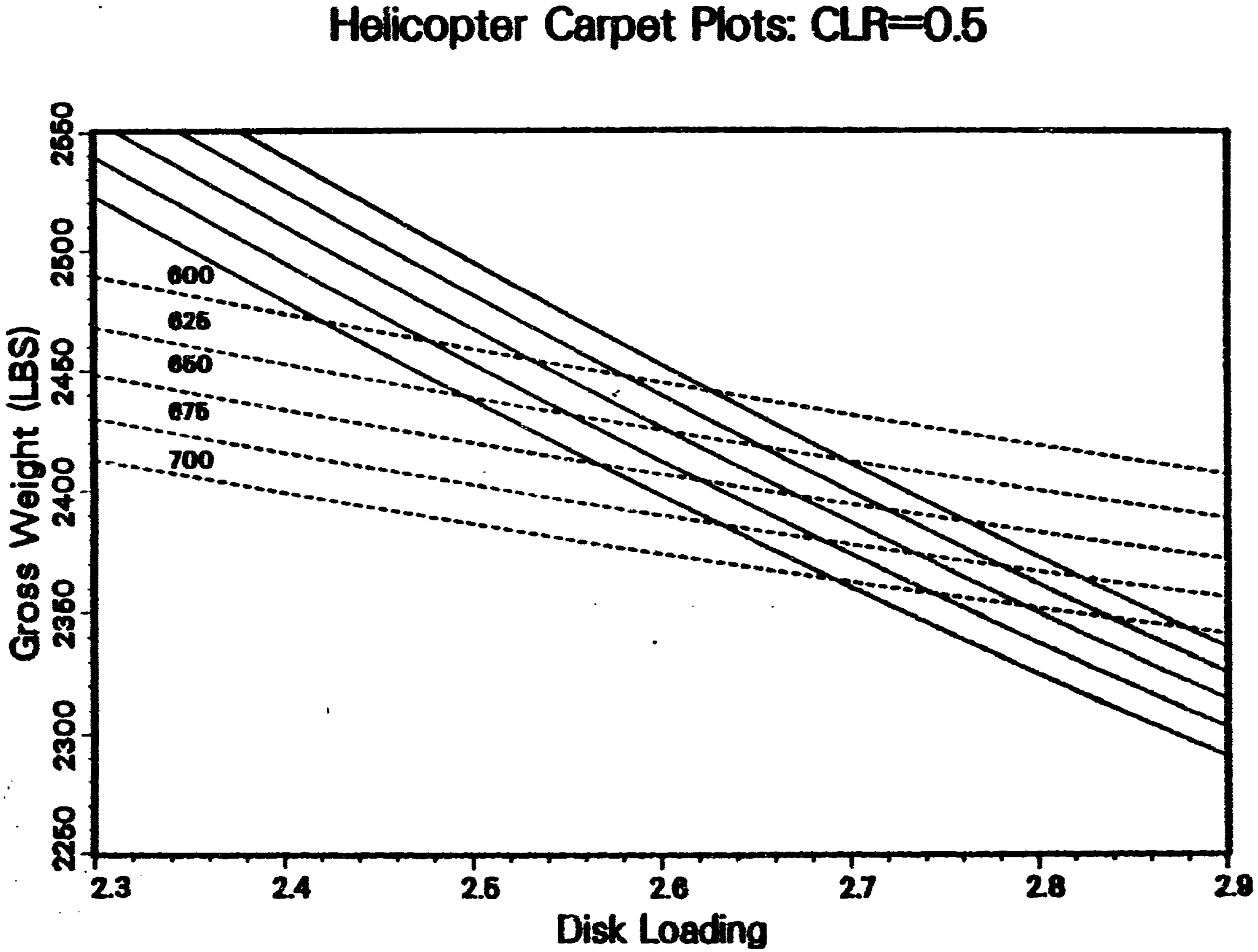

Figure 3.2. Helicopter Carpet Plots: $C_{LR} = 0.5$

values. Figure 3.3 is basic plot for a carpet plot design study. Programs are provided in Appendix D which will generate the required data sets and plots of Figures 3.2 and 3.3.

The solution field depicted in Figure 3.3 is too large to be of great analytic value and as such must be reduced. Three parameters, maximum gross weight, rotor diameter (both specified in the Design Specification) and the aspect ratio can be used to narrow the field of solutions.

### 1. Rotor Diameter Boundary

A net to exceed value for the rotor diameter is generally given in the design specifications. This limiting value is based on the operating environment of the helicopter. With R max specified, there is a linear relationship between the disk loading and the gross weight.

$$DL = \frac{W}{A} = \frac{W}{\pi R^2}$$

The resulting bracketing of the solution field by applying both the maximum gross weight and maximum rotor diameter limits to the carpet plot are shown in Figure 3.4.

### 2. Respect Ratio Boundary

It is evident that a further restriction is still necessary to completely define the region of acceptable

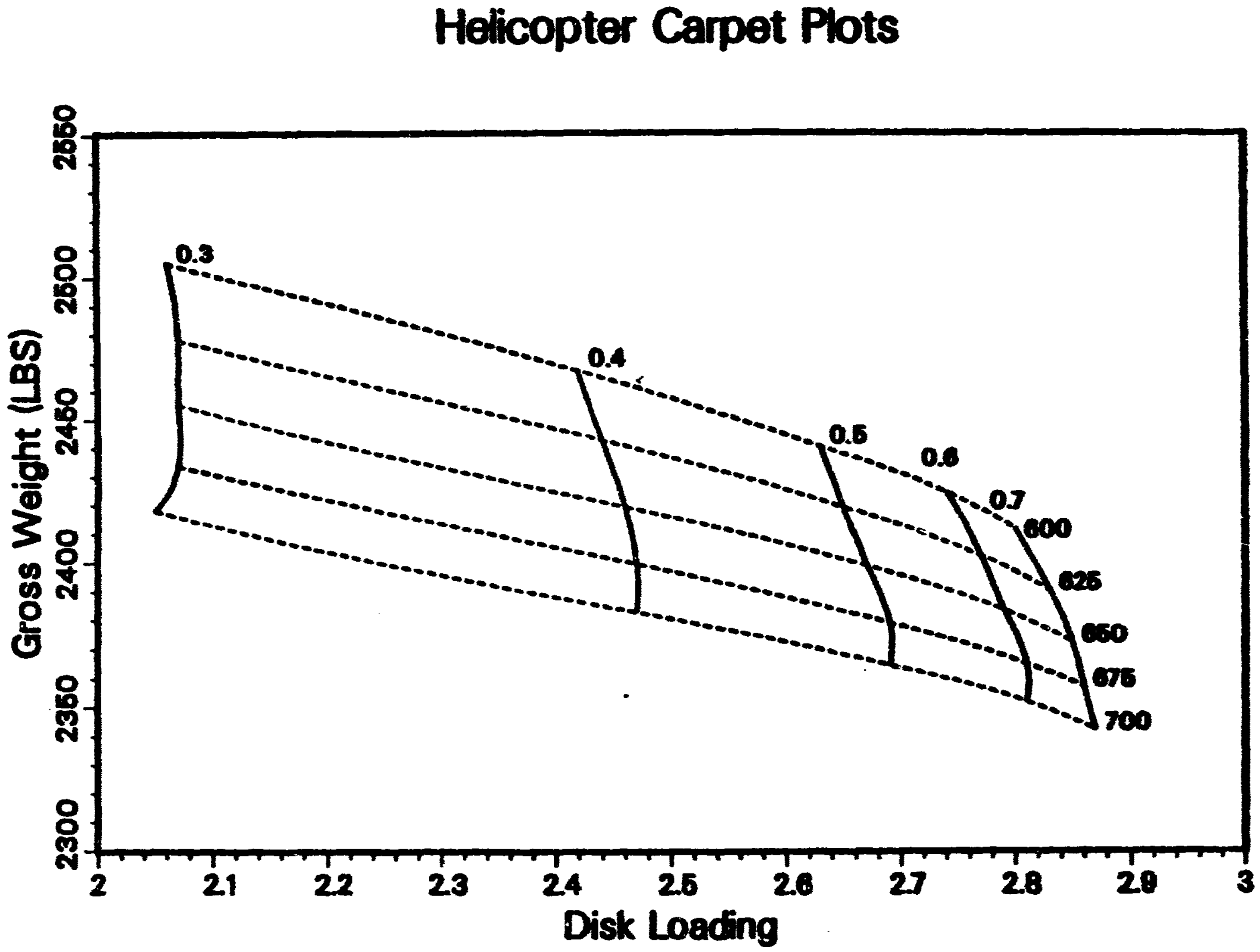

Figure 3.3. Helicopter Carpet Plots
Family of Solutions

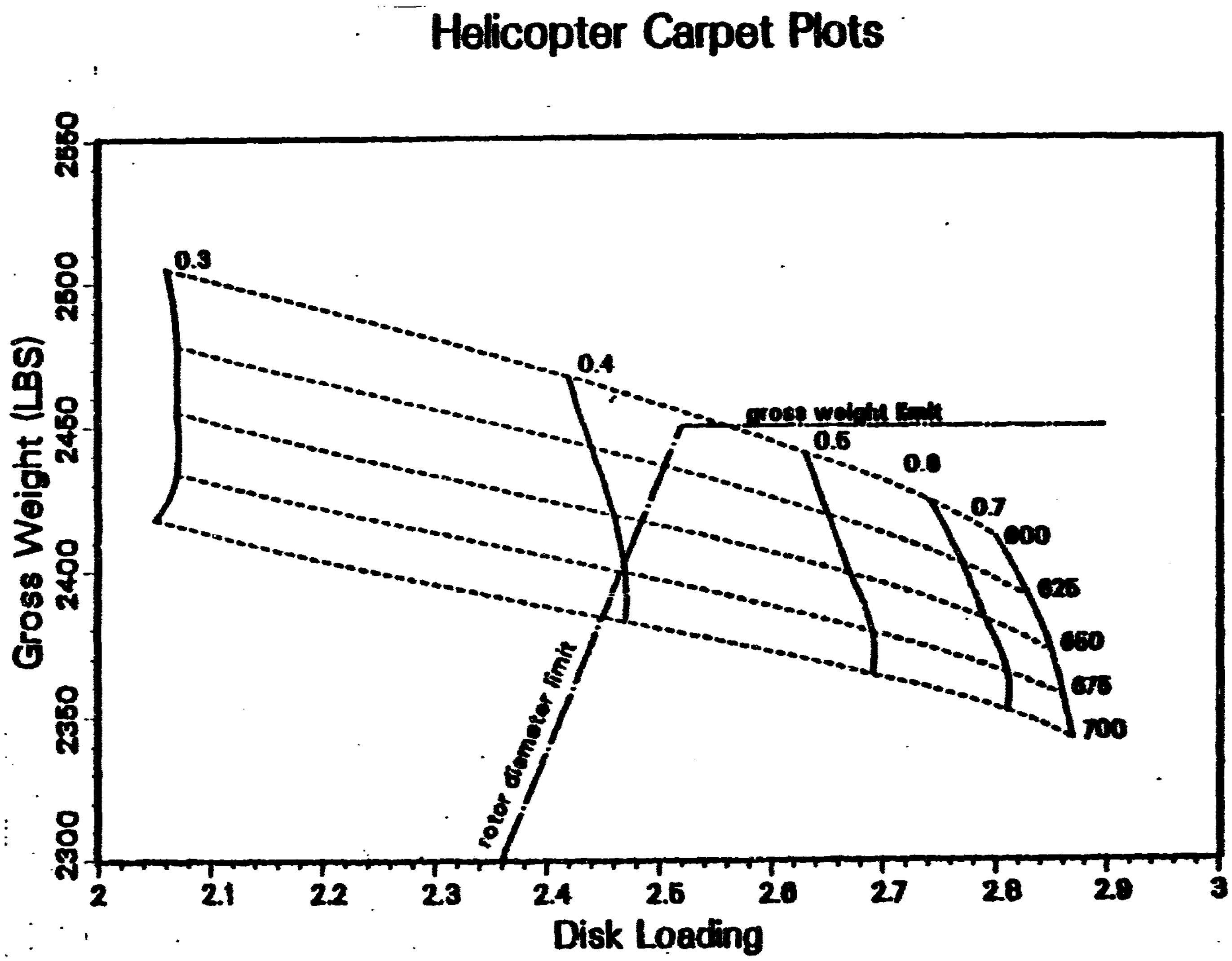

Figure 3.4. Helicopter Carpet Plots Rotor Diameter and Weight Limits

design solutions. Studies have indicated that a main rotor aspect ratio of 21,[1] is a representative upper limit. Thus

$$21 \geq \frac{R\langle mr\rangle}{C\langle mr\rangle} = \frac{b}{\pi\sigma} = \frac{b\ \rho_o\ C_{LR}\ V_T^{\ 2}}{\sigma\pi\ DL}$$

or

$$DL \geq \frac{b\ \rho\ C_{LR}\ V_T^{\ 2}}{126\pi}$$

For the case of a two bladed main rotor equation (3.30) reduces to:

$$DL \geq .000012\ C_{LR}\ V_T^{\ 2}$$

The detemination of this boundary graphically is as follows:

The hover solution plot of Figure 3.2 is replotted[2] relative to the coordinates disk loading and design mean blade lift coefficient. The limiting curves for $DL = .000012\ C_{LR}\ V_T^{\ 2}$ are then plotted. The intersection with the appropriate constant tip speed lines of the hover solution represent the aspect ratio boundary; Figure 3.5.

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[1] For a helicopter rotor, the aspect ratio is defined as the radius divided by the chord.

[2] For clarity lines of constant gross weight are omitted.

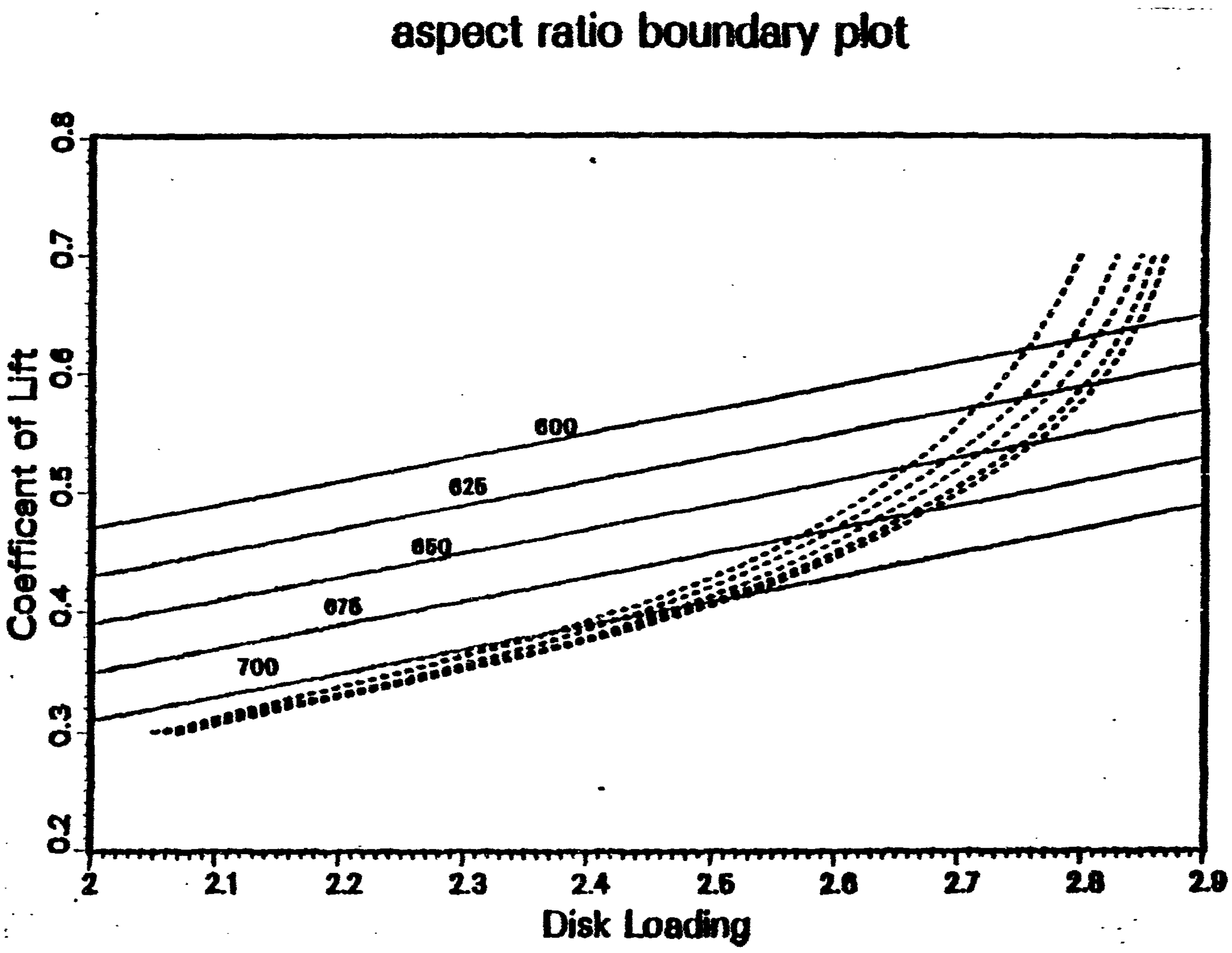


Figure 3.5. Aspect Ratio Boundary Plot

These intersection points are then cross plotted onto Figure 3.4. Figure 3.6 represents a graphical plot of the solution set satisfying the performance and structural design criteria of a small observation helicopter as specified in this study.

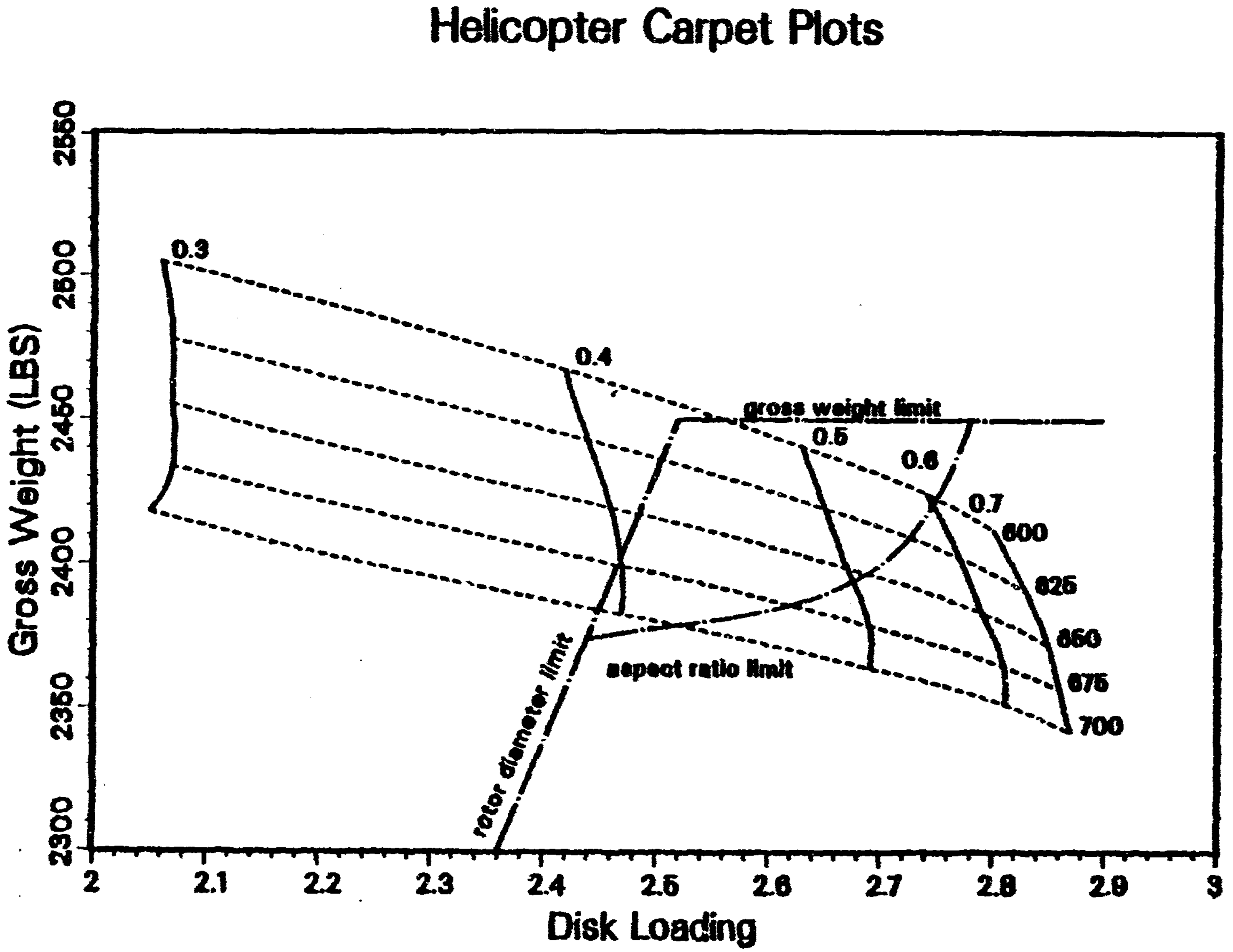


Figure 3.6. Helicopter Carpet Plots
Final Solution

# IV. HESCOMP

## A. DESCRIPTION OF PROGRAM

HESCOMP is a helicopter sizing and performance computer program developed by the Boeing Vertol Company. The program was originally formulated to provide for rapid configuration design studies.

