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DEVELOPMENT OF A METHOD FOR THE
ANALYSIS OF IMPROVED HELICOPTER DESIGN
CRITERIA

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"two-point design criterion". A computer program known as ZODIAC II was developed to implement these and other analytical models. A user's guide for the program and illustrative computations are presented.

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PREFACE

The work presented in this report was performed by Kaman Aerospace Corporation under Contract DAAJ02-72-C-0064 (DA Task 1F162208AA8201), for the Eustis Directorate, U. S. Army Air Mobility Research and Development Laboratory, Fort Eustis, Virginia. The program was under the technical direction of Mr. H. I. MacDonald of the Technology Applications Division. The authors wish to express their appreciation to Mr. MacDonald and also to Mr. J. P. Whitman and Mr. J. P. Trant, Jr., all of the Eustis Directorate for their helpful suggestions.

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INTRODUCTION

A "single-point" design is defined as a helicopter which satisfies a specification defining a single altitude, temperature, payload combination, in addition to some prescribed mission. While it is admittedly an oversimplification to describe present helicopters as pure single-point design vehicles, this criterion is certainly a major factor in their final configuration.

A "two-point" design is defined as one which, in addition to the single-point criterion, has been sized so as to be able to make full use of the additional power, torque, and lifting capability available at some other altitude and temperature condition (usually lower and cooler).

A single-point design has the advantage of being the lightest weight vehicle capable of performing the stated mission. The single-point design vehicle will also have lower initial costs than any other vehicle capable of performing the same mission. However, since the engines in a single-point design vehicle must be capable of producing enough power to hover at high density - altitude, usually 4000 ft, 95°F, it will have power available at lower density altitudes which cannot be handled by its power transmission system and lifting capability which cannot be handled by the fuselage structure. In actual operation, the helicopter will either be performing below its engine capabilities or exceeding torque and structural limits.

The two-point design will be heavier and have higher initial costs. It will, however, be able to take advantage of (some of) its additional capability. It will be able to safely carry greater loads and will have greater endurance. Because it is less susceptible to abuse, its maintenance costs will be reduced. Depending on what is selected as the second design point, the particular operating conditions, and the appropriate effectiveness criteria, this vehicle can be significantly more cost effective.

It is the purpose of this project to develop a method for the selection of the most cost-effective second design point and to develop a better understanding of the concept and the factors which affect the selection.

ANALYTICAL MODEL

The analytical model used to describe the interrelationships between the various factors affecting the cost and the effectiveness is crucial to the success of the project. Because of the wide variety of possible models reflecting missions, vehicle concepts, technology levels, available data, and the approach preferences of the agency performing the evaluation, a rather general computer program was developed to handle models of varying complexity and organization. All the details of the program are given in later sections. However, it is necessary to point out that the program is based on the implementation of analytical models in the form of logic diagrams. The diagrams contain computational units which are called "modules". The discussion of the models developed in this study will be presented in this framework, starting from the overall logic and progressing to the details of the individual computational units.

The analytical models developed in this report are considered to be adequate representations of the five types of helicopters included in this project, i.e., (1) utility, (2) cargo, (3) crane, (4) observation, and (5) gunship. These models, however, have been developed primarily as foundations to be built upon and modified as our knowledge increases and for the analysis of specific mission requirements. The computer implementation has been specifically developed to have the capability to easily handle minor or major changes in details or overall logic of the model.

GENERAL ORGANIZATION

The model is logically separated into four major units as illustrated in Figure 1. The first block indicates the preliminary design of the baseline single-point design. The major input items here are the single altitude and temperature condition and the basic mission definition.

The second block to be entered after the single-point design has been achieved indicates the computation of the changes in the aircraft based on a specified second altitude and temperature condition.

The third block computes the cost of the helicopter including production and operating costs but excluding maintenance which will be a function of the actual missions flown.