A number of programming options are available to the user of HESCOMP. When the type and mission profile of the helicopter are known, HESCOMP may be used to size the aircraft. Alternately, it may be used for mission profile calculations when the sizing details [gross weight, payload, engine size, etc.] are specified. A combination of these two options is also available; the program may be used to first size a helicopter for a primary mission and then calculate the off-design performance for other missions. Finally, HESCOMP may be used solely for obtaining helicopter weight.

Sensitivity studies involving both design and performance tradeoffs can easily be done with HESCOMP. Incremental multiplicative and additive factors can be imbedded in the input data.

The various helicopter configurations that may be studied using HESCOMP are detailed in Table 4.1.

# TABLE 4.1

## HELICOPTER CONFIGURATIONS WHICH MAY BE STUDIED USING HESCOMP

HELICOPTER CONFIGURATIONS WHICH MAY BE STUDIED USING HESCOMP.

| Helicopter Type (Both Single & Tandem Rotor) / Additional Lift/Propulsion System Components Which Must be Added to "Pure" Conf. | Wing | Propeller for Auxiliary Propulsion | Auxiliary Independent Engines | Type of Auxiliary Independent Engines | | |
|---|---|---|---|---|---|---|
| | | | | T/Shaft | T/Fan | T/Jet |
| Pure Helicopter | | | | | | |
| Winged Helicopter | X | | | | | |
| Compound Helicopter | | | | | | |
| (1) Coupled (prim. engines drive auxiliary propulsion system) | X | X | | | | |
| (2) Auxiliary independent propulsion system | | | | | | |
| (a) T/Shaft engine | X | X | X | X | | |
| (b) T/Fan engine | X | | X | | X | |
| (c) T/Jet engine | X | | X | | | X |
| Auxiliary Propulsion Helicopter | | | | | | |
| (1) Coupled (prim. engines drive auxiliary propulsion system) | | X | | | | |
| (2) Auxiliary independent propulsion system | | | | | | |
| (a) T/Shaft engine | | X | X | X | | |
| (b) T/Fan engine | | | X | | X | |
| (c) T/Jet engine | | | X | | | X |
| oaxial Rotor Helicopter | | | | | | |
| (1) Coupled (prim. engines drive auxiliary propulsion system) | | X | | | | |
| (2) Auxiliary independent propulsion system | | | | | | |
| (a) T/Shaft engine | | X | X | X | | |
| (b) T/Fan engine | | | X | | X | |
| (c) T/Jet engine | | | X | | | X |

## B. PROGRAM MODIFICATIONS AND IMPLEMENTATION

The computer program received from Boeing Vertol required some modification and reformating in order to run properly on the Naval Postgraduate School IBM system. These alterations did not, however, alter the program output or usability.

HESCOMP, as received from Boeing Vertol, was 17821 lines long and set-up as a sequential data set to be assemble on a 'G compiler'. The Batch processing system at the Naval Postgraduate School accepts only programs set to run on 'H compiler'. Normally, the differences between these two compilers are minor and programs that run on one will run on the other. However, this was not the case with HESCOMP.

In order to facilitate the program debugging process, HESCOMP was reformatted as a partitioned data set. What this effectively did was to break the program down into eight members of approximately 2000 lines. The program breakdown is illustrated in Table 4.2.

Each of these were compiled individually and then error codes analyzed. The member data set was then modified as required to properly compile.

Once all the members of the partitioned data set compiled properly, HESCOMP was again formated as a sequential data set and run utilizing input data for which there was a known output. This insured that the modifications made to the original program had not altered the logic, ie., gave faulty results.

The control language program to access HESCOMB on the Batch processing system and a sample input and out data set are shown in Appendix D. These are also available on the Aero disk for copying and use.

TABLE 4.2

PARTITIONED DATA SET

| MEMBER NAME | LINE NUMBER | SIZE | FIRST ROUTINE |
|---|---|---|---|
| S1 | 1 - 1681 | 1681 | AERO |
| S2 | 1682 - 4132 | 2451 | CLIMB |
| S3 | 4133 - 6531 | 2399 | XIBIV |
| S4 | 6532 - 8974 | 2443 | POWAVL |
| S5 | 8975 - 10870 | 1896 | PRINT 1 |
| S6 | 10871 - 13042 | 2172 | ROT POW |
| S7 | 13043 - 15383 | 2341 | CRUS 3 |
| S8 | 15384 - 17821 | 2448 | TAXI |

## C. PROGRAM FLOW

The program is conceptually outlined in Figure 4.1, [Ref. 7]. The program flow is monitored by a general loop, which controls a series of peripheral programs. There are

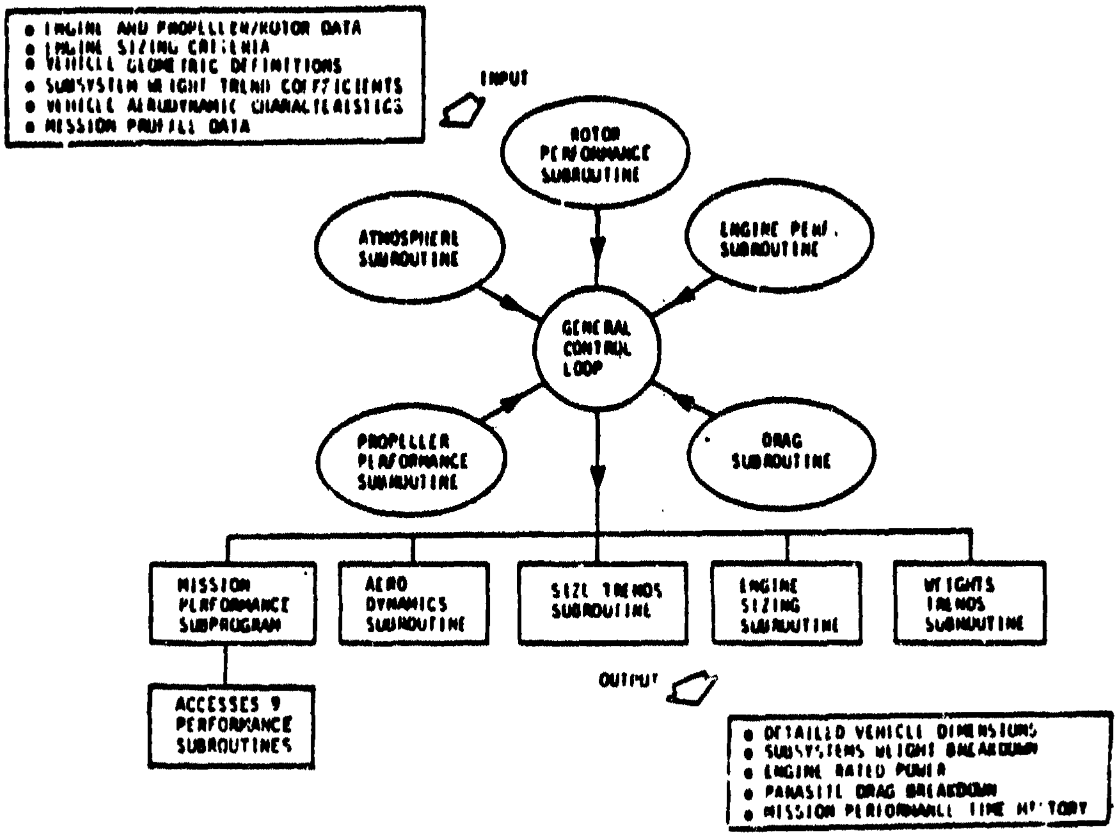


Figure 4.1. HESCOMP Program Flow

a total of 44 subroutines. Detailed program descriptions cam be found in Section 4 of the HESCOMP User's Manual.

## D. PROGRAM INPUT

Program input can be loosely group into ten categories: general information, aircraft descriptive information, mission profile information, rotor tip speed schedule, incremental rotor performance, auxiliary propulsion input schedule, engine cycle information, rotor performance information, propeller performance information, and supplementary input information.

The actual amount of input data requires varies greatly with the program options selected. An example of a data set formatted to run on the IBM system is shown in Appendix E. A more detailed explantion is available in Section 5 of the HESCOMP User's Manual.

## E. PROGRAM OUTPUT

An example of the program output is included in Appendix E. The printout consists of general data, input data, sizing data [program output] and mission performance data [for the size helicopter]. Detailed descriptions of these and diagnostic error statements are described in Section 6 of Reference 6.

# V. CONCLUSIONS AND RECOMMENDATIONS

Three approaches to analyzing a preliminary helicopter design were explored in the course of this paper. It was found that a number of the performance equations could be greatly simplified with little degradation in the final results. A sensitivity analysis brought further insight into the inter-play of the parameters and how changes in them tended to effect the helicopter performance equations.

Carpet Plots provided the most interesting method of analysis. Development of a graphical solution matrix using this method provides a usual interpretation of what is occurring when key parameters are varied.

Two cases were explored; a light observation helicopter in the 3,000 pound weight class and a heavier utility helicopter in the 20,000 pound weight class. The Carpet Plot method provided reasonable solutions in both cases. In doing the analysis for the utility helicopter, the initial weight estimation equation had to be adjusted upward by approximately 2,000 pounds for the equations to intersect properly. This is not considered a limitation to this method of analysis, however, it does point up an area for further investigation. It may be possible to develop more accurate weighing factors for this equation when dealing with higher gross weight helicopters.

HESCOMP provides a plethora of information to the user. However, the price is the amount of inputed data required for even a simplified analysis. At a preliminary design level of analysis, the other methods explored provide a quicker first-cut look at the potential design.

# APPENDIX A: NOMENCLATURE

| TERM | DEFINITION | UNITS |
|---|---|---|
| a | Slope of Airfoil Section Lift Curve | Radians |
| A | Rotor Disk Area | $ft^2$ |
| AR | Aspect Ratio | Dimensionless |
| $A_{TR}$ | Tail Rotor Disk Area | $ft^2$ |
| b | Number of Rotor Baldes | Dimensionless |
| B | Tip Loss Factor | Dimensionless |
| C | Main Rotor Cord | ft |
| $C_{do}$ | Profile Drag Coefficient at Zero Lift | Dimensionless |
| $C_{LRo}$ | Design Mean Blade Lift Coefficient at Sea Level | Dimensionless |
| $C_T$ | Coefficient of Thrust | Dimensionless |
| $C_p$ | Coefficient of Power | Dimensionless |
| $\delta$ | Blade Section Drag Coefficient | Dimensionless |
| DL | Disk Loading | $lb/ft^2$ |
| FM | Figure of Merit | Dimensionless |
| HP | Horsepower | |
| $L_{TR}$ | Tail Rotor Moment Arm | ft |
| $\rho$ | Air Density | $lb\ sec^2/ft^4$ |
| $\mu$ | Advance Ratio | Dimensionless |
| R | Rotor Radius | ft |

| TERM | DEFINITION | UNITS |
|---|---|---|
| $P_T$ | Total Power | HP |
| $P_{TM}$ | Main Rotor Total Power | HP |
| $P_{TTR}$ | Tail Rotor Total Power | Hp |
| $P_o$ | Profile Power | HP |
| $P_i$ | Induced Power | HP |
| $P_p$ | Parasite Power | HP |
| PL | Power Loading | LB/HP |
| R | Rotor Radius | ft |
| T | Thrust | HP |
| $V_I$ | Induced Velocity | ft/sec |
| $V_F$ | Forward Velocity | ft/sec |
| V | Aircraft Forward Speed | ft/sec |
| $V_T$ | Rotor Tip Speed | ft/sec |
| W | Aircraft Gross Weight | lbs |
| $W_c$ | Empty Weight | lbs |
| $W_F$ | Fuel Weight | lbs |
| $W_u$ | Useful Load | lbs |
| $W_{BAR}$ | Empty Weight Plust Useful Load | lbs |
| $\sigma$ | Solidity | Dimensionless |

# APPENDIX B: CARPET PLOT FORMULATION FOR 20,000 LB. CLASS HELICOPTER

## B1 SPECIFICATIONS:

Maximum Gross Weight: 20,000 pounds
Maximum Rotor Diameter: 30 feet

## B2 PRELIMINARY ENGINE SIZING:

B2.1 Utilize equation (2.14) to determine engine horsepower category.

$$W = [4.753P_T R]^{2/3}$$

$$20{,}000 = [47.53P_T\ 30]^{2/3}$$

$$P_T = 1983 \text{ HP}$$

B2.2 Use the engine selection parameters tables B.1 to determine the number and type of power plant [table taken from Reference 3].

B2.2a Type and number selected: 2 type C.

B2.2b Specifications:

Dry Weight Per Engine: 423 pounds

Shaft Horsepower at Standard Sea Level:

| | |
|---|---|
| Military | 1561 HP |
| Normal | 1318 HP |

## B3 WEIGHT EQUATION FORMULATION

B3.1 To obtain the engine control and accessory weight use items 7, 9, 10, 11, 12 and 13 of the weight estimation relationships developed in Reference 3 for a utility helicopter: #7: 609 lbs; #9: 129 lbs; #10: 76 lbs; #11: 410 lbs; #12: 439 lbs; and #13: 302 lbs.

# TABLE B.1

## ENGINE SELECTION PARAMETERS

The following turboshat power plant data are presented for one engine.

| Engines: | | A | B | C | D* | E | F |
|---|---|---|---|---|---|---|---|
| Dry Weight (lbs) | | 158 | 288 | 423 | 709 | 580 | 750 |
| SHP (ssl) | Military | 420 | 708 | 1561 | 1800 | 2500 | 3400 |
| | Normal | 370 | 659 | 1318 | 1530 | 2200 | 3000 |
| | Cruise | 278 | 494 | 1989 | 1148 | 1650 | 2250 |
| SFC (ssl) | Military | .650 | .573 | .460 | .595 | .615 | .543 |
| | Normal | .651 | .573 | .470 | .606 | .622 | .562 |
| | Cruise | .709 | .599 | .510 | .661 | .678 | .610 |
| Initial Costs | | $93K | $100K | $580K | $360K | $640K | $700K |
| Operating Cost per hour/engine | | $8 | $16 | $20 | $35 | $40 | $60 |
| Preventative Maint per hour/engine | | $25 | $50 | $100 | $125 | $160 | $220 |
| MTBMA (hrs) | | 3.5 | 3.0 | 2.0 | 3.0 | 4.0 | 3.5 |
| MDT (hrs) | | 0.7 | 0.6 | 0.5 | 1.3 | 2.0 | 2.6 |
| MTBF (hrs) | | 185 | 210 | 205 | 285 | 280 | 320 |
| MTBR (hrs) | | 600 | 750 | 800 | 800 | 1000 | 750 |

### B3.2 Simplifications

$$\frac{W}{DL} - A = \pi R^2 \quad , \quad \frac{W}{\ell pm} = MHP = 31,00 \quad ; \quad P = \sqrt{\frac{A}{V_T}}$$

### B3.3 Engine Group

$$.053(5100)^{1.07} = 272 \text{ lbs}$$

### B3.4 Main Transmission

$$10.43 \frac{W^{1.295}}{(\ell pm\ V_t)^{.863} \left[\frac{W}{A}\right]^{.432}} = 10.43 \frac{W^{.863} A^{+.432}}{(\ell pm)^{.863} V_T^{.863}}$$

$$= (10.43)(3100)^{.863} P^{.863}$$

$$= 10,748 P^{.863}$$

### B3.5 Rotor Drive Shaft

$$5.56 \frac{W^{1.05}}{(\ell pm\ V_T)^{.7} \left[\frac{W}{A}\right]^{.35}} = 5.56(3100)^{.7} P^{.7}$$

$$= 1545 P^{.7}$$

### B3.6 Tail Rotor

$$32.22 \frac{W^{1.14}}{(\ell pm\ V_T)^{1.14}} = \frac{307,600}{V_T^{1.14}}$$

B3.7 Tail Rotor Gear Box

$$3.7 \frac{W^{.75}}{(\ell pm\ V_T)^{.5}\ [\frac{W}{A}]^{.25}} = (3.7)(3100)^{.5}P^{.5}$$

$$= 206P^{.5}$$

B3.8 Tail Rotor Drive Shaft

$$.124 \frac{W^{1.355}}{(\ell pm)^{.57}\ \frac{W^{.785}}{A^{.785}}} = (.124)(3100)^{.57}P^{.57}\ \sqrt{A}$$

$$= 12.12P^{.57}\ \sqrt{A}$$

B3.9 Landing Gear

$$= .191W^{.916} + .0294W^{.99}$$

B3.10 Rotor Blades Articulated

$$19.77 \frac{W^{1.206}}{V_T}\frac{\sigma^{.33}}{DL^{.205}}$$

$$= 19.77 \frac{W}{V_T} A^{.205}\sigma^{.33}$$

B3.11 Rotor Hub Articulated

$$.00975 \frac{W^{1.21}}{DL^{.21}} = .00975WA^{.21}$$

B3.12 Fuel System $.0615\ W_F$

Calculation of fuel weight three hours at cruise SHP

1513 lbs + 10%

1664 lbs

B3.13 Total Equation

$$WB = 12{,}987,^{*} + 107948P^{.863} + 1545P^{.7}$$

$$+ \frac{307600}{V_T^{1.14}} + 206P^{.5} + 12.12P^{.57}\sqrt{A}$$

$$+ .191W^{.916} + .0294W^{.99}$$

$$+ 19.77\,\frac{W}{V_T}\,A^{.205}S^{.33} + .00975WA^{.21}$$

## B4 HOVER EQUATION

Following the formulation in Section of Chapter 3, the weight equation based on the design mean lift coefficient and power required is:

$$W = \frac{K_2\left[1 - 411.51\,\frac{DL^{3/4}}{V_T^{3/2}}\left(1 + K_3\,\frac{V_T}{\sqrt{DL}}\right)^{1/2}\right] - K_4}{V_T + K_5\sqrt{DL}}$$

---

[*] This number was increased from 8987 to 12987 to bring the curves together. This reflects a 4000 lb useful load.

where:

$$K_1 = \frac{.9583}{C_{LRo}} (1 + 1.8078\ C_{LRo}{}^2)$$

$$K_2 = P_{T6000/950}\ \frac{(10^5)}{K_1}$$

$$K_3 = \frac{0.00025929}{C_{LR_o}} \quad (1 + 1.8078 C_{LRo}{}^2)$$

$$K_4 = \frac{553480.0}{K_1}$$

$$K_5 = \frac{3695.7}{K_1}$$

## B.5 GRAPHICAL RESULTS

Figure B.1 is an example of equation (3.13) plotted against equation (B.4) for a specific design mean lift coefficient.

Figure B.2 illustrates the family of curves obtained when the design mean lift coefficient is varied from 0.3 to 0.7 .

In Figure B.3 the solution matrix depicted in Figure B.2 is narrowed by the constraints placed on the gross weight, rotor diameter and aspect ratio.

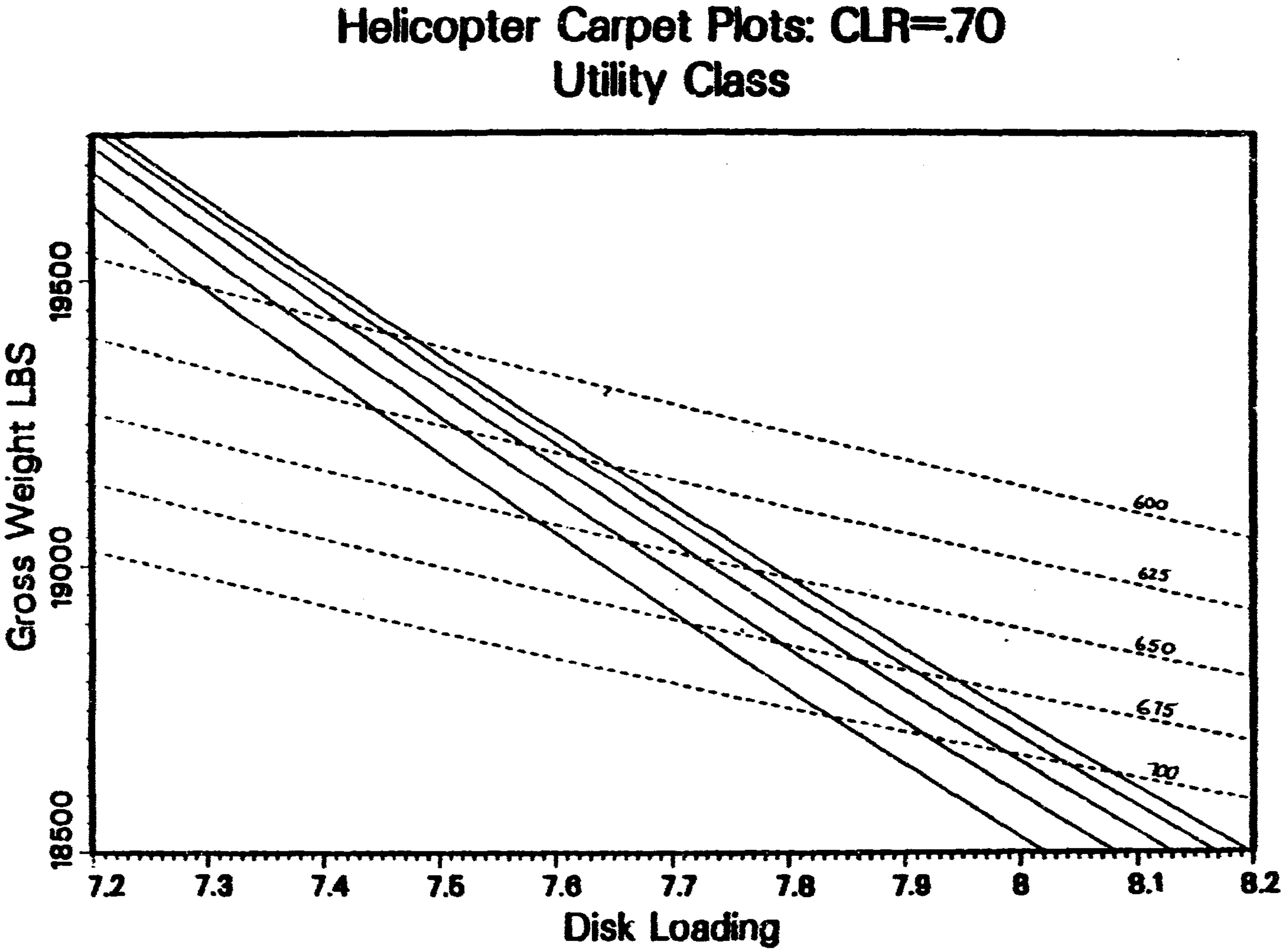


Figure B1. Helicopter Carpet Plots: $C_{LR}$ = .70
Utility Class

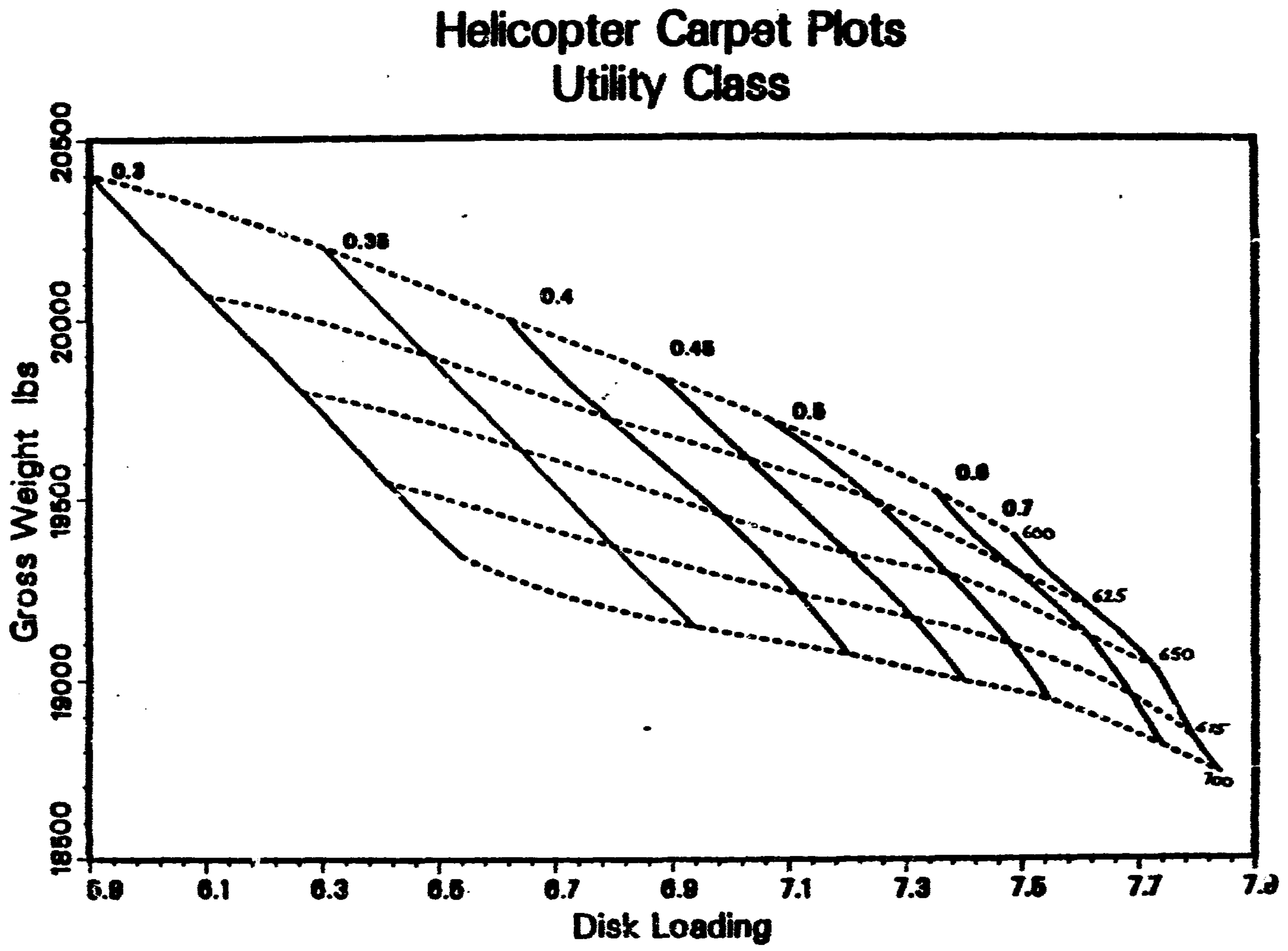


Figure B2. Helicopter Carpet Plots
Utility Class

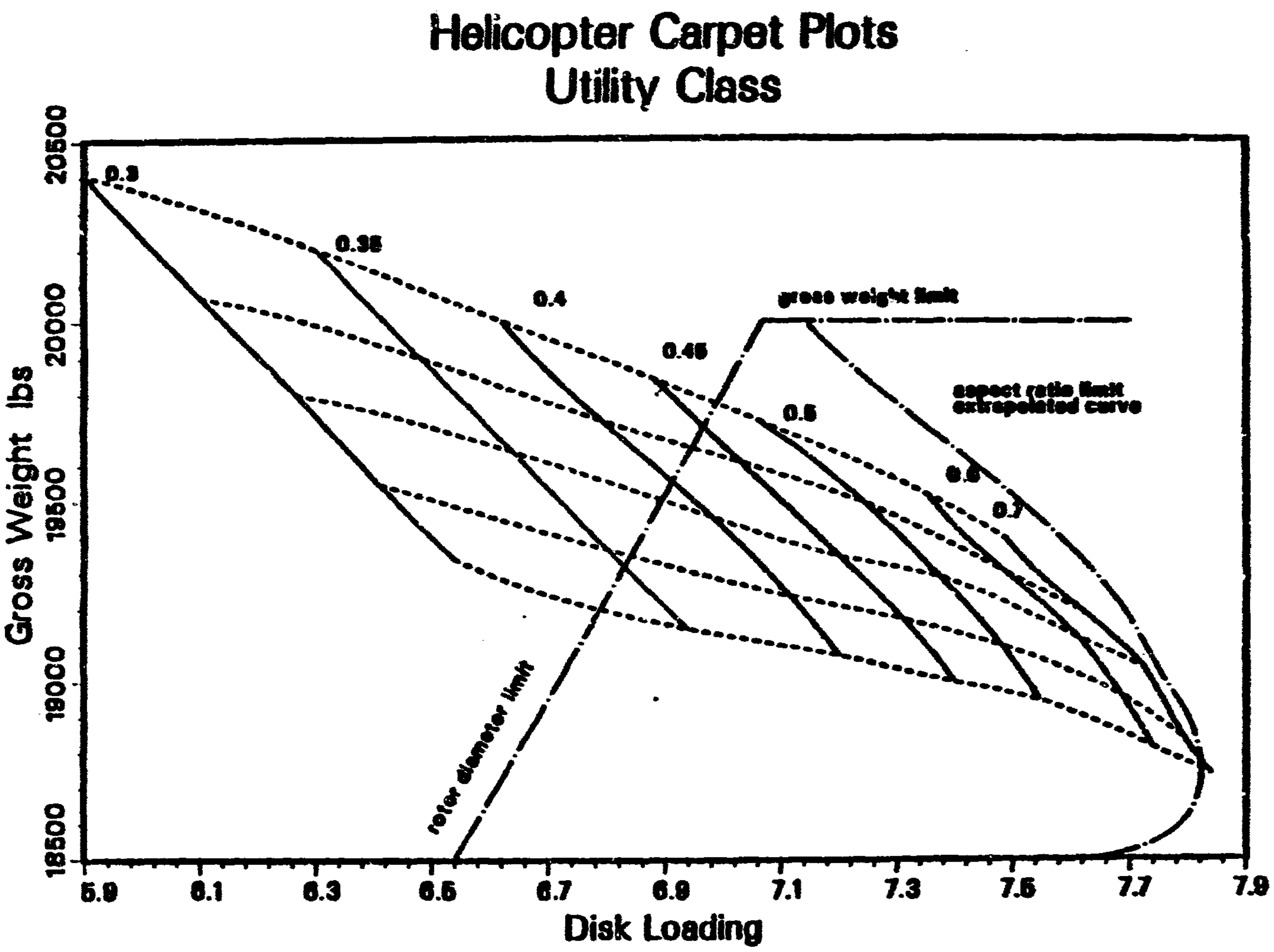
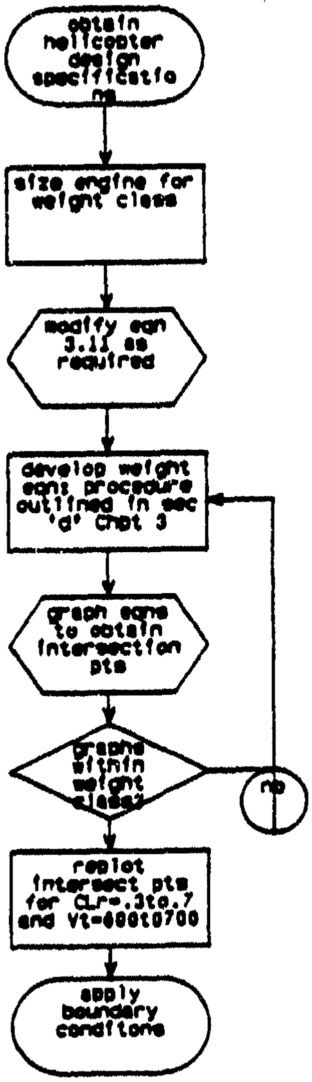


Figure B3. Helicopter Carpet Plots
Utility Class

# APPENDIX C. CARPET PLOT METHODOLOGY FLOW CHART AND EXAMPLE PROGRAMS:

This section contains a flow chart to help organize a carpet analysis and example IBM computer programs to produce the data sets and disspla graphs.