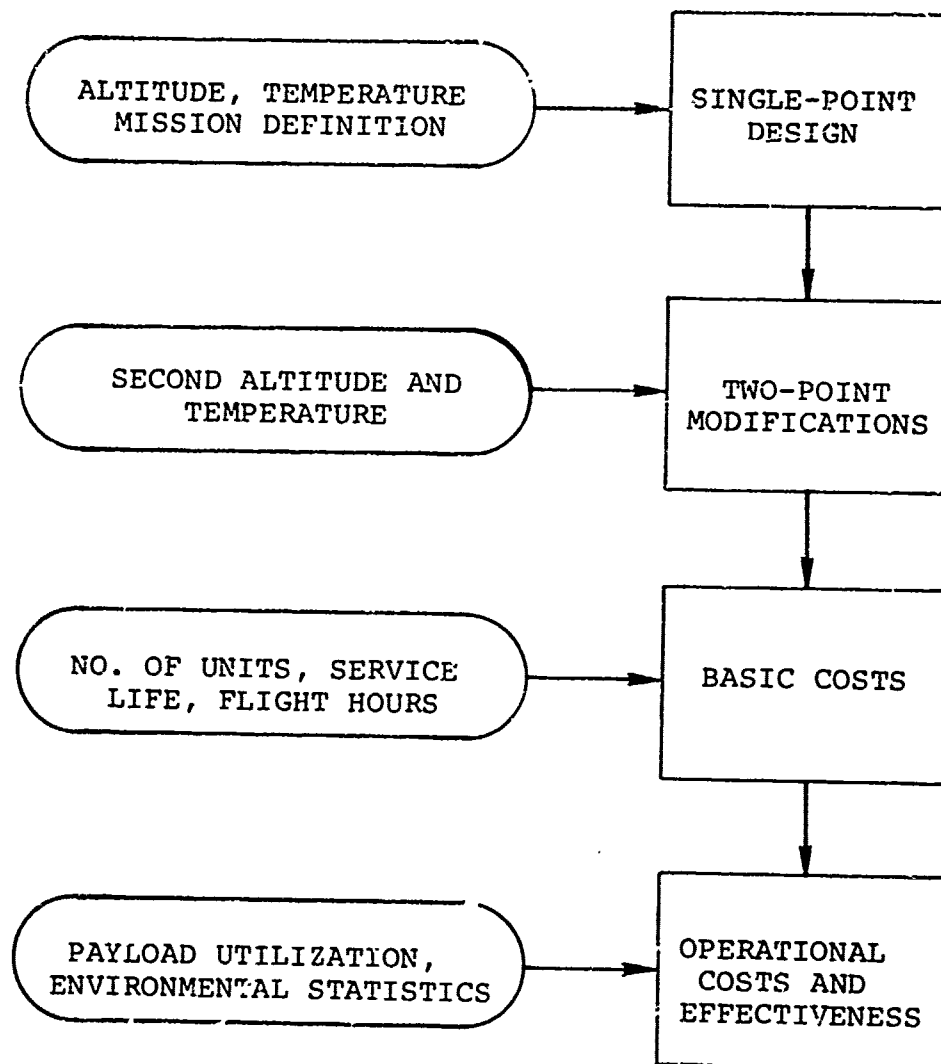


Figure 1. Major Units of Model and Major Input Data.

Primary data includes the production quantity, the attrition rate and service life and flight hours.

The last logical block makes use of payload utilization data, environmental data and results in the determination of total costs and effectiveness.

These four blocks will now be described in more detail in terms of the modules included in them. These modules represent the basic computation required. In this discussion, the function of each module will be indicated but the actual relationships used will be presented in later sections. The model described here is for a utility helicopter but is typical of all the models. When details are discussed, the differences between the models will be indicated.

Single-Point Design

The modules in the first major block of operations are computed in the following order:

SIZE
TO ALLOWANCE AND CRUISE
MAX RANGE
TOTAL FUEL
STAT WEIGHT
GROSS WEIGHT

The functions of each of these modules are given in the following paragraphs.

SIZE - This module computes the power required, based on the temperature, altitude, rate of climb, gross weight, and disc loading. In addition, such data as flat plate area, main rotor radius, and takeoff power are also computed.

TO ALLOWANCE AND CRUISE - This module computes the fuel consumed during the takeoff and cruise at V_{max} segments of the mission.

MAX RANGE - The speed for maximum range is determined, and cruise at this speed is carried out with a fuel used computation.

TOTAL FUEL - In this module the required fuel reserve is added to the two previously determined increments to obtain total fuel requirement.

STAT WEIGHT - Based on a statistical weights model appropriate to the type of helicopter being studied, the weight of each component is computed.

GROSS WEIGHT - This module simply adds the empty weight, fuel weight, crew and payload.