obtain helicopter design specifications
size engine for weight class
modify eqn 3.11 as required
develop weight eqns procedure outlined in sec 'd' Chpt 3
graph eqns to obtain intersection pts
graphs within weight class?
no
replot intersect pts for CLr=.3to.7 and Vt=600to700
apply boundary conditons

```
C***********************************************************************
C***********************************************************************
C**********        GRAPHICAL HELICOPTER DESIGN PROGRAM        **********
C*********               CARPET PLOT NUMBER 1                  *********
C*********                  BY AL HANSEN                       *********
C*********                                                     *********
C*********   THIS PROGRAM IS DESIGNED TO PROVIDE A WEIGHT VS.  *********
C*********    DISK LOADING GRAPH AT SEVERAL DIFFERENT ROTOR    *********
C*********     TIP VELOCITIES FOR A SPECIFIED DESIGN MEAN      *********
C*********                LIFT COEFFICENT.                     *********
C**********             OBSERVATION CLASS                    **********
C***********************************************************************
C***********************************************************************
C****                                                              *****
C**                          NOMENCLATURE                            ***
C*                                                                    **
C*       VARIABLES:                                                   **
C*                                                                    **
C*       CLR      DESIGN MEAN LIFT COEFFICENT                         **
C*       VT       TIP VELOCITY                                        **
C*       DL       DISK LOADING
C*       W        WEIGHT AS CALCULATED FROM POWER EQUATION            **
C*       WB       USEFUL LOAD PLUS EMPTY WEIGHT                       **
C*       PA       POWER AVAILABLE IN HORSEPOWER                       **
C*                                                                    **
C****                                                              *****
C***********************************************************************
      REAL CLR,DL(150),W1(150),W2(150),W3(150),W4(150),W5(150),
     1WB1(150),WB2(150),WB3(150),WB4(150),WB5(150)
C
      INTEGER I
C
C
C---- DEFINE FILES -----------------------------------------------------
C
      CALL FRTCMS ('FILEDEF ','3       ','DISK    ','CRPT35',
     1            'DATA    ','A       ')
C
C
      CALL FRTCMS ('FILEDEF ','4       ','DISK    ','CRPT45',
     1            'DATA    ','A       ')
C---- READ DATA FROM FILE: CRPTX DATA A ------------------------------
C
      DO 10 I=1,99
C     CRPT1 DATA A
      READ (3,70) DL(I),W1(I),WB1(I),W2(I),WB2(I)
C     CRPT2 DATA A
      READ (4,71) W3(I),WB3(I),W4(I),WB4(I),W5(I),WB5(I)
10    CONTINUE
C
C---- CALL DISSPLA ROUTINES FOR PLOT -----------------------------------
C
      CALL TEK618
      CALL MEDEUP
      CALL RESET (3HALL)
      CALL HWSCAL ('SCREEN')
      CALL PAGE (12.0, 9.5)
      CALL GRACE (0.0)
      CALL PHYSOR (1.0,1.2)
      CALL AREA2D (10.0,6.5)
      CALL FRAME
      CALL SWISSL
      CALL BASALF ('L/CSTD')
      CALL MIXALF ('STAND')
      CALL INTAXS
      CALL YTICKS (5)
      CALL XTICKS (5)
      CALL SHDCHR (90,1,.015,1)
      CALL HEIGHT (.16)
      CALL XNAME ('(D)ISK (L)OADING$',100)
      CALL YNAME ('(G)ROSS (W)EIGHT ((LBS))$',100)
      CALL HEIGHT (.290)
      CALL HEADIN ('(H)ELICOPTER (C)ARPET (P)LOTS: (CLR=0.5)$',
     1            100,1.0,1)
C     CALL MESSAG ('(H)ELICOPTER (C)ARPET (P)LOTS: (CLR=0.5)$',
C    1            100,3.25,7.55)
```

```
      CALL HEIGHT (.20)
      CALL GRAF (2.3,.1,2.9,2250.,50.,2550.,
      IYGRID=5
      CALL THKCRV (.018)
      CALL LEGLIN
      CALL CURVE (DL,W1,95,0)
      CALL CURVE (DL,W2,95,0)
      CALL CURVE (DL,W3,95,0)
      CALL CURVE (DL,W4,95,0)
      CALL CURVE (DL,W5,95,0)
      CALL DASH
      CALL CURVE (DL,WB1,95,0)
      CALL CURVE (DL,WB2,95,0)
      CALL CURVE (DL,WB3,95,0)
      CALL CURVE (DL,WB4,95,0)
      CALL CURVE (DL,WB5,95,0)
      CALL THKCRV (.030)
C     CALL BLREC (4.2,4.65,1.6,1.35,1)
C     CALL GRID (1,IYGRID)
C     CALL BLOFF (1)
      MAXLIN=LINEST(IPAK1,300,20)
      CALL HEIGHT (.12)
      CALL LINESP (2.0)
      CALL LINES ('(W)EIGHTS$',IPAK1,1)
C     CALL LINES ('(I)NDUCED$',IPAK1,2)
C     CALL LINES ('(F)ECFILES$',IPAK1,3)
C     CALL LINES ('(P)ARASITES$',IPAK1,4)
C     CALL MYLEGN ('(P)OWER (C)URVES$',16)
C     CALL LEGEND (IPAK1,4,4.43,4.8)
      CALL DONEPL
      STOP
C     FORMAT STATEMENTS
 70   FORMAT (5(2X,F10.3))
 71   FORMAT (6(2X,F10.3))
      END
```

```
C***********************************************************************
C***********************************************************************
C**********       GRAPHICAL HELICOPTER DESIGN PROGRAM         **********
C********                FAMILY OF SOLUTIONS                   *********
C********               CARPET PLOT NUMBER 2                   *********
C********                   BY AL HANSEN                       *********
C********                                                      *********
C********     THIS PROGRAM IS DESIGNED TO ILLUSTRATE THE FAMILY ********
C********       OF SOLUTIONS FOR HOVER AND USEFUL LOAD         *********
C********        REQUIREMENTS OF A TEETERING ROTOR SYSTEM      *********
C********           WITHOUT ANY BOUNDARY CONDITIONS           ********
C********                CONSERVATION CLASS                    *********
C**********                                                   **********
C***********************************************************************
C***********************************************************************
C****                                                              *****
C**                          NOMENCLATURE                            ***
C*                                                                    **
C*     VARIABLES:                                                     **
C*                                                                    **
C*     CLR      DESIGN MEAN LIFT COEFFICENT                           **
C*     VT       TIP VELOCITY                                          **
C*     DL       DISK LOADING
C*     W        WEIGHT AS CALCULATED FROM POWER EQUATION              **
C*     WB       USEFUL LOAD PLUS EMPTY WEIGHT                         **
C*     PA       POWER AVAILABLE IN HORSEPOWER                         **
C*                                                                    **
C****                                                              *****
C*     DL3 EQUALS THE DISK LOADING FOR CLR=.3
C*     DL4 EQUALS THE DISK LOADING FOR CLR=.4
C*     DL5 EQUALS THE DISK LOADING FOR CLR=.5
C*     DL6 EQUALS THE DISK LOADING FOR CLR=.6
C*     DL7 EQUALS THE DISK LOADING FOR CLR=.7
C*     W3 EQUALS THE WEIGHT FOR CLR=.3
C*     W4 EQUALS THE WEIGHT FOR CLR=.4
C*     W5 EQUALS THE WEIGHT FOR CLR=.5
C*     W6 EQUALS THE WEIGHT FOR CLR=.6
C*     W7 EQUALS THE WEIGHT FOR CLR=.7
C*     WVT1 EQUALS WEIGHTS AT VT=600
C*     WVT2 EQUALS WEIGHTS AT VT=625
C*     WVT3 EQUALS WEIGHTS AT VT=650
C*     WVT4 EQUALS WEIGHTS AT VT=675
C*     WVT5 EQUALS WEIGHTS AT VT=700
C*     DVT1 EQUALS THE CORRESPONDING DISK LOADING AT VT=600
C*     DVT2 EQUALS THE CORRESPONDING DISK LOADING AT VT=625
C*     DVT3 EQUALS THE CORRESPONDING DISK LOADING AT VT=650
C*     DVT4 EQUALS THE CORRESPONDING DISK LOADING AT VT=675
C*     DVT5 EQUALS THE CORRESPONDING DISK LOADING AT VT=700
C***********************************************************************
      REAL*4 DL3(5),DL4(5),DL5(5),DL6(5),DL7(5),W3(5),W4(5),
     *W5(5),W6(5),W7(5),WVT1(5),WVT2(5),WVT3(5),WVT4(5),
     *WVT5(5),DVT1(5),DVT2(5),DVT3(5),DVT4(5),DVT5(5)
C
C---- DEFINE DATA ------------------------------------------------------
      DATA DL3/2.06,2.07,2.07,2.07,2.05/
      DATA W3/2505.,2478.2,2455.46,2433.85,2418.25/
      DATA DL4/2.42,2.44,2.46,2.47,2.47/
      DATA W4/2467.17,2442.95,2419.62,2399.72,2382.99/
      DATA DL5/2.63,2.65,2.67,2.69,2.69/
      DATA W5/2440.72,2419.51,2399.00,2379.13,2364.65/
      DATA DL6/2.74,2.77,2.79,2.81,2.81/
      DATA W6/2424.68,2402.48,2383.58,2365.10,2352./
      DATA DL7/2.80,2.83,2.85,2.86,2.87/
      DATA W7/2411.92,2390.72,2372.50,2357.35,2342.25/
      DATA WVT1/2505.,2467.17,2440.72,2424.68,2411.92/
      DATA WVT2/2478.2,2442.95,2419.51,2402.48,2390.72/
      DATA WVT3/2455.46,2419.62,2399.,2383.58,2372.5/
      DATA WVT4/2433.85,2399.72,2379.13,2365.1,2357.35/
      DATA WVT5/2418.25,2382.99,2364.65,2352.,2342.25/
      DATA DVT1/2.06,2.42,2.63,2.74,2.80/
      DATA DVT2/2.07,2.44,2.65,2.77,2.83/
      DATA DVT3/2.07,2.46,2.67,2.79,2.85/
      DATA DVT4/2.07,2.47,2.69,2.81,2.86/
      DATA DVT5/2.05,2.47,2.69,2.81,2.87/
C
C
```

```
C---- CALL DISSPLA ROUTINES FOR PLOT ----------------------------------
C
      CALL TEK618
      CALL HEDEUP
      CALL RESET (3HALL)
      CALL HWSCAL ('SCREEN')
      CALL PAGE (12.0, 9.5)
      CALL GRACE (0.0)
      CALL PHYSOR (1.0,1.2)
      CALL AREA2D (10.0,6.5)
      CALL FRAME
      CALL SWISSL
      CALL BASALF ('L/CSTD')
      CALL MIXALF ('STAND')
      CALL INTAXS
      CALL YTICKS (5)
      CALL XTICKS (5)
      CALL SHDCHR (90,1,.015,1)
      CALL HEIGHT (.16)
      CALL XNAME ('(D)ISK (L)OADING$',100)
      CALL YNAME ('(G)ROSS (W)EIGHT ((LBS))$',100)
      CALL HEIGHT (.290)
      CALL HEADIN ('(H)ELICOPTER (C)ARPET (P)ILOTS$',
     1             100,1.0,1)
      CALL HEIGHT (.20)
      CALL GRAF (2.0,.1,3.0,2300.,50.,2550.)
      IYGRID=5
      CALL THKCRV (.018)
      CALL PARA3
      CALL LEGLIN
      CALL CURVE (DL3,W3,5,0)
      CALL CURVE (DL4,W4,5,0)
      CALL CURVE (DL5,W5,5,0)
      CALL CURVE (DL6,W6,5,0)
      CALL CURVE (DL7,W7,5,0)
      CALL DASH
      CALL CURVE (DVT1,WVT1,5,0)
      CALL CURVE (DVT2,WVT2,5,0)
      CALL CURVE (DVT3,WVT3,5,0)
      CALL CURVE (DVT4,WVT4,5,0)
      CALL CURVE (DVT5,WVT5,5,0)
      CALL THKCRV (.030)
C     CALL BLREC (4.2,4.65,1.6,1.35,1)
C     CALL GRID (1,IYGRID)
C     CALL BLOFF (1)
C     MAXLIN=LINEST(IPAK1,300,20)
C     CALL HEIGHT (.12)
C     CALL LINESP (2.0)
C     CALL LINES ('(W)EIGHTS$',IPAK1,1)
C     CALL LINES ('(I)NDUCED$',IPAK1,2)
C     CALL LINES ('(P)ROFILES$',IPAK1,3)
C     CALL LINES ('(P)ARASITES$',IPAK1,4)
C     CALL MYLEGN ('(P)OWER (C)URVES',16)
C     CALL LEGEND (IPAK1,4,4.43,4.8)
      CALL DONEPL
      STOP
C     FORMAT STATEMENTS
C70   FORMAT (5(2X,F10.3))
C71   FORMAT (6(2X,F10.3))
      END
```

```
C***********************************************************************
C***********************************************************************
C**********     GRAPHICAL HELICOPTER DESIGN PROGRAM           **********
C*********          ASPECT RATIO BOUNDARY                       ********
C********       LOCI OF HOVER AND USEFUL-LOAD SOLUTIONS         ********
C********              CARPET PLOT NUMBER 3                     ********
C********                  BY AL HANSEN                         ********
C********                                                       ********
C********    THIS PROGRAM IS DESIGNED TO GRAPHICALLY DETERMINE  ********
C********      THE ASPECT RATIO BOUNDARY REQUIREMENTS FOR       ********
C********      A ROTOR SYSTEM USING PREVIOUSLY GENERATED DATA   ********
C**********                                                   **********
C***********************************************************************
C***********************************************************************
C****                                                              *****
C**                          NOMENCLATURE                            ***
C*                                                                    **
C*    VARIABLES:                                                      **
C*                                                                    **
C*    CLR     DESIGN MEAN LIFT COEFFICENT                             **
C*    VT      TIP VELOCITY                                            **
C*    DL      DISK LOADING
C*    AR      ASPECT RATIO. HISTORICALLLY ASSUMED TO BE LESS THAN 21  **
C*                                                                    **
C****                                                              *****
C*    DVT1 EQUALS THE CORRESPONDING DISK LOADING AT VT=600
C*    DVT2 EQUALS THE CORRESPONDING DISK LOADING AT VT=625
C*    DVT3 EQUALS THE CORRESPONDING DISK LOADING AT VT=650
C*    DVT4 EQUALS THE CORRESPONDING DISK LOADING AT VT=675
C*    DVT5 EQUALS THE CORRESPONDING DISK LOADING AT VT=700
C*    C600 EQUALS THE LIFT COEF AT VT=600
C*    C625 EQUALS THE LIFT COEF AT VT=625
C*    C650 EQUALS THE LIFT COEF AT VT=650
C*    C675 EQUALS THE LIFT COEF AT VT=675
C*    C700 EQUALS THE LIFT COEF AT VT=700
C***********************************************************************
      REAL*4 CLR(5),DL(10),C600(10),C625(10),C650(10),
     *C675(10),C700(10),
     *DVT1(5),DVT2(5),DVT3(5),DVT4(5),DVT5(5)
C
C---- DEFINE DATA ------------------------------------------------------
      DATA DVT1/2.06,2.42,2.63,2.74,2.80/
      DATA DVT2/2.07,2.44,2.65,2.77,2.83/
      DATA DVT3/2.07,2.46,2.67,2.79,2.85/
      DATA DVT4/2.07,2.47,2.69,2.81,2.86/
      DATA DVT5/2.05,2.48,2.70,2.82,2.87/
      DATA CLR/.3,.4,.5,.6,.7/
      DATA DL/2.,2.1,2.2,2.3,2.4,2.5,2.6,2.7,2.8,2.9/
      DATA C600/.47,.49,.51,.53,.55,.57,.59,.61,.63,.65/
      DATA C625/.43,.45,.47,.49,.51,.53,.55,.57,.59,.61/
      DATA C650/.39,.41,.43,.45,.47,.49,.51,.53,.55,.57/
      DATA C675/.35,.37,.39,.41,.43,.45,.47,.49,.51,.53/
      DATA C700/.31,.33,.35,.37,.39,.41,.43,.45,.47,.49/
C
C
C---- CALL DISSPLA ROUTINES FOR PLOT -----------------------------------
C
      CALL TEK618
      CALL MEDBUF
      CALL RESET (3HALL)
      CALL HWSCAL ('SCREEN')
      CALL PAGE (12.0, 9.5)
      CALL GRACE (0.0)
      CALL PHYSOR (1.0,1.2)
      CALL AREA2D (10.0,6.5)
      CALL FRAME
      CALL SWISSL
      CALL BASALF ('L/CSTD')
      CALL MIXALF ('STAND')
      CALL INTAXS
      CALL SHDCHR (.90,1,.015,1)
      CALL HEIGHT (.16)
      CALL XNAME ('(D)ISK (L)OADING$',100)
      CALL YNAME ('(C)OEFFICENT OF (L)IFT$',100)
      CALL HEIGHT (.290)
      CALL MESSAG ('(H)ELICOPTER (C)ARPET (P)LOTS$',
```

```
1                  100.3.25,7.55)
      CALL HEIGHT (.20)
      CALL GRAF (2.0,.1,2.9,.2,.05,.8)
      IYGRID=5
      CALL THKCRV (.018)
      CALL PARA3
      CALL LEGLIN
      CALL CURVE (DL,C600,10,0)
      CALL CURVE (DL,C625,10,0)
      CALL CURVE (DL,C650,10,0)
      CALL CURVE (DL,C675,10,0)
      CALL CURVE (DL,C700,10,0)
      CALL DASH
      CALL CURVE (DVT1,CLR,5,0)
      CALL CURVE (DVT2,CIR,5,0)
      CALL CURVE (DVT3,CIR,5,0)
      CALL CURVE (DVT4,CIR,5,0)
      CALL CURVE (DVT5,CIR,5,0)
      CALL THKCRV (.030)
      CALL DONEPL
      STOP
      END
```

```
C*************************************************************
C*************************************************************
C**********       GRAPHICAL HELICOPTER DESIGN PROGRAM        **********
C*********              FAMILY OF SOLUTIONS                   *********
C*********              CARPET PLOT NUMBER 4                  *********
C*********                  BY AL HANSEN                      *********
C*********                                                    *********
C*********     THIS PROGRAM IS DESIGNED TO ILLUSTRATE THE FAMILY *********
C*********        OF SOLUTIONS FOR HOVER AND USEFUL LOAD        *********
C*********        REQUIREMENTS OF A TEETERING ROTOR SYSTEM      *********
C*********        WITH ROTOR DIAMETER AND MAX GROSS BOUNDRIES.  *********
C*********             OBSERVATION CLASS HELICOPTER            *********
C**********                                                  **********
C*************************************************************
C*************************************************************
C****                                                        *****
C**                         NOMENCLATURE                       ***
C*                                                              **
C*      VARIABLES:                                              **
C*                                                              **
C*      CLR      DESIGN MEAN LIFT COEFFICENT                    **
C*      VT       TIP VELOCITY                                   **
C*      DL       DISK LOADING
C*      W        WEIGHT AS CALCULATED FROM POWER EQUATION       **
C*      WB       USEFUL LOAD PLUS EMPTY WEIGHT                  **
C*      PA       POWER AVAILABLE IN HORSEPOWER                  **
C*                                                              **
C****                                                        *****
C*      DL3 EQUALS THE DISK LOADING FOR CLR=.3
C*      DL4 EQUALS THE DISK LOADING FOR CLR=.4
C*      DL5 EQUALS THE DISK LOADING FOR CLR=.5
C*      DL6 EQUALS THE DISK LOADING FOR CLR=.6
C*      DL7 EQUALS THE DISK LOADING FOR CLR=.7
C*      W3 EQUALS THE WEIGHT FOR CLR=.3
C*      W4 EQUALS THE WEIGHT FOR CLR=.4
C*      W5 EQUALS THE WEIGHT FOR CLR=.5
C*      W6 EQUALS THE WEIGHT FOR CLR=.6
C*      W7 EQUALS THE WEIGHT FOR CLR=.7
C*      WVT1 EQUALS WEIGHTS AT VT=600
C*      WVT2 EQUALS WEIGHTS AT VT=625
C*      WVT3 EQUALS WEIGHTS AT VT=650
C*      WVT4 EQUALS WEIGHTS AT VT=675
C*      WVT5 EQUALS WEIGHTS AT VT=700
C*      DVT1 EQUALS THE CORRESPONDING DISK LOADING AT VT=600
C*      DVT2 EQUALS THE CORRESPONDING DISK LOADING AT VT=625
C*      DVT3 EQUALS THE CORRESPONDING DISK LOADING AT VT=650
C*      DVT4 EQUALS THE CORRESPONDING DISK LOADING AT VT=675
C*      DVT5 EQUALS THE CORRESPONDING DISK LOADING AT VT=700
C*      RDB ROTOR DISK BOUNDARY
C*      WMG MAX GROSS WEIGHT BOUNDARY
C*************************************************************
        REAL*4 DL3(5),DL4(5),DL5(5),DL6(5),DL7(5),W3(5),W4(5),RDB(2),
     *W5(5),W6(5),W7(5),WVT1(5),WVT2(5),WVT3(5),WVT4(5),WMG(2),
     *WVT5(5),DVT1(5),DVT2(5),DVT3(5),DVT4(5),DVT5(5),D1(2),D2(2)
C
C---- DEFINE DATA -----------------------------------------------
        DATA DL3/2.06,2.07,2.07,2.07,2.05/
        DATA W3/2505.,2478.2,2455.46,2433.85,2418.25/
        DATA DL4/2.42,2.44,2.46,2.47,2.47/
        DATA W4/2467.17,2442.95,2419.62,2399.72,2382.99/
        DATA DL5/2.63,2.65,2.67,2.69,2.69/
        DATA W5/2440.72,2419.51,2399.00,2379.13,2364.65/
        DATA DL6/2.74,2.77,2.79,2.81,2.81/
        DATA W6/2424.67,2402.48,2383.58,2365.10,2352./
        DATA DL7/2.80,2.83,2.85,2.86,2.87/
        DATA W7/2411.92,2390.72,2372.50,2357.35,2342.25/
        DATA WVT1/2505.,2467.17,2440.72,2424.67,2411.92/
        DATA WVT2/2478.2,2442.95,2419.51,2402.53,2390.72/
        DATA WVT3/2455.46,2419.62,2399.,2383.58,2372.5/
        DATA WVT4/2433.85,2399.72,2379.13,2365.1,2357.35/
        DATA WVT5/2418.25,2382.99,2364.65,2352.,2342.25/
        DATA DVT1/2.06,2.42,2.63,2.74,2.80/
        DATA DVT2/2.07,2.44,2.65,2.77,2.83/
        DATA DVT3/2.07,2.46,2.67,2.79,2.85/
        DATA DVT4/2.07,2.47,2.69,2.81,2.86/
        DATA DVT5/2.05,2.47,2.69,2.81,2.87/
```

```
      DATA D1/2.52,2.9/
      DATA WMG/2450.,2450./
      DATA D2/2.36,2.52/
      DATA RDB/2300.,2450./
C
C
C---- CALL DISSPLA ROUTINES FOR PLOT -----------------------------------
C
      CALL TEK618
      CALL MEDBUF
      CALL RESET (3HALL)
      CALL HWSCAL ('SCREEN')
      CALL PAGE (12.0, 9.5)
      CALL GRACE (0.0)
      CALL PHYSOR (1.0,1.2)
      CALL AREA2D (10.,6.5)
      CALL FRAME
      CALL SWISSL
      CALL BASALF ('L/CSTD')
      CALL MIXALF ('STAND')
      CALL INTAXS
      CALL YTICKS (5)
      CALL XTICKS (5)
      CALL SHDCHR (.90,1,.015,1)
      CALL HEIGHT (.16)
      CALL XNAME ('(D)ISK (L)OADING$',100)
      CALL YNAME ('(G)ROSS (W)EIGHT ((LBS))$',100)
      CALL HEIGHT (.290)
      CALL HEADIN ('(H)ELICOPTER (C)ARPET (P)LOTS$',
     1           100,1.0,1)
      CALL HEIGHT (.20)
      CALL GRAF (2.0,.1,3.0,2300.,50.,2550.)
      IYGRID=5
      CALL THKCRV (.018)  .
      CALL PARA3
      CALL LEGLIN
      CALL CURVE (DL3,W3,5,0)
      CALL CURVE (DL4,W4,5,0)
      CALL CURVE (DL5,W5,5,0)
      CALL CURVE (DL6,W6,5,0)
      CALL CURVE (DL7,W7,5,0)
      CALL DASH
      CALL CURVE (DVT1,WVT1,5,0)
      CALL CURVE (DVT2,WVT2,5,0)
      CALL CURVE (DVT3,WVT3,5,0)
      CALL CURVE (DVT4,WVT4,5,0)
      CALL CURVE (DVT5,WVT5,5,0)
      CALL THKCRV (.030)
      CALL CHNDOT
      CALL CURVE (D1,WMG,2,0)
      CALL CURVE (D2,RDB,2,0)
      CALL DONEPL
      STOP
      END
```

```
C**********************************************************
C**********************************************************
C**********       GRAPHICAL HELICOPTER DESIGN PROGRAM       **********
C*********             FAMILY OF SOLUTIONS                 *********
C*********            CARPET PLOT NUMBER 5                 *********
C*********               BY AL HANSEN                      *********
C*********                                                 *********
C*********   THIS PROGRAM IS DESIGNED TO ILLUSTRATE THE FAMILY  *********
C*********    OF SOLUTIONS FOR HOVER AND USEFUL LOAD       *********
C*********    REQUIREMENTS OF A TEETERING ROTOR SYSTEM     *********
C*********    WITH ROTOR DIAMETER, MAX GROSS WEIGHT AND    *********
C*********         ASPECT RATIO BOUNDARIES.                *********
C*********        OBSERVATION CLASS HELICOPTER             *********
C***********                                             ***********
C**********************************************************
C**********************************************************
C*****                                                        *****
C**                         NOMENCLATURE                       ***
C*                                                              **
C*     VARIABLES:                                               **
C*                                                              **
C*     CLR       DESIGN MEAN LIFT COEFFICENT                    **
C*     VT        TIP VELOCITY                                   **
C*     DL        DISK LOADING
C*     W         WEIGHT AS CALCULATED FROM POWER EQUATION       **
C*     WE        USEFUL LOAD PLUS EMPTY WEIGHT                  **
C*     PA        POWER AVAILABLE IN HORSEPOWER                  **
C*                                                              **
C****                                                        *****
C*     DL3 EQUALS THE DISK LOADING FOR CLR=.3
C*     DL4 EQUALS THE DISK LOADING FOR CLR=.4
C*     DL5 EQUALS THE DISK LOADING FOR CLR=.5
C*     DL6 EQUALS THE DISK LOADING FOR CLR=.6
C*     DL7 EQUALS THE DISK LOADING FOR CLR=.7
C*     W3 EQUALS THE WEIGHT FOR CLR=.3
C*     W4 EQUALS THE WEIGHT FOR CLR=.4
C*     W5 EQUALS THE WEIGHT FOR CLR=.5
C*     W6 EQUALS THE WEIGHT FOR CLR=.6
C*     W7 EQUALS THE WEIGHT FOR CLR=.7
C*     WVT1 EQUALS WEIGHTS AT VT=600
C*     WVT2 EQUALS WEIGHTS AT VT=625
C*     WVT3 EQUALS WEIGHTS AT VT=650
C*     WVT4 EQUALS WEIGHTS AT VT=675
C*     WVT5 EQUALS WEIGHTS AT VT=700
C*     DVT1 EQUALS THE CORRESPONDING DISK LOADING AT VT=600
C*     DVT2 EQUALS THE CORRESPONDING DISK LOADING AT VT=625
C*     DVT3 EQUALS THE CORRESPONDING DISK LOADING AT VT=650
C*     DVT4 EQUALS THE CORRESPONDING DISK LOADING AT VT=675
C*     DVT5 EQUALS THE CORRESPONDING DISK LOADING AT VT=700
C*     RDB ROTOR DISK BOUNDARY
C*     WMG MAX GROSS WEIGHT BOUNDARY
C*     AR WEIGHTS FOR THE ASPECT RATIO BOUNDARY
C*     D3 DISK LOADING CORRESPONDING TO THE ASPECT RATIO WEIGHTS
C**********************************************************
      REAL*4 DL3(5),DL4(5),DL5(5),DL6(5),DL7(5),W3(5),W4(5),RDB(2),
     *W5(5),W6(5),W7(5),WVT1(5),WVT2(5),WVT3(5),WVT4(5),WMG(2),
     *WVT5(5),DVT1(5),DVT2(5),DVT3(5),DVT4(5),DVT5(5),D1(2),D2(2),
     *D3(5),AR(5)
C
C---- DEFINE DATA -----------------------------------------------
      DATA DL3/2.06,2.07,2.07,2.07,2.05/
      DATA W3/2505.,2478.2,2455.46,2433.85,2418.25/
      DATA DL4/2.42,2.44,2.46,2.47,2.47/
      DATA W4/2467.17,2442.95,2419.62,2399.72,2382.99/
      DATA DL5/2.63,2.65,2.67,2.69,2.69/
      DATA W5/2440.72,2419.51,2399.00,2379.13,2364.65/
      DATA DL6/2.74,2.77,2.79,2.81,2.81/
      DATA W6/2424.66,2402.48,2383.58,2365.10,2352./
      DATA DL7/2.80,2.83,2.85,2.86,2.87/
      DATA W7/2411.52,2390.72,2372.50,2357.35,2342.25/
      DATA WVT1/2505.,2467.17,2440.72,2424.67,2411.92/
      DATA WVT2/2478.2,2442.95,2419.51,2402.53,2390.72/
      DATA WVT3/2455.46,2419.62,2399.,2383.58,2372.5/
      DATA WVT4/2433.85,2399.72,2379.13,2365.1,2357.35/
      DATA WVT5/2418.25,2382.99,2364.65,2352.,2342.25/
      DATA DVT1/2.06,2.42,2.63,2.74,2.80/
```

```
      DATA DVT2/2.07,2.44,2.65,2.77,2.83/
      DATA DVT3/2.07,2.46,2.67,2.79,2.85/
      DATA DVT4/2.07,2.47,2.69,2.81,2.88/
      DATA DVT5/2.05,2.47,2.69,2.81,2.87/
      DATA D1/2.52,2.9/
      DATA WHG/2450.,2450./
      DATA D2/2.36,2.82/
      DATA RDB/2300.,2450./
      DATA AR/2374.461,2390.,2405.,2420.,2450./
      DATA D3/2.44,2.65,2.715,2.745,2.78/
C
C
C---- CALL DISSPLA ROUTINES FOR PLOT ---------------------------------
C
      CALL TEK618
      CALL MZCEDF
      CALL RESET (3HALL)
      CALL HWSCAL ('SCREEN')
      CALL PAGE (12.0, 9.5)
      CALL GRACE (0.0)
      CALL PHYSOR (1.0,1.2)
      CALL AREA2D (10.,6.5)
      CALL FRAME
      CALL SWISSL
      CALL BASALF ('L/CSTD')
      CALL MIXALF ('STAND')
      CALL INTAXS
      CALL YTICKS (5)
      CALL XTICKS (5)
      CALL SHDCHR (.90,1,.015,1)
      CALL HEIGHT (.16)
      CALL XNAME ('(D)ISK (L)OADING$',100)
      CALL YNAME ('(G)ROSS (W)EIGHT ((LBS))$',100)
      CALL HEIGHT (.290)
      CALL HEADIN ('(H)ELICOPTER (C)ARPET (P)LOTS$',
     1             100,1.0,1)
      CALL HEIGHT (.20)
      CALL GRAF (2.0,.1,3.0,2300.,50.,2550.)
      IYGRID=5
      CALL THKCRV (.018)
      CALL PARA3
      CALL LEGLIN
      CALL CURVE (DI3,W3,5,0)
      CALL CURVE (DI4,W4,5,0)
      CALL CURVE (DI5,W5,5,0)
      CALL CURVE (DI6,W6,5,0)
      CALL CURVE (DI7,W7,5,0)
      CALL DASH
      CALL CURVE (DVT1,WVT1,5,0)
      CALL CURVE (DVT2,WVT2,5,0)
      CALL CURVE (DVT3,WVT3,5,0)
      CALL CURVE (DVT4,WVT4,5,0)
      CALL CURVE (DVT5,WVT5,5,0)
      CALL THKCRV (.030)
      CALL CHNDOT
      CALL CURVE (D1,WHG,2,0)
      CALL CURVE (D2,RDB,2,0)
      CALL CURVE (D3,AR,5,0)
      CALL DONEPL
      STOP
      END
```

```
C  THIS PROGRAM IS DESIGN TO GENERATE THE DATA FOR THE GRAPHICAL
C  SOLUTION OF THE WEIGHT AND THE USEFUL LOAD EQUATION.  THIS IS THE
C  FIRST STEP IN A CARPET PLOT HELICOPTER DESIGN PARAMETRIC OPTIMIZATION
C
C     ASSUMPTIONS:
C                  1> ENGINESPECIFIED
C VARIABLE OPTIONS
C
      REAL*4 CLR,PA,DL,K1,K2,K3,K4,K5,R,S,A,P,W(10),WB(10)
      INTEGER VT,D,I,CL
C
C---------------------------------------------------------------------
      CALL FRTCMS ('FILEDEF ','02      ','DISK    ','CRPT1',
     >'DATA    ','A       ')
C---------------------------------------------------------------------
C---------------------------------------------------------------------
      CALL FRTCMS ('FILEDEF ','03      ','DISK    ','CRPT2',
     >'DATA    ','A       ')
C---------------------------------------------------------------------
C
C
C     CLR= DESIGN MEAN LIFT COEFFICIENT
      DO 90 CL=3,7
      CLR=CL*(0.1)
      WRITE(2,10)CLR
C     PA= POWER AVAILABLE HP
      PA=206
C     DL= DISK LOADING
C     VT= TIP VELOCITY FT/SEC
C
C     CONSTANTS BASED ON CLR
C
      K1=(0.9583)/CLR*(1+1.8078*CLR**2)
      K2=PA*10**5/K1
      K3=(0.0025929)/CLR*(1+1.8078*CLR**2)
      K4=553480.0/K1
      K5=3695.7/K1
      DO 100  D=200,300
       DL=D*(0.01)
       I=0
         DO 110  VT=600,700,25
C
C        ARRAY INCREMENTER
         I=I+1
C        WEIGHT EQUATION
C
      W(I)=(K2*(1-(411.51*DL**.75)/(VT**1.5)*(1+K3*VT/DL**.5)**.5)-K4)
     1/(VT+K5*DL**.5)
C
C     CALCULATION OF WE DATA
C
      A=W(I)/DL
      R=(A/3.14)**.5
      P=A**.5/VT
      S=(6.*DL)/(0.0023679*CLR*VT**2)
C
C     ASSUMING A TEETERING SYSTEM
C
      WE(I)= 1717.9+1221.*P**.863+266.*P**.7+17449./VT**1.14
     1+2.886*A**.5*P**.57+.191*W(I)**.916+.0294*W(I)**.99
     2+35.15*(W(I)/VT)*(A**.185)*S**.33+.0088*W(I)*A**.21
C        WRITE (5,20) VT
C        WRITE(5,30)R
 110     CONTINUE
         WRITE (2,31)DL,W(1),WB(1),W(2),WE(2)
         WRITE (3,31) DL,W(3),WB(3),W(4),WB(4),W(5),WB(5)
 100  CONTINUE
  90  CONTINUE
C     FORMAT STATEMENTS
 10   FORMAT ('1','CLR=',1F10.4///)
 31   FORMAT (6(2X,F10.3))
      STOP
      END
```

```
C*************************************************************
C*************************************************************
C   THIS PROGRAM IS DESIGN TO OBTAIN THE GROSS WEIGHT FROM THE       *
C   ASPECT RATIO GRAPH INTERSECTION POINT DATA. IN ORDER TO GRAPH    *
C   THE ASPECT RATIO BOUNDARY ON THE MAIN CARPET PLOT A              *
C   CORRESPONDING WEIGHT MUST BE OBTAINED. THIS PROGRAM UTILIZES     *
C   THE WEIGHT ESTIMATION FORMULATION FROM THE CARPET PROGRAM.       *
C*************************************************************
C*************************************************************
C   ASSUMPTIONS:                                                     *
C                     1> ENGINESPECIFIED                             *
C*************************************************************
C*************************************************************
C VARIABLE OPTIONS
      REAL*4 VT(5),DL(5),CLR(5),W(5)
      DATA CLR/.625,.575,.535,.460,.42/
      DATA VT/600.,625.,650.,675.,700./
      DATA DL/2.75,2.75,2.72,2.67,2.53/
C-------------------------------------------------------------------
      CALL FRTCMS ('FILEDEF ','03       ','DISK    ','CRPTAR',
     >'DATA    ','A        ')
C-------------------------------------------------------------------
C
      DO 90 L=1,5
      WRITE(3,10)CLR(L)
      WRITE(3,20)VT(L)
      WRITE(3,30)DL(L)
C     PA= POWER AVAILABLE HP
      PA=206
C     DL= DISK LOADING
C     VT= TIP VELOCITY FT/SEC
C
C     CONSTANTS BASED ON CLR
C
      K1=(0.9583)/CLR(L)*(1+1.8078*CLR(L)**2)
      K2=PA*10**5/K1
      K3=(0.00025929)/CLR(L)*(1+1.8078*CLR(L)**2)
      K4=553480.0/K1
      K5=3695.7/K1
C        WEIGHT EQUATION
C
      W(L)=(K2*(1-(411.51*DL(L)**.75)/(VT(L)**1.5)*
     1(1+K3*VT(L)/DL(L)**.5)**.5)-K4)/(VT(L)+K5*(DL(L)**.5))
      WRITE (3,31) W(L)
 90   CONTINUE
C     FORMAT STATEMENTS
 10   FORMAT ('1','CLR=',1F10.4///)
 20   FORMAT (2X,'VT=',1F10.4///)
 30   FORMAT (2X,'DL=',1F10.4///)
 31   FORMAT (2X,F10.3)
      STOP
      END
```

# APPENDIX D. PROGRAMS TO ACCESS HESCOMP

This section contains the control language programs needed to access HESCOMP on the IBM main-frame computer.

```
C*****************************************************************
C*****************************************************************
C******                                                    *******
C**  NOTE!!!! THE PROGRAM INPUT CARDS (DATA LINES) DO NOT HAVE TO  ***
C**     BE IN NUMERICAL ORDER. ERASE THESE COMMENT LINES IF RUNNING ***
C**    PROGRAM                                                   ***
C******                                                    *******
C*****************************************************************
C*****************************************************************
//HESCOMP1 JOB (2399,5555),'AL HANSEN',CLASS=B
//*MAIN ORG=NPGVM1.2399F,LINES=(10)
//    EXEC HESCOMP
//SYSIN DD *
77777
   SAMPLE CASE NO. 1   RUN 1               1/26/84
120150.           0.             0.           2.             0.
120610.
122310.965
130151.761        0.159          0.           0.032          950.
130651100.        1656.          2000.        2000.          8.
13115870.         1200.          1400.        1600.          1800.
131652000.        2200.          2600.        5.             0.
132140.2          0.4            0.6          0.8
132650.           0.             0.           0.             0.
13325.163         .1676          .1613        .2041          .236
13385.335         .3444          .3725        .4194          .4851
13445.544         .5592          .6049        .6511          .7877
13505.770         .7916          .8562        .964           1.115
135651.0          1.028          1.112        1.252          1.448
136251.2          1.2336         1.3344       1.5024         1.7376
136851.55         1.5934         1.7236       1.9406         2.2444
137458.           870.           1200.        1400.          1600.
137951800.        2000.          2200.        2600.          5.
138450.           0.2            0.4          0.6            0.8
13905.065         .0651          .0653        .067           .071
13965.115         .116           .118         .128           .15
14025.180         .181           .15          .208           .227
14085.26          .261           .273         .295           .325
14145.342         .347           .362         .389           .425
14205.425         .435           .451         .486           .517
14265.5           .511           .53          .56            .61
14325.626         .631           .66          .718           .78
143863.           870.           1600.        2600.
144743.           0.             0.4          0.8
145430.26         0.271          0.29
146030.82         0.84           0.90
146631.09         1.116          1.165
150258.           870.           1200.        1400.          1600.
150751800.        2000.          2200.        2600.          5.
151250.           0.2            0.4          0.6            0.8
151850.26         0.265          0.271        0.28           0.29
152450.52         0.527          0.54         0.56           0.59
153050.68         0.69           0.705        0.73           0.76
153650.82         0.824          0.84         0.868          0.90
154250.92         0.93           0.95         0.98           1.02
154851.0          1.002          1.02         1.05           1.09
155451.052        1.055          1.07         1.10           1.131
156051.09         1.10           1.118        1.135          1.165
66666
120150.           0.             0.           2.             0.
120610.
122320.965        0.
130151.761        0.159          0.           0.032          950.
130651100.        1656.          2000.        2000.          8.
13115870.         1200.          1400.        1600.          1800.
131652000.        2200.          2600.        5.             0.
132140.2          0.4            0.6          0.8
132650.           0.             0.           0.             0.
13325.163         .1676          .1613        .2041          .236
13385.335         .3444          .3725        .4194          .4851
13445.544         .5592          .6049        .6811          .7877
13505.770         .7916          .8562        .964           1.115
135651.0          1.028          1.112        1.252          1.448
136251.2          1.2336         1.3344       1.5024         1.7376
136851.55         1.5934         1.7236       1.9406         2.2444
137458.           870.           1200.        1400.          1600.
```

```
024622.          1.105
024851.          900.        10.         .075        .97
025310.
02542.82         .80
02572140.        3.
026114.0
026240.          0.2         0.4         0.8
02724.85         .63         .80         .78
031241130.       .555        .75         1.0
032310.0
032711.02
032821.464COCOCE 066.28
033017.0
033150.0         0.2         0.4         0.6         0.8
033621.0         1.4
03355.006        .0062       .007        .008        .0095
03442.012        .020
260232200.       450.        2000.
26053100.        0.          0.
260E50.          0.          0.          0.          0.
2613525.         25.         25.         0.          0.
2618430.         .18         25.         0.
262225125.       2.08        .04         .8          0.
262751.          0.          2.06        2.0         24.1
263251.0         .75         1.0         .75         0.
263754.          2.2         61.         .286        1.15
264614.2         14.2        1.0         1.0         250.
264753.          250.        250.        1.          .11
26522.17         .17
265451.0         1.0         1.0         1.0         1.0
265551.0         1.0         1.0         1.0         1.0
266451.0         1.0         1.0         1.0         1.0
266951.0         1.0         1.0         1.0         1.0
034753.0         3.0         0.0         0.5         1.0
035430.0         0.5         1.0
036131.0         1.0         1.0
036831.0         1.0         1.0
037531.0         1.0         1.0
040110.
041111.0333
042110.
043111.0
044111.105
046121.0         1.0
048120.          0.
050120.          0.
051120.          0.
052121.06        1.06
05312.02         .02
054121.105       1.105
05512.1          .2
057121.          1.
059120.          0.
06012.3          .4
061120.          0.
062125000.       500.
063122.          2.
064125000.       3000.
065121.105       1.105
066126.          6.
067121.105       1.105
068121.          1.
069120.          0.
070121.          1.
072132.          4.          4.
073111170.
074130.          0.          0.
07513.5          .5          .5
076130.          0.          0.
0771315.         15.         15.
078132.          2.          2.
0791360.         150.        100.
080131.105       1.105       1.105
081130.          0.          0.
082131.105       1.105       1.105
083130.          0.          0.
```

```
137551800.     2000.     2260.     2600.     5.
138450.        0.2       0.4       0.6       0.8
13905.065      .0651     .0653     .067      .071
13965.115      .116      .118      .128      .14
14025.180      .181      .19       .208      .227
14085.26       .261      .273      .295      .325
14145.342      .347      .362      .389      .425
14205.425      .435      .451      .486      .517
14265.5        .511      .53       .56       .61
14325.626      .631      .66       .718      .78
143043.        870.      1600.     2600.
144743.        0.        0.4       0.8
145430.26      0.271     0.29
146030.62      0.84      0.96
146631.09      1.118     1.165
150258.        870.      1200.     1400.     1600.
150751800.     2000.     2200.     2600.     5.
151250.        0.2       0.4       0.6       0.8
151850.26      0.265     0.271     0.23      0.29
152450.52      0.527     0.54      0.56      0.59
153050.66      0.69      0.705     0.73      0.76
153650.82      0.824     0.84      0.868     0.90
154250.92      0.93      0.95      0.98      1.02
154851.0       1.002     1.02      1.05      1.09
155451.052     1.055     1.07      1.10      1.131
156051.09      1.10      1.118     1.135     1.165
66666
160123.0       -9.0
16035.0074918  -.028     .262      .276      2.45
16083.865
16055.0079059  2.82      .09       1.17      .00124
16102.758      .743
1616510.       0.        .004      .007      .009
16215.010      .011      .0115     .012      .0155
16265.022      1.018     1.065     1.154     1.233
163151.279     1.314     1.327     1.337     1.364
163611.357
000151.        1.        2.        0.        1.
000654.        4.        1.        1.        3.
001151.        2.        0.        1.        1.
001642.        2.        2.        0.
002252.        25000.    0.        0.        0.
002750.        .33       220.      220.      3.5
003251.0       0.0       1.05      1.0       2.0
003754.0       3.0       4.0       9.0       2.0
004250.0       6.0       3.0       4.0       60.
004711100.
010310.5
01055.20       .12       0.        .5        1.0
01105.2        .8        4.0       1.15      .12
01152.0162     .5
012050.0       0.0       7.0       6.5       1.3
012551.6       12.       0.        .55       5.
01302.3        1.1
01365.45       .15       .8        .85       .5
01415180.      .035      2.0       .078      0.1
01465.035      2.0       .078      0.        0.
01511.1
01525.4        .2        .5        .4        3.
017133.        1.        11.
017654.        -9.       .25       .075      .1
01815725.      .12       1.06      165.      3000.
0186543.2      .110      1.75      1.35      1.0
019131.53      0.        .85
020355.        -4.       .3        .075      690.
02085.17       .30       .75       1.00      .72
021331.00      1.0       1.05
021610.
021711.761
021932.0       2.0       1.0
02235.97       100.      1.0       1.0       4000.
022851.06      50.3      1.105     0.0       .95
023350.0       2.0       3000.     170.      43.2
023641.105     .75       .30       0.
024211.761
024511.0
```

```
08411.55            .60           .70
085130.             0.            0.
1C3120.             0.
10412.4             .4
1C5120.             0.
10612.05            .05
107121.105          1.105
10812.5             .25
109121.105          1.105
110120.0            0.0
11111.35
112120.0            0.0
113120.0            0.0
11611-1000.
11711.01
118111000.
119111.0
88888
59999
/*
//
```

# APPENDIX E: HESCOMP INPUT AND OUTPUT EXAMPLES

This section contains samples of the IBM computer input and output.

```
                              H E S C O M P
        HELICOPTER SIZING & PERFORMANCE COMPUTER PROGRAM     E-

        THE FOLLOWING IS A CARD BY CARD REPRODUCTION OF THE INPUTS THIS CASE

LOC.    CORRESPONDS TO LOCATION NUMBER GIVEN ON INPUT SHEET
NUM     STANDS FOR THE NUMBER OF SEQUENTIAL INPUT VALUES STARTINGC. (MAX. =5)
VAL     EQUALS VALUE FOR VARIABLE CORRESPONDING TO LOC.
VAL1           VALUE              CORRESPONDING TO LOC.+0001
VAL2           VALUE              CORRESPONDING TO LOC.+0002
        ETC.

LOC.        NUM        VAL              VAL1             VA      VAL3             VAL4

        NOTE : IN USING AUXILIARY ENGINES ; AUXILIARY ENGINE CYCLLOCATIONS CAN BE CREATED
        BY PLACING A 66666 CARD IN FRONT AND BEHIND A STANDARD ENIE

1201        5          .0               .0               .0      2.0000           .0
1206        1          .0
1223        1          .90500
1301        5          1.7610           .15900           .0      .32000E-01       950.00
1306        5          1100.0           1856.0           200     2030.0           8.0000
1311        5          870.00           1230.0           140     1600.0           1800.0
1316        5          2000.0           2230.0           260     5.0000           .0
1321        4          .20000           .40000           .60     .80000
1326        5          .0               .0               .0      .0               .0
1332        5          .16300           .16760           .18     .20410           .23600
1338        5          .33500           .34440           .37     .41940           .38510
1344        5          .54400           .55920           .60     .68110           .78773
1350        5          .77000           .79160           .65     .96400           1.1150
1356        5          1.0000           1.0280           1.1     1.2520           1.4480
1362        5          1.2000           1.2336           1.3     1.5024           1.7176
1368        5          1.5500           1.5934           1.7     1.9406           2.2444
1374        5          8.0000           870.00           120     1400.0           1600.0
1379        5          1800.0           2000.0           220     2600.0           5.0000
1384        5          .0               .20000           .40     .60000           .80000
1390        5          .65000E-01       .65100E-01       .65     .67000E-01       .71000E-01
1396        5          .11500           .11600           .11     .12800           .14000
1402        5          .18000           .18100           .19     .20800           .22700
1408        5          .26000           .26100           .27     .29500           .32500
1414        5          .34200           .34700           .36     .38900           .42500
1420        5          .42500           .43500           .45     .48600           .51700
1426        5          .50000           .51100           .53     .56000           .61000
1432        5          .62600           .63100           .66     .71800           .78000
1438        4          3.0000           870.00           160     2600.0
1447        4          3.0000           .0               .40     .80000
1454        3          .26000           .27100           .29
1460        3          .82000           .84000           .90
1466        3          1.0500           1.1180           1.1
1502        5          8.0000           870.00           120     1430.0           1600.0
1507        5          1800.0           2000.0           220     2600.0           5.0000
1512        5          .0               .20000           .40     .60000           .80000
1518        5          .26000           .26500           .27     .28000           .29000
1524        5          .52000           .52700           .54     .56000           .59000
1530        5          .66000           .69000           .70     .73000           .76000
1536        5          .82000           .82400           .84     .86800           .90000
1542        5          .92000           .93000           .95     .93000           1.0200
1548        5          1.0000           1.0020           1.0     1.0500           1.0900
1554        5          1.0520           1.0550           1.0     1.1000           1.1310
1560        5          1.0500           1.1000           1.1     1.1350           1.1650
2201        5          .0               .0               .0      2.0000           .0
2206        1          .0
```

```
2223   2   .90500        .0
2301   5   1.7610        .15900         .0     .32000E-01   950.00
2306   2   1100.0        1850.0         200    2030.0       8.0000
2311   5   870.00        1230.0         140    1600.0       1800.0
2316   2   2000.0        2230.0         260    5.0000       .0
2321   4   .20000        .40000         .60    .80000
2326   4   .0            .0             .0     .0           .0
2332   5   .16300        .16760         .18    .20410       .23600
2338   2   .33500        .34440         .37    .41940       .48510
2344   2   .54400        .55920         .60    .68110       .78770
2350   2   .77000        .79160         .85    .96400       1.1150
2356   5   1.0000        1.0280         1.1    1.2520       1.4480
2362   2   1.2000        1.2336         1.3    1.5024       1.7376
2368   2   1.5500        1.5934         1.7    1.9406       2.2444
2374   2   8.0000        873.00         120    1400.0       1600.0
2379   5   1800.0        2030.0         220    2600.0       5.0000
2384   5   .0            .23000         .40    .60000       .80000
2390   5   .65000E-01    .65100E-01     .65    .67000E-01   .71000E-01
2396   2   .11500        .11600         .11    .12800       .14000
2402   5   .18000        .18100         .19    .20800       .22700
2408   2   .26000        .26100         .27    .29500       .32500
2414   5   .34200        .34700         .36    .38900       .42500
2420   2   .42500        .43500         .45    .48600       .51700
2426   5   .50000        .51100         .53    .56000       .61000
2432   5   .62600        .63100         .66    .71800       .78000
2438   4   3.0000        870.00         160    2600.0
2447   4   3.0000        .0             .40    .80000
2454   3   .26000        .27100         .29
2460   3   .62000        .84000         .90
2466   3   1.0500        1.1180         1.1
2502   2   8.0000        873.00         120    1400.0       1600.0
2507   5   1800.0        2030.0         220    2600.0       5.0000
2512   5   .0            .23000         .40    .60000       .80000
2518   5   .26000        .26500         .27    .28000       .29000
2524   2   .52000        .52700         .54    .56000       .59000
2530   5   .68000        .69000         .70    .73000       .76000
2536   2   .82000        .82400         .84    .86800       .90000
2542   5   .92000        .93000         .55    .98000       1.0230
2548   5   1.0000        1.0020         1.0    1.0500       1.0900
2554   5   1.0520        1.0550         1.0    1.1000       1.1310
2560   5   1.0500        1.1000         1.1    1.1350       1.1650
1601   2   3.0000        -9.3000
1603   5   .74518E-02    -.28000E-01    .26    .27600       2.4500
1608   1   .86530
1609   5   .75059E-02    2.8200         .90    1.1700       .12400E-02
1614   2   .75600        .74300
1616   5   10.000        .0             .40    .73000E-02   .90000E-02
1621   2   .10000E-01    .11000E-01     .11    .12000E-01   .15500E-01
1626   2   .22000E-01    1.0180         1.0    1.1540       1.2330
1631   5   1.2790        1.3140         1.3    1.3370       1.3640
1636   1   1.3570
   1   5   1.2000        1.0000         2.0    .0           1.0000
   6   2   4.0000        4.0000         1.0    1.0000       3.0000
  11   5   1.0000        2.0000         .0     1.0000       1.0000
  16   4   2.0000        2.0000         2.0    .0
  22   5   2.0000        25000.         .0     .0           .0
  27   5   .0            .33000         220    220.00       3.5000
  32   5   1.0000        .0             1.0    1.0000       2.0000
  37   2   4.0000        3.0000         4.0    9.0000       2.0000
  42   5   8.0000        6.0000         3.0    4.0000       60.000
  47   1   100.00
 103   1   .50000
 105   5   .20000        .12000         .0     .50000       1.0000
 110   5   .20000        .80000         4.0    1.1500       .12000
```