Notice that the gross weight is required in the first module and is recalculated in the last. In operation gross weight is estimated and the entire process iterated until a converged gross weight is obtained. At this point all the design parameters for the single-point design have been determined.

Two-Point Modifications

The second block of Figure 1 which determines the changes due to the additional design point contains the following modules in this order:

SIZE (Two-point data)
TO ALLOWANCE AND CRUISE
MAX RANGE
TOTAL FUEL
ANAL WEIGHT
GROSS WEIGHT TWO
TO ALLOWANCE AND CRUISE
MAX RANGE
TOTAL FUEL
PAYLOAD
ERROR

The first four modules are the same as used previously except they have as data the altitude and temperature of the two-point design.

ANAL WEIGHT - This module corrects the previously obtained weight by analytically taking into account the changes in torque and gross weight. These effects are used to modify the weight of the drive system, rotor, and fuselage.

GROSS WEIGHT TWO - The gross weight of the two-point design helicopter is obtained.

The next three modules determine the mission fuel with the new gross weight.

PAYLOAD - This module determines the payload capability at the first design point.

ERROR - The payload just determined is compared with the requirements. If the payload is deficient, the gross weight is increased by the deficiency and the entire block is repeated until convergence.

Basic Costs

The computation of the basic costs is accomplished with a single module:

PAPC COSTS

This module computes the production, attrition, crew, and miscellaneous costs on a per-hour, per-production helicopter basis.

Operational Costs and Effectiveness

PAYLOADS

OGWS
TO ALLOWANCE AND CRUISE
MAX RANGE
TOTAL FUEL.

MAINT COSTS

HOVER PROB

MEI

PAYLOADS - This module refers to input tables to obtain discrete payloads and their respective utilization frequency.

OGWS - The gross weight with one of the above payloads is obtained.

The next three modules then, as previously, determine the total fuel for the standard mission with the specified payload. The process is iterated from the module OGWS until the fuel load (and gross weight) converges.

MAINT COSTS - The maintenance costs are computed based on the ratios of gross weights, computed MTBF's, and overload effects.

HOVER PROB - This module uses environmental data to determine the integrated probability that the helicopter can perform the required mission.

MEI - The mission effectiveness index and the overall cost effectiveness are computed.

MISSION DEFINITIONS

One of the objectives of this study is to develop models that have the capability to treat a mission profile consisting of a number of different types of mission segments. These are: (a) ground operation, e.g., engine start, warmup, and check-out; (b) takeoff; (c) climb; (d) cruise at given airspeed; (e) cruise at airspeed for maximum range; (f) dash at V_{max} ; (g) loiter; (h) hover, e.g., loading or unloading of cargo; (i) descent; and (j) landing with a fuel reserve. The five mission profiles compiled for the five types of helicopters were compiled in such a way that all of the above specified mission segments are represented. The one exception is the descent segment, which is only implied by the altitude change between the preceding and following mission segments, but for which no calculations are performed because past specifications reviewed do not allow distance credit for the descent segment. Additional segments were defined using recent RFQ's as samples to permit construction of any recently used mission profile.

Each mission segment is calculated for a given altitude and temperature. Depending on the type of segment, time, distance or airspeed is specified. In the case of climb and loiter, the airspeed is not directly specified but is determined as the speed for minimum power. For cruise mission segments, the airspeed is either specified or calculated to meet specified criteria as will be explained later. In any case, the calculation procedure includes checks that no applicable stall or power or torque limit is exceeded.

Performance at each mission segment is calculated for the gross weight at the start of the mission segment. Weight reduction due to fuel consumption is accounted for by subtracting used fuel weight for each succeeding mission segment. Payload changes, as due to unloading or loading of cargo, rescues, troops, or armament, may be accounted for in determination of the initial gross weight of any segment.

The drag changes due to off-loading or picking up of external cargo, or disposing of weapons during the mission can be accounted for similarly to payload changes discussed above.