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 115   2   .16200E-01   .50000
 120   5   .0           .0           7.0    6.5000       1.3000
 125   5   1.0000       12.000       .0     .55000       5.0000
 130   2   .30000       1.1000
 136   5   .45000       .15000       .80    .85000       .50000
 141   5   180.00       .35000E-01   2.0    .73000E-01   .10000
 146   5   .35000E-01   2.0000       .78    .0           .0
 151   1   .10000
 152   5   .40000       .20000       .50    .40000       3.0000
 171   3   3.0000       1.0000       11.
 176   5   4.0000       -9.0000      .25    .75000E-01   .10000
 181   5   725.00       .12000       1.0    165.00       3000.0
 186   5   43.200       .11000       1.7    1.3500       1.0000
 191   3   1.5300       .0           .85
 203   5   5.0000       -4.0000      .30    .75000E-01   690.00
 208   5   .17000       .33000       .75    1.0000       .72000
 213   3   1.0000       1.0000       1.0
 216   1   .0
 217   1   1.7610
 219   3   2.0000       2.0000       1.0
 223   5   .97000       100.00       1.0    1.0000       4000.0
 228   5   1.0000       50.300       1.1    .0           .95000
 233   5   .0           2.0000       300    170.00       43.200
 238   4   1.1050       .75000       .30    .0
 242   1   1.7610
 245   1   1.0000
 246   2   2.0000       1.1050
 248   5   1.0000       900.00       10.    .75000E-01   .97000
 253   1   .0
 254   2   .82000       .40000
 257   2   140.00       3.0000
 261   1   4.0000
 262   4   .0           .20000       .40    .80000
 272   4   .85000       .80000       .80    .78000
 316   4   1130.0       .55500       .75    1.0000
 323   1   .0
 327   1   1.0200
 328   2   .14640E+07   6.2800
 330   1   7.0000
 331   5   .0           .20000       .40    .60000       .80000
 336   2   1.0000       1.4000
 339   5   .60000E-02   .62000E-02   .70    .80000E-02   .95000E-02
 344   2   .12000E-01   .20000E-01
2602   3   2200.0       450.00       200
2605   3   100.00       .0           .0
2608   5   .0           .0           .0     .0           .0
2613   5   25.000       25.000       25.    .0           .0
2618   4   30.000       .18000       25.    .0
2622   5   125.00       2.0800       .40    .80000       .0
2627   5   1.0000       .0           2.0    2.0000       24.100
2632   5   1.0000       .75000       1.0    .75000       .0
2637   5   44.000       2.2000       61.    .28600       1.1500
2642   5   14.200       14.200       1.0    1.0000       250.00
2647   5   3.0000       250.00       250    1.0000       .11000
2652   2   .17000       .17000
2654   5   1.0000       1.0000       1.0    1.0000       1.0000
2659   5   1.0000       1.0000       1.0    1.0000       1.0000
2664   5   1.0000       1.0000       1.0    1.0000       1.0000
2665   5   1.0000       1.0000       1.0    1.0000       1.0000
 347   5   3.0000       3.0000       .0     .50000       1.0000
 354   3   .0           .50000       1.0
 361   3   1.0000       1.0000       1.0
 368   3   1.0000       1.0000       1.0
```

```
 375    3     1.0000        1.0000       1.0
 401    1      .0
 411    1      .33300E-01
 421    1      .0
 431    1     1.0000
 441    1     1.1050
 461    2     1.0000        1.0000
 481    2      .0            .0
 501    2      .0            .0
 511    2      .0            .0
 521    2     1.0600        1.0600
 531    2      .20000E-01    .20000E-01
 541    2     1.1050        1.1050
 551    2      .10000        .20000
 571    2     1.0000        1.0000
 591    2      .0            .0
 601    2      .30000        .40000
 611    2      .0            .0
 621    2     500.00        500.00
 631    2     2.0000        2.0000
 641    2     5000.0        3000.0
 651    2     1.1050        1.1050
 661    2     6.0000        6.0000
 671    2     1.1050        1.1050
 681    2     1.0000        1.0000
 691    2      .0            .0
 701    2     1.0000        1.0000
 721    3     2.0000        4.0000       4.0
 731    1     170.00
 741    3      .0            .0           .0
 751    3      .50000        .50000       .50
 761    3      .0            .0           .0
 771    3     15.000        15.000       15.
 781    3     2.0000        2.0000       2.0
 791    3     60.000        150.00       300
 801    3     1.1050        1.1050       1.1
 811    3      .0            .0           .0
 821    3     1.1050        1.1050       1.1
 831    3      .0            .0           .0
 841    3      .35000        .60000       .70
 851    3      .0            .0           .0
1031    2      .0            .0
1041    2      .40000        .40000
1051    2      .0            .0
1061    2      .50000E-01    .50000E-01
1071    2     1.1050        1.1050
1081    2      .50000        .25000
1091    2     1.1050        1.1050
1101    2      .0            .0
1111    1      .35000
1121    2      .0            .0
1131    2      .0            .0
1161    1    -1000.0
1171    1      .10000E-01
1181    1     1000.0
1191    1     1.0000
WG = 0.250000E+05  WFA = 0.0           WFK = 0.0
WG = 0.250000E+05  WFA = 0.738579E+04  WFK = 0.512283E+04
WG = 0.217672E+05  WFA = 0.580161E+04  WFB = 0.453304E+04
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                               H E S C O M P
              HELICOPTER SIZING & PERFORMANCE COMPUTER PROGRAM     E-

   SINGLE ROTOR
           COMPOUND HELICOPTER
                          AUX. INDEPENDENT T/SHAFT CRUISION

S I Z E  D A T A  THIS RUN CONVERGED IN  3 ITERATIONS
                          GROSS WEIGHT =  17643.  LB

       FUSELAGE

          LF            LENGTH(BODY+TAILBOOM)                  50.1 FT.
          LC            LENGTH(CABIN)                          12.0 FT.
          LB            LENGTH(BODY)                           27.5 FT.
          LTB           LENGTH(TAILBOOM)                       22.6 FT.
          XM            FWD. ROTOR LOCATION                    15.1 FT.
          WF            WIDTH                                   6.5 FT.
          SF            WETTED AREA                           737.5 SQ. FT.

       WING

          AR            ASPECT RATIO                            4.51
          SW            AREA                                  113.3 SQ. FT.
          BW            SPAN                                   22.6 FT.
          CBARW         MEAN CHORD                              5.0 FT.
          LAMBDA C/4    QUARTER CHORD SWEEP                     0.0 DEG.
          LAMBDA        TAPER RATIO                           0.500
          (T/C)R        ROOT THICKNESS/CHORD                  0.200
          (T/C)T        TIP THICKNESS/CHORD                   0.120
          WG/SW         WING LOADING                          155.7 LBS/SQ. FT.
          GRW           ROTOR/WING GAP                          8.6 FT.
          CF/C          FLAP CHORD/MEAN CHORD RATIO           1.000
       HOR. TAIL

          ARHT          ASPECT RATIO                          4.000
          SHT           AREA                                   35.5 SQ. FT.
          BHT           SPAN                                   11.9 FT.
          CBARHT        MEAN CHORD                              3.0 FT.
          LAMBDA H      TAPER RATIO                           0.500
          (T/C)HT       THICKNESS/CHORD                       0.120
          LTH           HOR. TAIL ARM                          26.0 FT.
       VERT. TAIL

          ARVT          ASPECT RATIO                          1.523
          SVT           AREA                                   21.2 SQ. FT.
          BVT           SPAN                                    5.7 FT.
          CBARVT        MEAN CHORD                              3.7 FT.
          LAMBDA VT     TAPER RATIO                           0.450
          ZTR           TAIL ROTOR(VERT.) LOCATION              4.6 FT.
          ZETAVT        TAIL ROTOR/VERT. TAIL OVERLAP RATIO   0.800
          (T/C)VT       THICKNESS/CHORD                      .0.150
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                          H E S C O M P
   HELICOPTER SIZING & PERFORMANCE COMPUTER PROGRAM     E-

 SINGLE ROTOR
          COMPOUND HELICOPTER
                            AUX. INDEPENDENT T/SHAFT CRUISION

S I Z E   D A T A   THIS RUN CONVERGED IN  3 ITERATIONS

                         GROSS WEIGHT =  17643.  LB

       FUSELAGE

          LF            LENGTH(BODY+TAILBOOM)                50.1 FT.
          LC            LENGTH(CABIN)                        12.0 FT.
          LB            LENGTH(BODY)                         27.5 FT.
          LTB           LENGTH(TAILBOOM)                     22.6 FT.
          XM            FWD. ROTOR LOCATION                  15.1 FT.
          BF            WIDTH                                 6.5 FT.
          SF            WETTED AREA                         717.5 SQ. FT.

       WING

          AR            ASPECT RATIO                         4.51
          SW            AREA                                113.3 SQ. FT.
          BW            SPAN                                 22.6 FT.
          CBARW         MEAN CHORD                            5.0 FT.
          LAMBDA C/4    QUARTER CHORD SWEEP                   0.0 DEG.
          LAMBDA        TAPER RATIO                         0.500
          (T/C)R        ROOT THICKNESS/CHORD                0.200
          (T/C)T        TIP THICKNESS/CHORD                 0.120
          WG/SW         WING LOADING                        155.7 LBS/SQ. FT.
          GRW           ROTOR/WING GAP                        8.6 FT.
          CF/C          FLAP CHORD/MEAN CHORD RATIO         1.000

       HOR. TAIL

          ARHT          ASPECT RATIO                        9.000
          SHT           AREA                                 15.5 SQ. FT.
          BHT           SPAN                                 11.9 FT.
          CBARHT        MEAN CHORD                            1.3 FT.
          LAMBDA H      TAPER RATIO                         0.500
          (T/C)HT       THICKNESS/CHORD                     0.120
          LTH           ECG. TAIL ARM                        26.0 FT.

       VERT. TAIL

          ARVT          ASPECT RATIO                        1.523
          SVT           AREA                                 21.2 SQ. FT.
          BVT           SPAN                                  5.7 FT.
          CBARVT        MEAN CHORD                            3.7 FT.
          LAMBDA VT     TAPER RATIO                         0.450
          ZTR           TAIL ROTOR(VERT.) LOCATION            4.6 FT.
          ZETAVT        TAIL ROTOR/VERT. TAIL OVERLAP RATIO 0.300
          (T/C)VT       THICKNESS/CHORD                     0.150
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MAIN ROTOR PYLON

     AR             ASPECT RATIO                             0.500
     SWP            WETTED AREA                               39.1 SQ. FT.
     FAPF           FRONTAL AREA                               6.2 SQ. FT.
     HPY            HEIGHT                                     3.0 FT.
     CBARPF         MEAN CHORD                                 6.0 FT.
     LAMBDA PP      TAPER RATIO                              0.400
     (T/C)R         ROOT THICKNESS/CHORD                     0.400
     (T/C)T         TIP THICKNESS/CHORD                      0.200

PRIMARY ENGINE NACELLE

     LN             LENGTH                                     5.8 FT.
     DN             MEAN DIAMETER                               2. FT.
     SN             WETTED AREA(TOTAL FOR ALL ENGINES)        60.8 SQ. FT.

AUXILIARY INDEPENDENT ENGINE NACELLE

     LNI            LENGTH                                     4.8 FT.
     DNI            MEAN DIAMETER                               1. FT.
     SNI            WETTED AREA(TOTAL FOR ALL ENGINES)         19. SQ. FT.

AUXILIARY INDEPENDENT ENGINE NACELLE STRUT

     SSTR           WETTED AREA(TOTAL)                          0. SQ. FT.
     BNS            SPAN                                       3.1 FT.
     CNS            MEAN CHORD                                 2.8 FT.

PROPELLER(AUXILIARY PROPULSION)

     DAP            DIAMETER                                  10.0 FT.
     AF             ACTIVITY FACTOR PER BLADE                140.0
     SIGAP          SOLIDITY                                 0.171
     NPA            NO. OF PROPELLERS                           1.
     NO. BLADES     NO. OF BLADES/PROP                          3.
     VTIP           TIP SPEED                                 900. FT./SEC

MAIN ROTOR

     DMR            DIAMETER                                  45.2 FT.
     SIGMR          SOLIDITY                                 0.128
     WG/A           DISC LOADING                              11.0 LB/SQ. FT.
     CT/SIGMA       THRUST COEFF./SOLIDITY                   0.110
     NR             NO. OF ROTORS                               1.
     NO. BLADES     NO. OF BLADES/ROTOR                         4.
     THETA          BLADE TWIST                             -9.000 DEG.
     XC             BLADE CUTOUT/RADIUS RATIO                0.250
     VTIP           TIP SPEED                                 725. FT./SEC.

TAIL ROTOR

     DTR            DIAMETER                                  10.8 FT.
     SIGTR          SOLIDITY                                 0.237
     (T/A)NET       NET DISC LOADING                          17.6 LB./SQ. FT.
     CT/SIGMA       THRUST COEFF./SOLIDITY                   0.170
     NO. BLADES     NO. OF BLADES/ROTOR                         5.
     THETA          BLADE TWIST                             -4.000 DEG.
     XCTR           BLADE CUTOUT/RADIUS RATIO                0.100
     G              MAIN/TAIL ROTOR GAP                        1.0 FT.
     VTIP           TIP SPEED                                 690. FT./SEC.
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                                           H E S C O M P
        HELICOPTER SIZING & PERFORMANCE COMPUTER PROGRAM      E-


W E I G H T S   D A T A     IN LBS

                MLF               MANEUVER LOAD FACTOR
                GLF               GUST LOAD FACTOR
                ULF               ULTIMATE LOAD FACTOR

            PROPULSION GROUP
                    WRRG          TOTAL MAIN ROTOR GROUP                    .
                K12 WBLD               MAIN ROTOR BLADE (PER ROTOR)       1023.
                K13 WHB                MAIN ROTOR HUB (PER ROTOR)          511.
                    WBF                BLADE FOLDING(PER ROTOR)            230.
                K15 WAR           AUXILIARY PROPULSION ROTOR GROUP          .
                    WDS           DRIVE SYSTEM                              .
                K16 WRDS               MAIN ROTOR DRIVE SYSTEM            1359.
                K20 WTRDS              TAIL ROTOR DRIVE SYSTEM             118.
                K17 WADS               AUXILIARY PROPULSION DRIVE SYSTEM   205.
                K19 WPE           PRIMARY ENGINES                           .
                K15 WEA           AUXILIARY ENGINES                         .
                    WPEI          PRIMARY ENGINE INSTALLATION               .
                    WAEI          AUXILIARY ENGINE INSTALLATION             .
                    WFS           FUEL SYSTEM                               .
                DELTA WP          PROPULSION GROUP WEIGHT INCREMENT         .
                      WP    TOTAL PROPULSION GROUP WEIGHT                          5091.

            STRUCTURES GROUP
                K8  WW            WING
                    WTG           TAIL GROUP                                .
                K9  WHT                HOR. TAIL                            71.
                K14 WTR                TAIL ROTOR                          123.
                K6  WB            FUSELAGE                                  .
                K7  WLG           LANDING GEAR                              .
                    WNG                NOSE GEAR                           141.
                    WMG                MAIN GEAR                           565.
                    WTES          TOTAL ENGINE SECTION                      .
                    WPES               PRIMARY ENGINE SECTION              145.
                    WAES               AUXILIARY ENGINE SECTION             51.
                DELTA WST         STRUCTURE WEIGHT INCREMENT                .
                      WST   TOTAL STRUCTURE WEIGHT                                 3272.

            FLIGHT CONTROLS GROUP
                    WPFC          PRIMARY FLIGHT CONTROLS                   .
                    WCC                COCKPIT CONTROLS                     81.
                K1  WRC                MAIN ROTOR CONTROLS                 356.
                K2  WSC                MAIN ROTOR SYSTEMS CONTROLS         248.
                K3  WFW                FIXED WING CONTROLS                   0.
                    WTM                TILT MECHANISM                        0.
                    WSAS               SAS                                  30.
                    WAFC          AUXILIARY FLIGHT CONTROLS                 .
                K4  WPCA               AUX. PROPULSION ROTOR CONTROLS       24.
                K5  WSCA               AUX. PROPULSION ROTOR SYS. CONTRO    32.
                    WMC                MISCELLANEOUS CONTROLS                0.
                DELTA WFC         CONTROL WEIGHT INCREMENT                  .
                      WFC   TOTAL CONTROL WEIGHT                                    870.
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WFE       WEIGHT OF FIXED EQUIPMENT              2200.
WE        WEIGHT EMPTY                          11433.
WFUL      FIXED USEFUL LOAD                       450.
OWE       OPERATING WEIGHT EMPTY                11883.
WPL       PAYLOAD                                2000.
(WF)A     FUEL                                   3760.
WG        GROSS WEIGHT                          17643.
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A E R O D Y N A M I C S   D A T A
        FE              TOTAL EFFECTIVE FLATPLATE AREA                  SQFT
        SWET            TOTAL WETTED AREA                               SQFT
        CFAVG           MEAN SKIN FRICTION COEFF.
      D R A G   B R E A K D O W N            IN  SQFT
        FEW             WING FE                                    .729
        FEF             FUSELAGE FE                                .233
        FEFP            FORWARD(MAIN) ROTOR PYLON FE               .0
        FEAP            AFT ROTOR PYLON FE                         .0
        FEMRH           MAIN ROTOR HUB(S) FE                       .0
        FETRH           TAIL ROTOR HUB FE                          .0
        FEVT            VERTICAL TAIL FE                           .0
        FEHT            HORIZONTAL TAIL FE                         .0
        FEN             PRIMARY ENGINE NACELLE FE                  .0
        FEAI            AUX. INDEPENDENT CRUISE ENG. NAC. FE       .0
        FEAS            AUX. INDEPENDENT CRUISE ENG. STRUT FE      .0
        DELTA FE        INCREMENTAL FE                             .0
A E R O D Y N A M I C   C O E F F .
        A5                                                         79
        A6                                                         64
        A7                                                         20
        A8                                                         13
        A9                                                         48
        E         WING LIFT EFFICIENCY FACTOR                     C.
        EVT       VERTICAL TAIL LIFT EFFICIENCY FACTOR            0.
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R O T O R   D A T A

          ROTOR CYCLE NO.     3.0000

          MAIN ROTOR SOLIDITY SIZED BY MANUEVER CONDITIONS
          H =      3000.0 FT. , TEMP =       91.5 DEG. , V =     KT.
          100.0 PERCENT HOVER RPM
          ROTOR MANUEVER G'S =  1.350 , CT/SIGMA = 0.110

          TAIL ROTOR SIZED AT       1.650 TIMES THE SOLIDITY
          REQUIRED TO SATISFY HOVERING TURN REQUIREMENTS AT :
                         H                              =      4000
                         TEMP                           =      95.0F.
                         CTG/CTNET                      =       1.2
                         YAW RATE                       =      0.7EC.
                         YAW ACCELERATION               =      0.3EC2
                         TAIL ROTOR POLAR
                         MOM. OF INERTIA(PER BLADE)     =       4.1FT2
                         HELICOPTER YAW
                         MOM. OF INERTIA                =    36385FT2
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P R O P U L S I O N   D A T A
          PRIMARY PROPULSION CYCLE NO.     1.761
               TURBOSHAFT ENGINE

                2.  ENGINES

            BHP*E              MAX. STANDARD S.L. STATIC H.P.             H.P.

            ENGINE SIZED FOR TAKEOFF AT T/W =1.06
             95.0 PERCENT MILITARY POWER SETTING,
            H = 4000. FT, TEMPERATURE = 95.04 DEG.F.,
             0.0   ENGINES INOPERATIVE, AND    0.0  FT/MIN VERTI OF CLIMB.

          AUX. INDEPENDENT PROPULSION CYCLE NO.     1.761
               TURBOSHAFT ENGINE

                1.  ENGINES

            BHP*PI              MAX. STANDARD S.L. STATIC H.P.      .     H.P.

            ENGINE SIZED FOR CRUISE AT VC = 170. KNOTS,
             NORMAL  POWER SETTING,
            HC =  3000. FT, TEMPERATURE =  91.50 DEG.F.,
            AND  0.0   ENGINES INOPERATIVE.


               MAIN AND TAIL ROTOR DRIVE SYSTEM RATING                H.P.


               MAIN ROTOR DRIVE SYSTEM RATING          2914.

          XMSN SIZED AT 100. PERCENT OF MAIN ROTOR HOVER POWER REQ
          AT H = 4000. FT, TEMP = 95.04 DEG.F., 100.0 PERCENT HOVE

               TAIL ROTOR DRIVE SYSTEM RATING           436.

          XMSN SIZED AT 100. PERCENT OF TAIL ROTOR HOVER POWER REQ
          AT H = 4000. FT, TEMP = 95.04 DEG.F., 100.0 PERCENT HOVE

               AUXILIARY INDEPENDENT PROPULSION DRIVE SYSTEM RA        871.     H.P.

          XMSN SIZED AT 100. PERCENT OF AUX. PROPULSION CRUISE POWER  AT VC =170. KT,
          HC =  3000. FT, TEMP= 91.50 DEG.F.
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                                        H E S C O M P
                    HELICOPTER SIZING & PERFORMANCE COMPUTER PROGRAM     E-


               MISSION PERFORMANCE DATA

         TAXI  FOR  0.033  HRS. AT GROUND IDLE ENGINE RATING
                                                              PRIM.     PRIM.   TOTAL      AUX.     AUX.     AUX.     AUX. ENG.   TEMP.
 TIME      RANGE      FUEL      WEIGHT    PRESS.     TAS      TURB.     ENG.    FUEL       TURB.    ENG.     ENG.     FUEL FLOW   DEG.
 (HRS)     (N.M.)     USED      (LBS.)    ALT.       (KTS)    TEMP.     CODE    FLOW       TEMP.    CODE     PERF     (LBS/HR)    (F)
                      (LBS)               (FT)                (R)               (LBS/HR)   (R)
 0.0          0.0       0.0     17643.     0.         0.0     950.0      T        438.     550.0     T        0.0        95.      59.0
 0.033        0.0      14.6     17628.     0.         0.0     950.0      T        438.     550.0     T        0.0        95.      59.0
         TAKEOFF, HOVER, OR LAND AT  T/W = 1.060 FOR  0.100 HRS.
                                                              PRIM.     PRIM.   TOTAL      THRUST
 TIME      RANGE      FUEL      WEIGHT    PRES.      TAS      TURB.     ENG.    FUEL         TO
 (HRS)     (N.M.)     USED      (LBS.)    ALT.       (KTS)    TEMP.     CODE    FLOW       WEIGHT    FM       BHP         CT       CT/SIGMA
                      (LBS)               (FT)                .(R)              (LBS/HR)
 M.ROTOR   M.ROTOR    T.ROTOR   T.ROTOR   VRC      PRIM.ENG   AUX.ENG   ROTLI   TEMP
  VTIP      RHP        VTIP      RHP      RHP      FUEL FLOW  FUEL FLOW  CODE   DEG.      DELDCM    FMI      CPPRO       CPIND      CDC
                       (FPS)                       (LBS/HR)   (LBS/HR)          (F)
 0.033        0.0      14.6     17628.     0.         0.0     1685.7     P      1527.     1.060    0.705     2889.     0.0093     0.073
 725.0      2387.     690.0       318.     0.      1432.        95.     A       59.0    0.0       0.705   0.00011    0.00079    0.0068
 0.053        0.0      45.1     17598.     0.         0.0     1684.2     P      1524.     1.060    0.705     2881.     0.0093     0.073
 725.0      2380.     690.0       317.     0.      1429.        95.     A       59.0    0.0       0.705   0.00011    0.00077    0.0068
 0.073        0.0      75.6     17567.     0.         0.0     1682.8     P      1521.     1.060    0.705     2872.     0.0093     0.073
 725.0      2373.     690.0       316.     0.      1427.        95.     A       59.0    0.0       0.705   0.00011    0.00079    0.0068
 0.093        0.0     106.0     17537.     0.         0.0     1681.3     P      1519.     1.060    0.705     2864.     0.0093     0.072
 725.0      2367.     690.0       314.     0.      1424.        95.     A       59.0    0.0       0.705   0.00011    0.00079    0.0068
 0.113        0.0     136.4     17507.     0.         0.0     1679.9     P      1516.     1.060    0.705     2856.     0.0093     0.072
 725.0      2360.     690.0       313.     0.      1421.        95.     A       59.0    0.0       0.705   0.00011    0.00078    0.0068
 0.133        0.0     166.7     17476.     0.         0.0     1678.5     P      1513.     1.060    0.705     2848.     0.0092     0.072
 725.0      2353.     690.0       312.     0.      1418.        95.     A       59.0    0.0       0.705   0.00011    0.00078    0.0068
 0.133        0.0     166.7     17476.     0.         0.0     1678.5     P      1513.     1.060    0.705     2848.     0.0092     0.072
 725.0      2353.     690.0       312.     0.      1418.        95.     A       59.0    0.0       0.705   0.00011    0.00078    0.0069
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     CRUISE AT   170.0  KNOTS TAS, LIMITED BY  NORMAL   ENGINE RATING
                                                          PRIM.     PRIM.                       CT PRIME
                                                          TURB.    . ENG.                         OVER    ALPHA      SPEC.
TIME       RANGE     FUEL      WEIGHT     PRES.     TAS      TEMP.     CODE      EAS       MU      SIGMA    D/L        RANGE        BHP
(HRS)      (N.M.)    USED      (LBS.)     ALT.      (KTS)    (R)                 (KTS)                      (DEG)      (NM/LB)
                     (LBS)                (FT)
                                                                                          AUX.     AUX.     AUX.                   AUX.
M.ROTOR    M.ROTOR   T.ROTOR   T.ROTOR    PROP     PRIM.ENG  BHP       ETAP    UX. ENG.   TURB.    ENG.     ENG.                ENG. BHP
 VTIP       RHP       VTIP      RHP       VTIP     FUEL FLOW AUX       PROP    FUEL FLOW  TEMP.    CODE     PERF                OR THRUST
(FPS)                (FPS)                (FPS)    (LBS/HR)                    (LBS/HR)

CPPRO      CPINC     CPPAR     CPAUD      CDO      DELCDS    DELCDM    CXR       J        CP       CT       CLM        CD=          MM


0.133          0.0     166.7     17476.      0.     170.0    1604.6       P     170.0    0.396    0.046    -5.0      .10066       2545.
725.0        2216.     650.0      156.     ----     1239.     ----     0.821    400.    1679.4     P       0.620                    1119.
0.000478  0.000049  0.000265  0.000042  0.01735  0.00012   0.00933  0.000517   ----     ----     ----     0.500      0.007        0.682

0.222        15.00     315.7     17327.      0.     170.0    1602.8       P     170.0    0.396    0.046    -5.0      .10091       2534.
725.0        2206.     650.0      155.     ----     1295.     ----     0.821    400.    1679.0     P       0.619                    1119.
0.000476  0.000048  0.000265  0.000042  0.01727  0.00010   0.00927  0.000517   ----     ----     ----     0.500      0.007        0.680

0.310        30.00     464.4     17179.      0.     170.0    1600.9       P     170.0    0.396    0.045    -5.1      .10116       2523.
725.0        2195.     650.0      155.     ----     1281.     ----     0.821    400.    1678.5     P       0.618                    1119.
0.000474  0.000047  0.000265  0.000041  0.01720  0.00009   0.00921  0.000516   ----     ----     ----     0.503      0.007        0.677

0.358        45.00     612.7     17030.      0.     170.0    1599.1       P     170.0    0.396    0.045    -5.1      .10140       2512.
725.0        2185.     650.0      154.     ----     1277.     ----     0.821    399.    1678.0     P       0.618                    1119.
0.000472  0.000046  0.000268  0.000041  0.01713  0.00008   0.00915  0.000516   ----     ----     ----     0.500      0.007        0.674

0.486        60.00     760.6     16882.      0.     170.0    1597.3       P     170.0    0.396    0.044    -5.2      .10164       2501.
725.0        2175.     650.0      154.     ----     1273.     ----     0.821    399.    1677.6     P       0.617                    1119.
0.000471  0.000044  0.000268  0.000040  0.01707  0.00008   0.00909  0.000515   ----     ----     ----     0.500      0.007        0.671
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CRUISE AT SPEED FOR 99 PER CENT BEST RANGE WITH HEADWIND OF    0.0

                              FUEL                 PRES.              PRIM.      PRIM.                           CT PRIME
TIME      RANGE              USED       WEIGHT     ALT.      TAS      TURB.      ENG.                             OVER      ALPHA
(HRS)     (N.M.)             (LBS)      (LBS.)     (FT)      (KTS)    TEMP.      CODE      EAS        MU          SIGMA      C/L        SPEC.
                                                                      (R)                  (KTS)                             (DEG)      RANGE        BHP
                                                                                                                                        (NMIP)

M.ROTOR   M.ROTOR    T.ROTOR    T.ROTOR    PROP      PRIM.ENG    BHP       ETAP      LX. ENG.    AUX.        AUX.       AUX.                     AUX.
 VTIP      RHP        VTIP       RHP       VTIP      FUEL FLOW   AUX       FRCP      UEL FLOW    TURB.       ENG.       ENG.                 ENG. BHP
(FPS)                (FPS)                 (FPS)     (LBS/HR)                        (LBS/HR)    TEMP.       CODE       PERF                 OR THRUST

CPFRC     CPINC      CPFTR      CPAUD      CDO       DELCDS      DELCDM    CXR       J           CP          CT         CLW        CDV          KN


0.597       67.95      845.5     16797.    5000.     149.1       1517.6     P        138.4       0.347      0.059       -2.8      .11667        1877.
725.0       1616.      690.0      108.     ----       994.       ----      0.826      285.      1538.1        P         0.471                     549.
0.000412 0.000092 0.000152   0.000054 0.01654   0.00021     0.00843   0.000371    ----       ----        ----       0.500      0.007         0.781

0.688       82.55      974.1     16669.    5000.     149.1       1515.6     P        138.4       0.347      0.059       -2.8      .11700        1867.
725.0       1606.      690.0      107.     ----       991.       ----      0.826      285.      1537.7        P         0.471                     548.
0.000410 0.000090 0.000152   0.000054 0.01647   0.00019     0.00837   0.000370    ----       ----        ----       0.500      0.007         0.779

0.788       97.95     1102.3     16541.    5000.     149.1       1513.6     P        138.4       0.347      0.058       -2.9      .11734        1856.
725.0       1597.      690.0      107.     ----       987.       ----      0.826      284.      1537.3        P         0.470                     547.
0.000408 0.000088 0.000152   0.000053 0.01640   0.00018     0.00832   0.000370    ----       ----        ----       0.500      0.007         0.778

0.889      112.55     1230.2     16413.    5000.     149.1       1511.6     P        138.4       0.347      0.058       -2.9      .11766        1846.
725.0       1587.      690.0      107.     ----       984.       ----      0.826      284.      1536.8        P         0.470                     547.
0.000406 0.000086 0.000152   0.000053 0.01633   0.00017     0.00826   0.000370    ----       ----        ----       0.500      0.007         0.776

0.989      127.95     1357.6     16285.    5000.     149.1       1509.7     P        138.4       0.347      0.057       -2.9      .11799        1836.
725.0       1578.      690.0      106.     ----       981.       ----      0.826      284.      1536.4        P         0.469                     546.
0.000405 0.000084 0.000152   0.000052 0.01626   0.00015     0.00821   0.000369    ----       ----        ----       0.500      0.007         0.774

1.090      142.55     1484.8     16156.    5000.     149.1       1507.7     P        138.4       0.347      0.056       -2.9      .11832        1826.
725.0       1569.      690.0      106.     ----       977.       ----      0.826      284.      1536.0        P         0.469                     546.
0.000403 0.000083 0.000152   0.000052 0.01620   0.00014     0.00815   0.000369    ----       ----        ----       0.500      0.007         0.772

1.137      150.00     1544.4     16095.    5000.     149.1       1506.8     P        138.4       0.347      0.056       -2.9      .11847        1822.
725.0       1565.      690.0      106.     ----       976.       ----      0.826      284.      1535.7        P         0.468                     545.
0.000402 0.000082 0.000152   0.000051 0.01616   0.00014     0.00813   0.000368    ----       ----        ----       0.500      0.007         0.772
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     CLIMB  TO  5000.  FT. WITH  MAXIMUM R/C  AT  NORMAL  ENGINE RAT
      ** TAS(AND EAS) IS THE HORIZONTAL COMPONENT OF THE FLIGHT PATH

                                                      PRIM.     PRIM.                          CT PRIME
TIME      RANGE     FUEL      WEIGHT    PRES.         TURB.     ENG.                             OVER   ALPHA
(MIN)     (N.M.)    USED      (LBS.)    ALT.   TAS    TEMP.     CODE    EAS       MU           SIGMA  D/L     GAMMA    SHP     R/C
                    (LBS)               (FT)   (KTS)  (R)               (KTS)                         (DEG)   (DEG)            (FPM)

M.ROTOR   M.ROTOR   T.ROTOR   T.ROTOR   PROF   PRIM.ENG SHP     ETAP    AUX. ENG.  AUX.        AUX.   AUX.             AUX.
VTIP      RPM       VTIP      RPM       VTIP   FUEL FLOW AUX    PROP    FUEL FLOW  TURB.       ENG.   ENG.             ENG. SHP
(FPS)               (FPS)               (FPS)  (LBS/HR)                 (LBS/HR)   TEMP.       CODE   RENF             (N INDUC.)

CPPRO     CPINC     CPPAR     CPHUD     CDO    DELCDS   DELCDM  CXR     J          CP          CT     CLM     CDM      HM

0.486        60.00     760.6     16882.      0.     76.4   1856.0      1     76.4     0.180   0.063   -2.4      7.3   1949. 1012.
725.0        1111.     650.0        64.    ----     896.    ----   0.820       0.   1856.0      1    0.835             0.
0.000152 0.000200 0.000061 0.000011 0.00830 0.00000 0.00047 0.000332  ----    ----    ----    0.300   0.007   0.959

0.494        60.64     768.0     16875.    500.     76.4   1856.0      1     75.9     0.180   0.064   -2.3      7.1   1926.  976.
725.0        1123.     650.0        64.    ----     885.    ----   0.820       0.   1856.0      1    0.837             0.
0.000153 0.000206 0.000061 0.000011 0.00834 0.00000 0.00051 0.000333  ----    ----    ----    0.300   0.007   0.960

0.503        61.30     775.6     16868.   1000.     76.4   1856.0      1     75.3     0.180   0.065   -2.3      6.8   1907.  935.
725.0        1125.     650.0        63.    ----     874.    ----   0.820       0.   1856.0      1    0.838             0.
0.000154 0.000213 0.000061 0.000011 0.00838 0.00000 0.00055 0.000334  ----    ----    ----    0.300   0.007   0.960

0.512        61.99     783.3     16860.   1500.     77.4   1856.0      1     75.7     0.182   0.066   -2.3      6.5   1887.  902.
725.0        1129.     650.0        63.    ----     864.    ----   0.820       0.   1856.0      1    0.840             0.
0.000156 0.000216 0.000063 0.000012 0.00845 0.00000 0.00062 0.000342  ----    ----    ----    0.300   0.007   0.960

0.521        62.71     791.3     16852.   2000.     77.4   1856.0      1     75.2     0.183   0.067   -2.3      6.2   1866.  864.
725.0        1132.     650.0        63.    ----     853.    ----   0.820       0.   1856.0      1    0.841             0.
0.000157 0.000223 0.000064 0.000012 0.00850 0.00001 0.00067 0.000343  ----    ----    ----    0.300   0.007   0.960

0.531        63.47     799.5     16844.   2500.     77.4   1856.0      1     74.6     0.183   0.068   -2.3      5.9   1846.  825.
725.0        1135.     650.0        62.    ----     842.    ----   0.820       0.   1856.0      1    0.843             0.
0.000157 0.000230 0.000064 0.000012 0.00855 0.00001 0.00071 0.000344  ----    ----    ----    0.300   0.007   0.961

0.541        64.26     808.0     16835.   3000.     78.4   1856.0      1     75.0     0.185   0.069   -2.3      5.6   1825.  786.
725.0        1140.     650.0        62.    ----     832.    ----   0.820       0.   1856.0      1    0.844             0.
0.000160 0.000233 0.000066 0.000013 0.00864 0.00001 0.00080 0.000352  ----    ----    ----    0.300   0.007   0.960

0.551        65.11     816.8     16826.   3500.     78.4   1856.0      1     74.5     0.185   0.070   -2.3      5.3   1804.  747.
725.0        1144.     650.0        62.    ----     821.    ----   0.820       0.   1856.0      1    0.846             0.
0.000161 0.000240 0.000066 0.000013 0.00878 0.00001 0.00086 0.000353  ----    ----    ----    0.300   0.007   0.961

0.563        65.99     826.0     16817.   4000.     79.4   1856.0      1     74.8     0.187   0.071   -2.3      5.0   1784.  707.
725.0        1149.     650.0        61.    ----     811.    ----   0.820       0.   1856.0      1    0.847             0.
0.000163 0.000244 0.000069 0.000013 0.00881 0.00002 0.00096 0.000361  ----    ----    ----    0.300   0.007   0.961

0.574        66.94     835.6     16807.   4500.     79.4   1856.0      1     74.3     0.187   0.072   -2.3      4.7   1763.  666.
725.0        1153.     650.0        61.    ----     801.    ----   0.820       0.   1856.0      1    0.849             0.
0.000165 0.000252 0.000069 0.000013 0.00887 0.00002 0.00102 0.000362  ----    ----    ----    0.300   0.007   0.961

0.587        67.95     845.5     16797.   5000.     79.4   1856.0      1     73.7     0.187   0.073   -2.2      4.4   1743.  626.
725.0        1156.     650.0        61.    ----     790.    ----   0.820       0.   1856.0      1    0.850             0.
0.000166 0.000260 0.000069 0.000014 0.00894 0.00003 0.00109 0.000364  ----    ----    ----    0.300   0.007   0.962
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TRANSFER ALTITUDE TO     1000. FT.

                               FUEL                          PRES.
    TIME         RANGE         USED          WEIGHT          ALT.
    (HRS)        (N.M.)        (LBS)         (LBS.)          (FT)
    1.137         150.00       1544.4         16099.          5000.
    1.137         150.00       1544.4         16099.          1000.

TAKEOFF, HOVER, OR LAND AT  T/W = 1.060 FOR  0.200 HRS.