Table I is a listing of segments included in the five mission profiles. The approaches to the analysis of these segments are given in the following paragraphs.

| TABLE I. MISSION PROFILE | | | | |
|--------------------------------------|---|---------------|---------------|-------------|
| Mission Segment | TAS | Distance | Time | Power |
| Ground Operation | 0 | 0 | Spec. | Flight Idle |
| T.O. | 0 | 0 | Spec. | Spec. |
| Climb | Look up speed for min. power | Calc | Calc | Spec. |
| Cruise @ Given A/S | Spec. | Calc Spec. | Spec. Calc | Calc |
| Cruise @ Given A/S for Maximum Range | Calc | Calc Spec. | Spec. Calc | Calc |
| V-max, Dash | Calc | Calc Spec. | Calc Calc | Spec. |
| Loiter | Look up speed for min. power | Calc | Spec. | Calc |
| Hover | 0 | 0 | Spec. | Calc |
| Reserve | Any mission segment above or percent initial fuel or both | | | |
| Calc = Calculated | Spec. = Specific | | | |

Ground operation fuel flow is determined directly from engine statistics. The engine is assumed to be at flight idle setting as would be the case for preflight checking of aircraft systems. Review of engine data showed that fuel flow is a function of engine size and pressure altitude resulting in:

$$FL = .15 (PRA) (PR) (TIC) / 60$$

Fuel allowance for the takeoff mission segment is calculated per military specifications as fuel used at a given power and in a given time period. The power usually specified is the maximum continuous power rating. The calculations procedure selects the lesser of the two - engine or transmission power level - for the specified rating and atmospheric conditions and determines the fuel flow for that using parametric part power SFC vs referred power variation data.

The climb segment requires that both initial and final altitudes and temperatures are specified. Power rating is specified as either intermediate or maximum continuous, and the calculation procedure determines average altitude and temperature. The engine power available at the specified rating and average atmospheric conditions is compared with the transmission limit, and the lesser of the two is used. The average fuel flow is determined now for this power. Time-to-climb determination involves determination of minimum level flight power from the appropriate table. Then,

$$R/C = \frac{33,000 \text{ (HP available - minimum HP required)}}{\text{Gross Weight}}$$

and

$$\text{Time} = \frac{\Delta \text{ Altitude}}{R/C}$$

With known time and fuel flow, the fuel used is now calculated.

Range for cruise at a given airspeed is determined in a very straightforward manner. Power is determined at the specified airspeed from appropriate parametric power required tables, for which fuel flow may now be determined using part power SFC data. Either time or distance may be specified and the other is calculated. The fuel used is simply the fuel flow times the time.

Cruise at airspeed for maximum range is similar to the preceding segment except that the airspeed is first determined by a procedure where specific air range is calculated over a range of airspeeds. Peak value is determined, and the corresponding airspeed is then compared to stall, transmission or power limited airspeed. The least of these becomes the cruise speed for maximum range and is used for subsequent calculations, as described above.

Range at maximum airspeed is specified for either intermediate or maximum continuous power rating. If intermediate power is specified, then the airspeed is defined as the dash airspeed. In either case, engine power available under the given atmospheric conditions is checked against transmission limit, and the smaller of these is used for airspeed determination. : airspeed is checked so that it does not exceed stall limit airspeed. Power, the fuel flow, and fuel load are calculated as described before.

For all of the range segments, the distance may be specified as the total required distance less distance covered during the preceding climb segment, if any. This accounts for these range or radius missions where mission profile requires "climb on course to cruise altitude...".

Loiter airspeed and power are determined from tables of performance at minimum power in forward flight. Determination of resulting fuel flow and fuel is straightforward.

Hover is determined using the parametric hover power equation. Fuel flow and fuel load determination is straightforward.

Reserve may be specified as a percentage of initial fuel or it may be specified as any other mission segment; i.e., a specified time or distance at some specified airspeed or power level. Most commonly used percentage is 10 percent.

Table II lists the primary mission (first point) definitions used in this study. The intention is to cover as many types of segments as possible and to specify representative missions.

PERFORMANCE RELATIONSHIPS

The performance and weight models consist of relationships to permit specified requirements to be combined with a given technology level to result in defining aircraft general characteristics. The requirements include ability to hover or to have a maximum speed capability, ability to fly specified mission profiles with a specified payload. Technology level is defined by characteristics of helicopter components that will be attainable at a given time, such as component weight/size relationships, engine SFC characteristics, aircraft drag, power-weight-speed relationships, etc. The application of the performance and weight models results in characteristics such as rotor dimensions, weight buildup and engine ratings.