                                                                       PRIM.     PRIM.    TOTAL        THRUST
                          FUEL                   PRES.                 TURB.     ENG.     FUEL           TO
TIME       RANGE          USED      WEIGHT       ALT.        TAS       TEMP.     CODE     FLOW         WEIGHT      FM        SHP         CT       CT/SIGMA
(HRS)      (N.M.)         (LBS)     (LBS.)       (FT)       (KTS)      (R)                (LBS/HR)

M.ROTOR    M.ROTOR        T.ROTOR   T.ROTOR      VRC       PRIM.ENG    AUX.ENG   ROTOR    TEMP
 VTIP       RHP            VTIP      RHP         RHP       FUEL FLOW   FUEL FLOW  CODE    DEG.         DELDCP      FMI       CPPRC       CQINW      CDC
                           (FPS)                           (LBS/HR)    (LBS/HR)           (F)

1.137       150.00        1544.4     16099.      1000.        0.0      1633.1      P      1390.        1.060     0.709       2544.     0.0088      0.068
725.0        2101.         650.0       270.         0.     1298.         92.       A        55.4       0.0       0.709    0.00011     0.0071      0.0068

1.157       150.00        1572.1     16071.      1000.        0.0      1631.9      P      1387.        1.060     0.709       2538.     0.0088      0.068
725.0        2095.         650.0       269.         0.     1295.         92.       A        55.4       0.0       0.709    0.00011     0.0071      0.0068

1.177       150.00        1599.9     16043.      1000.        0.0      1630.6      F      1385.        1.060     0.709       2531.     0.0087      0.068
725.0        2090.         650.0       268.         0.     1293.         92.       A        55.4       0.0       0.709    0.00011     0.0071      0.0068

1.197       150.00        1627.6     16015.      1000.        0.0      1629.4      P      1383.        1.060     0.709       2524.     0.0087      0.068
725.0        2084.         650.0       267.         0.     1291.         92.       A        55.4       0.0       0.709    0.00011     0.0070      0.0068

1.217       150.00        1655.3     15988.      1000.        0.0      1628.2      P      1380.        1.060     0.709       2517.     0.0087      0.068
725.0        2079.         650.0       266.         0.     1288.         92.       A        55.4       0.0       0.709    0.00011     0.0070      0.0068

1.237       150.00        1682.9     15960.      1000.        0.0      1627.0      F      1378.        1.060     0.709       2511.     0.0087      0.068
725.0        2073.         650.0       265.         0.     1286.         92.       A        55.4       0.0       0.709    0.00011     0.0070      0.0068

1.257       150.00        1710.4     15933.      1000.        0.0      1625.8      F      1376.        1.060     0.709       2504.     0.0087      0.068
725.0        2067.         650.0       264.         0.     1284.         92.       A        55.4       0.0       0.709    0.00011     0.0070      0.0068

1.277       150.00        1737.9     15905.      1000.        0.0      1624.6      P      1374.        1.060     0.709       2497.     0.0087      0.068
725.0        2062.         650.0       263.         0.     1282.         92.       A        55.4       0.0       0.709    0.00011     0.0070      0.0069

1.297       150.00        1765.4     15878.      1000.        0.0      1623.4      P      1371.        1.060     0.709       2490.     0.0086      0.068
725.0        2056.         650.0       262.         0.     1279.         92.       A        55.4       0.0       0.709    0.00011     0.0069      0.0068

1.317       150.00        1792.8     15850.      1000.        0.0      1622.2      F      1369.        1.060     0.709       2484.     0.0086      0.067
725.0        2051.         650.0       261.         0.     1277.         92.       A        55.4       0.0       0.709    0.00011     0.0069      0.0068

1.337       150.00        1820.2     15823.      1000.        0.0      1621.0      F      1367.        1.060     0.709       2477.     0.0086      0.067
725.0        2045.         650.0       260.         0.     1275.         92.       A        55.4       0.0       0.709    0.00011     0.0065      0.0068

1.337       150.00        1820.2     15823.      1000.        0.0      1621.0      P      1367.        1.060     0.709       2477.     0.0086      0.067
725.0        2045.         650.0       260.         0.     1275.         92.       A        55.4       0.0       0.709    0.00011     0.0065      0.0068
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CHANGE PAYLOAD, REMOVE    1000. LB.

                           FUEL                   PRES.
 TIME      RANGE           USED        WEIGHT     ALT.
 (HRS)     (N.M.)          (LBS)       (LBS.)     (FT)
 1.337       150.00        1820.2       15823.    1000.
 1.347       150.00        1820.2       14823.    1000.
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      LOITER  FOR  0.500 HRS.

                                                                   PRIM.    PRIM.                     CT PRIME
TIME      RANGE      FUEL      WEIGHT     PRES.                    TURB.    ENG.                        OVER     ALPHA     TOTAL
(HRS)     (N.M.)     USED      (LBS.)     ALT.      TAS            TEMP.    CODE     EAS       MU       SIGMA    D/L       FUEL FLOW     BHP
                     (LBS)                (FT)      (KTS)          (R)                (KTS)                       (DEG)     (LBS/HR)

M.ROTOR   M.ROTOR    T.ROTOR   T.ROTOR    PROP      PRIM.ENG       BHP      ETAP     AUX. ENG.  AUX.    AUX.     AUX.                    AUX.
 VTIP      RHP        VTIP      RHP       VTIP      FUEL FLOW      AUX      PRCP     FUEL FLOW  TURB.   ENG.     ENG.                 ENG. BHP
(FPS)                (FPS)                (FPS)     (LBS/HR)                         (LBS/HR)   TEMP.   CODE     PCHF                 OR THRUST

CPFRC     CPINC      CPPAR     CPNUD      CDO       DELCDS         DELCDM   CXR      J         CP       CT       CLM       CDM          RM


1.347       150.00    1820.2    14823.    1000.      75.6          1375.0      P     74.5     0.176    0.056    -1.5       967.         1093.
725.0         906.     650.0       57.    ----       813.          ----     0.835    155.     1207.7     P      0.044                      55.
0.000150  0.000162  0.000033  0.000009  0.00822   0.0            0.00039  0.000183  ----     ----     ----     0.400      0.007         0.942

1.397       150.00    1868.6    14774.    1000.      75.6          1374.4      P     74.5     0.176    0.056    -1.5       966.         1090.
725.0         903.     650.0       57.    ----       812.          ----     0.835    155.     1207.6     P      0.044                      55.
0.000150  0.000160  0.000033  0.000009  0.00822   0.0            0.00038  0.000183  ----     ----     ----     0.400      0.007         0.942

1.447       150.00    1916.5    14726.    1000.      75.6          1373.8      P     74.5     0.176    0.056    -1.5       965.         1087.
725.0         900.     650.0       57.    ----       811.          ----     0.835    155.     1207.6     P      0.043                      55.
0.000150  0.000159  0.000033  0.000009  0.00822   0.0            0.00038  0.000183  ----     ----     ----     0.400      0.007         0.942

1.497       150.00    1965.2    14678.    1000.      75.6          1373.2      P     74.5     0.176    0.056    -1.5       964.         1083.
725.0         897.     650.0       57.    ----       810.          ----     0.835    155.     1207.6     P      0.043                      55.
0.000150  0.000158  0.000033  0.000009  0.00822   0.0            0.00038  0.000183  ----     ----     ----     0.400      0.007         0.942

1.547       150.00    2013.4    14630.    1000.      75.6          1372.6      P     74.5     0.176    0.055    -1.5       963.         1080.
725.0         894.     650.0       57.    ----       809.          ----     0.835    155.     1207.5     P      0.043                      55.
0.000150  0.000157  0.000033  0.000009  0.00821   0.0            0.00038  0.000183  ----     ----     ----     0.400      0.007         0.942

1.597       150.00    2061.6    14581.    1000.      75.6          1372.0      P     74.5     0.176    0.055    -1.5       962.         1077.
725.0         891.     650.0       57.    ----       808.          ----     0.835    155.     1207.5     P      0.043                      55.
0.000150  0.000156  0.000033  0.000009  0.00821   0.0            0.00038  0.000183  ----     ----     ----     0.400      0.007         0.941

1.647       150.00    2109.7    14533.    1000.      75.6          1371.4      P     74.5     0.176    0.055    -1.5       961.         1074.
725.0         888.     650.0       57.    ----       807.          ----     0.835    155.     1207.4     P      0.043                      55.
0.000150  0.000155  0.000032  0.000009  0.00821   0.0            0.00037  0.000182  ----     ----     ----     0.400      0.007         0.941

1.697       150.00    2157.7    14485.    1000.      75.6          1370.8      P     74.5     0.176    0.055    -1.5       960.         1070.
725.0         885.     650.0       56.    ----       806.          ----     0.835    155.     1207.4     P      0.043                      54.
0.000150  0.000154  0.000032  0.000009  0.00821   0.0            0.00037  0.000182  ----     ----     ----     0.400      0.007         0.941

1.747       150.00    2205.7    14437.    1000.      74.6          1370.5      P     73.5     0.174    0.055    -1.5       959.         1068.
725.0         883.     650.0       56.    ----       805.          ----     0.835    154.     1206.2     P      0.042                      53.
0.000149  0.000155  0.000031  0.000009  0.00818   0.0            0.00035  0.000179  ----     ----     ----     0.400      0.007         0.942

1.797       150.00    2253.7    14389.    1000.      74.6          1369.9      P     73.5     0.174    0.055    -1.5       958.         1065.
725.0         879.     650.0       56.    ----       804.          ----     0.835    154.     1206.2     P      0.042                      53.
0.000149  0.000154  0.000031  0.000009  0.00818   0.0            0.00035  0.000178  ----     ----     ----     0.400      0.007         0.942

1.847       150.00    2301.6    14341.    1000.      74.6          1369.3      P     73.5     0.174    0.054    -1.5       957.         1061.
725.0         876.     650.0       56.    ----       803.          ----     0.835    154.     1206.2     P      0.042                      53.
0.000149  0.000153  0.000031  0.000009  0.00818   0.0            0.00034  0.000178  ----     ----     ----     0.400      0.007         0.942
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     CLIMB  TO  3000.  FT. WITH   MAXIMUM R/C  AT  NORMAL   ENGINE RAT
        ** TAS(AND EAS) IS THE HORIZONTAL COMPONENT OF THE FLIGHT PATH
                                                              PRIM.    PRIM.                      CT PRIME
                             FUEL                 PRES.               TURB.    ENG.                         OVER     ALPHA
 TIME       RANGE            USED       WEIGHT    ALT.       TAS      TEMP.    CODE       EAS       MU       SIGMA     D/L      GAMMA     BHP      R/C
 (HRS)      (N.M.)           (LBS)      (LBS.)    (FT)      (KTS)     (R)                (KTS)                         (DEG)     (DEG)             (FPM)

                                                                                                    AUX.     AUX.     AUX.              AUX.
 M.ROTOR    M.ROTOR          T.ROTOR    T.ROTOR   PROF    PRIM.ENG    BHP      ETAP   UX. ENG.     TURB.    ENG.     ENG.            ENG. BHP
  VTIP       RHP              VTIP       RHP      VTIP    FUEL FLOW   AUX      FFCP   UEL FLOW     TEMP.    CODE     PERF            OR THRUST
 (FPS)                       (FPS)                (FPS)   (LBS/HR)                    (LBS/HR)

 CPFRC      CPINC            CPPAR      CPNUD     CDO      DELCDS     DELCDM   CXR        J        CP       CT       CLW      CDW       RA


 1.847         150.00     2301.6       14341.     1000.       71.5    1856.0      T      70.5    0.165    0.055     -2.6     11.3      1905. 1469.
 725.0            943.       650.0         56.     ----       874.     ----     0.820      0.    1856.0      T       0.838                 0.
 0.000147 0.000159 0.000054    0.000008 0.00813   0.0             0.00030 0.000317   ----     ----     ----      0.400    0.007      0.943

 1.853         150.41     2306.6       14336.     1500.       71.5    1856.0      T      69.9    0.165    0.055     -2.6     11.0      1884. 1429.
 725.0            943.       650.0         57.     ----       863.     ----     0.820      0.    1856.0      T       0.840                 0.
 0.000147 0.000164 0.000054    0.000008 0.00815   0.0             0.00033 0.000318   ----     ----     ----      0.400    0.007      0.946

 1.859         150.83     2311.6       14331.     2000.       72.5    1856.0      T      70.4    0.171    0.056     -2.6     10.6      1864. 1389.
 725.0            945.       650.0         57.     ----       852.     ----     0.820      0.    1856.0      T       0.841                 0.
 0.000149 0.000166 0.000056    0.000009 0.00820   0.0             0.00038 0.000326   ----     ----     ----      0.400    0.007      0.945

 1.865         151.28     2316.7       14326.     2500.       72.5    1856.0      T      69.9    0.171    0.057     -2.6     10.3      1843. 1349.
 725.0            946.       650.0         57.     ----       842.     ----     0.820      0.    1856.0      T       0.843                 0.
 0.000149 0.000171 0.000057    0.000009 0.00823   0.0             0.00041 0.000327   ----     ----     ----      0.400    0.007      0.946

 1.871         151.73     2321.9       14321.     3000.       72.5    1856.0      T      69.4    0.171    0.058     -2.5     10.0      1823. 1308.
 725.0            947.       650.0         56.     ----       831.     ----     0.820      0.    1856.0      T       0.844                 0.
 0.000150 0.000177 0.000057    0.000009 0.00826   0.0             0.00044 0.000328   ----     ----     ----      0.400    0.007      0.947
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CRUISE AT SPEED FOR 99 PER CENT BEST RANGE WITH HEADWIND OF    0.0

                                                           PRIM.     PRIM.                      CT PRIME
                            FUEL                 PRES.     TURB.     ENG.                         OVER    ALPHA      SPEC.
 TIME       RANGE           USED       WEIGHT    ALT.       IAS      TEMP.     CODE      EAS      MU        SIGMA    D/L        RANGE         BHP
 (HRS)      (N.M.)          (LBS)      (LBS.)    (FT)      (KTS)     (R)                 (KTS)                      (DEG)      (NMPP)

                                                                                                   AUX.     AUX.    AUX.
 M.ROTOR    M.ROTOR        T.ROTOR    T.ROTOR    PROP     PRIM.ENG   BHP       ETAP     AUX. ENG.  TURB.    ENG.    ENG.                   AUX.
  VTIP       BHP            VTIP       BHP       VTIP     FUEL FLOW  AUX       PROP     FUEL FLOW  TEMP.    CODE    PERF                ENG. BHP
 (FPS)                      (FPS)                (FPS)    (LBS/HR)                      (LBS/HR)                                         OR THRUST

 CPPRO      CPINC          CPFAR      CPNUO      CDO      DELCOS     DELCDM    CXR       J         CP       CT      CLW        CDW           RN


 1.871       151.73       2321.5      14321.    3000.      150.1    1460.1       P      143.6     0.345    0.044    -2.8      .11817        1613.
 725.0        1367.        650.0        100.     ----       937.      ----     0.826     335.    1509.1      P      0.547                     672.
 0.000361 0.000050    0.000114    0.000041  0.01443    0.00001   0.00652  0.000273    ----      ----     ----     0.500       0.007        0.722

 1.971       166.73       2448.5      14194.    3000.      150.1    1458.7       P      143.6     0.345    0.044    -2.8      .11842        1605.
 725.0        1360.        650.0        100.     ----       934.      ----     0.826     334.    1608.7      P      0.547                     672.
 0.000360 0.000049    0.000114    0.000040  0.01438    0.00001   0.00647  0.000273    ----      ----     ----     0.500       0.007        0.721

 2.071       181.73       2575.5      14067.    3000.      150.1    1457.3       P      143.6     0.345    0.043    -2.8      .11867        1597.
 725.0        1353.        650.0        100.     ----       932.      ----     0.826     334.    1608.2      P      0.546                     671.
 0.000359 0.000048    0.000113    0.000040  0.01434    0.00001   0.00643  0.000273    ----      ----     ----     0.500       0.007        0.718

 2.171       196.73       2701.9      13941.    3000.      150.1    1455.9       P      143.6     0.345    0.042    -2.9      .11892        1590.
 725.0        1346.        650.0         99.     ----       929.      ----     0.826     334.    1607.7      P      0.546                     670.
 0.000357 0.000047    0.000113    0.000039  0.01429    0.00000   0.00639  0.000272    ----      ----     ----     0.500       0.007        0.716

 2.271       211.73       2828.1      13815.    3000.      150.1    1454.6       P      143.6     0.345    0.042    -2.9      .11917        1582.
 725.0        1339.        650.0         99.     ----       927.      ----     0.826     334.    1607.2      P      0.545                     670.
 0.000356 0.000045    0.000113    0.000039  0.01425    0.00000   0.00634  0.000272    ----      ----     ----     0.500       0.007        0.713

 2.371       226.73       2953.5      13689.    3000.      150.1    1453.2       P      143.6     0.345    0.041    -2.9      .11941        1575.
 725.0        1332.        650.0         99.     ----       925.      ----     0.826     333.    1606.8      P      0.544                     669.
 0.000355 0.000044    0.000113    0.000038  0.01420    0.00000   0.00630  0.000272    ----      ----     ----     0.500       0.007        0.711

 2.471       241.73       3079.6      13563.    3000.      150.1    1451.9       F      143.6     0.345    0.041    -3.0      .11966        1568.
 725.0        1325.        650.0         99.     ----       922.      ----     0.826     333.    1606.3      P      0.544                     668.
 0.000354 0.000043    0.000113    0.000038  0.01416    0.00000   0.00626  0.000271    ----      ----     ----     0.500       0.007        0.708

 2.571       256.73       3204.5      13438.    3000.      150.1    1450.6       F      143.6     0.349    0.040    -3.0      .11990        1561.
 725.0        1318.        650.0         99.     ----       920.      ----     0.826     333.    1605.8      P      0.543                     667.
 0.000353 0.000042    0.000113    0.000037  0.01412    0.00000   0.00622  0.000271    ----      ----     ----     0.500       0.007        0.705

 2.670       271.73       3330.0      13313.    3000.      150.1    1449.3       P      143.6     0.349    0.040    -3.0      .12015        1553.
 725.0        1312.        650.0         98.     ----       918.      ----     0.826     333.    1605.3      P      0.543                     667.
 0.000352 0.000041    0.000113    0.000037  0.01408    0.00000   0.00617  0.000271    ----      ----     ----     0.500       0.007        0.703

 2.770       286.73       3454.5      13188.    3000.      150.1    1448.0       P      143.6     0.349    0.039    -3.1      .12038        1546.
 725.0        1305.        650.0         98.     ----       916.      ----     0.826     332.    1604.9      P      0.542                     666.
 0.000351 0.000040    0.000113    0.000036  0.01403    0.00000   0.00613  0.000271    ----      ----     ----     0.500       0.007        0.700

 2.859       300.00       3565.1      13078.    3000.      150.1    1446.9       P      143.6     0.345    0.039    -3.1      .12060        1540.
 725.0        1259.        650.0         98.     ----       914.      ----     0.826     332.    1604.5      P      0.542                     665.
 0.000350 0.000039    0.000112    0.000036  0.01400    0.00000   0.00610  0.000270    ----      ----     ----     0.500       0.007        0.697
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LOITER  FOR  0.250 HRS. FOR RESERVE FUEL

                                                              PRIM.    PRIM.                   CT PRIME
                       FUEL                PRES.              TURB.    ENG.                      OVER     ALPHA     TOTAL
TIME      RANGE       USED      WEIGHT     ALT.       IAS     TEMP.    CODE     EAS     MU       SIGMA     D/L     FUEL FLOW     BHP
(HRS)     (N.M.)      (LBS)     (LBS.)     (FT)      (KTS)    (R)               (KTS)                     (DEG)    (LBS/HR)

                                                                                        AUX.     AUX.     AUX.                   AUX.
M.ROTOR  M.ROTOR    T.ROTOR    T.ROTOR    PROF    PRIM.ENG     BHP     ETAP   UX. ENG.  TURB.    ENG.     ENG.                ENG. BHP
 VTIP     RHP        VTIP       RHP       VTIP    FUEL FLOW    AUX     PROP   UEL FLOW  TEMP.    CODE     PERF                UX THRUST
(FPS)               (FPS)                 (FPS)   (LBS/HR)                    (LBS/HR)

CPPRO    CPIND      CPPAR      CPNUD      CDO      DELCDS     DELCOM    CXR      J       CP       CT       CLM       CDM         RN


2.859      300.00    3565.1     13078.   3000.      73.1    1361.3       F     69.9   0.170    0.053    -2.2       835.       1022.
725.0        841.     650.0        53.   ----       758.     ----    0.835      78.   852.1      P      0.0                      0.
0.000148 0.000146 0.000045   0.000008 0.00820   0.0       0.00037 0.000264   ----    ----     ----     0.400     0.007        0.943

2.909      300.00    3606.9     13036.   3000.      73.1    1360.9       F     69.9   0.170    0.052    -2.3       835.       1019.
725.0        839.     650.0        53.   ----       757.     ----    0.835      78.   852.1      P      0.0                      0.
0.000148 0.000145 0.000045   0.000008 0.00820   0.0       0.00037 0.000264   ----    ----     ----     0.400     0.007        0.942

2.959      300.00    3648.6     12994.   3000.      73.1    1360.3       P     69.9   0.170    0.052    -2.3       834.       1017.
725.0        836.     650.0        53.   ----       756.     ----    0.835      78.   852.1      P      0.0                      0.
0.000148 0.000144 0.000045   0.000008 0.00820   0.0       0.00036 0.000263   ----    ----     ----     0.400     0.007        0.942

3.009      300.00    3690.3     12953.   3000.      73.1    1359.7       F     69.9   0.170    0.052    -2.3       833.       1014.
725.0        833.     650.0        53.   ----       755.     ----    0.835      78.   852.1      P      0.0                      0.
0.000149 0.000143 0.000045   0.000008 0.00820   0.0       0.00036 0.000263   ----    ----     ----     0.400     0.007        0.942

3.059      300.00    3731.9     12911.   3000.      73.1    1359.2       P     69.9   0.170    0.052    -2.3       832.       1011.
725.0        831.     650.0        53.   ----       755.     ----    0.835      78.   852.1      P      0.0                      0.
0.000148 0.000142 0.000045   0.000008 0.00820   0.0       0.00036 0.000263   ----    ----     ----     0.400     0.007        0.942

3.109      300.00    3773.5     12869.   3000.      72.1    1358.6       P     69.0   0.168    0.052    -2.2       831.       1008.
725.0        828.     650.0        53.   ----       754.     ----    0.835      78.   852.1      P      0.0                      0.
0.000147 0.000144 0.000044   0.000007 0.00817   0.0       0.00034 0.000258   ----    ----     ----     0.400     0.007        0.943

                MISSION FUEL REQUIRED =  3565.08
                RESERVE FUEL REQUIRED =   208.46
                TOTAL   FUEL REQUIRED =  3773.53

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