TABLE II. PRIMARY MISSION DEFINITIONS

| | Pressure Altitude (ft) | OAT (°C) | TAS (kn) | Time (min) | Distance (n mi) | Change in Payload (lb) | Change in Drag (ft ²) |
|--------------------------------------|------------------------------|-------------|-------------|---------------|--------------------|---------------------------------|--|
| UTILITY - PL = 2640 lb | | | | | | | |
| Ground Operation | 4000 | 35 | 0 | 8 | 0 | | |
| V _{max} MCP | 4090 | 35 | | 20 | | | |
| Best Cruise Speed | 4000 | 35 | | 80 | | | |
| Reserve: Best Cruise | 4000 | 35 | | 30 | | | |
| GUN SHIP - PL = 2000 lb | | | | | | | |
| Cruise @ Given A/S | 4000 | 35 | 100 | 38 | | | |
| Hover | 4000 | 35 | 0 | 32 | 0 | | |
| V _{max} MCP | 4000 | 35 | | 8 | | -1540* | -5 |
| Cruise @ Best Cruise A/S | 4000 | 35 | | 6 | | | |
| Reserve: Cruise @ Best Cruise A/S | 4000 | 35 | | 30 | | | |
| CRANE - PL = 45,000 lb | | | | | | | |
| Ground Operation | 0 | 35 | 0 | 10 | 0 | | |
| T.O. Allowance (MCP) | 0 | 35 | 0 | 2 | 0 | | |
| Hover | 0 | 35 | 0 | 10 | 0 | | |
| Max. Range Cruise | 0 | 35 | | | 50 | | |
| Hover w/o Cargo | 0 | 35 | 0 | 10 | 0 | -45,000 | -100 |
| Max. Range Cruise | 0 | 35 | | | 50 | | |
| Reserve: Max. Range Cruise | 0 | 35 | | 30 | | | |
| OBSERVATION - PL = 300 lb | | | | | | | |
| T.O. Allowance (MCP) | SL | 15 | 0 | 3 | 0 | 0 | |
| Endurance (Loiter) | SL | 15 | | 180 | | 0 | |
| Reserve - 10% of Initial Fuel | | | | | | | |
| TRANSPORT - PL = 25,000 lb | | | | | | | |
| T.O. Allowance (MCP) | SL | 15 | 0 | 3 | 0 | 0 | |
| Climb | | | | | | | |
| Cruise (MCP) (Descend) | 7000 | 1 | | | 100 | | |
| Ground Operation | SL | 15 | 0 | 5 | 0 | -25,000 | |
| Climb | | | | | | | |
| Cruise (Best Range) | 7000 | 1 | | | 100 | | |
| Reserve - 10% of Initial Fuel | | | | | | | |
| * Expendable Ordnance | | | | | | | |

In this section, performance related technology levels will be discussed. It should be noted that in some cases the values chosen only serve as samples to illustrate the methodology for determining an optimum two-point design and do not necessarily represent the actual values.

Engine Performance

The performance of a "rubberized" turboshaft engine is characterized by how power available varies with atmospheric conditions and how specific fuel consumption is related to rated power and to part power condition.

Turboshaft engine rated power available varies with temperature, altitude and forward speed. The last effect, ram, is ignored as negligible for the relatively low-speed regime of helicopters treated in this study. The effect of atmospheric condition was determined empirically from current engine data as:

$$PA/PRA = PR[1 - 2.08(TR - 1)]$$

where PRA is the highest power rating given at 15°C, SL and $V = 0$, which in this study was equated to the 30-minute, intermediate power rating. Similarly, the ratio of maximum continuous power to the highest engine rating was determined empirically from current engine data resulting in:

$$P/PA = RA = .9$$

In this study the fuel consumption rate is determined for the specified power level using the "rubberized" SFC versus power curve keyed to an SFC at rated power. The SFC at rated power may vary from .55 to .7 for current engines for .36 to .49 for 1980's engines. This data is presented in Figure 2.

For this study the current engine technology data was put into an equation form as:

$$SFO = 1.136(PRA/NEN)^{-.105}$$

where NEN is the number of engines. Thus, PRA/NEN is the rating of one engine. SFO applies to the highest power rating at SL, 15°C, $V = 0$.

For advanced engines for 1980 and beyond, a 20-percent reduction of SFL is projected.

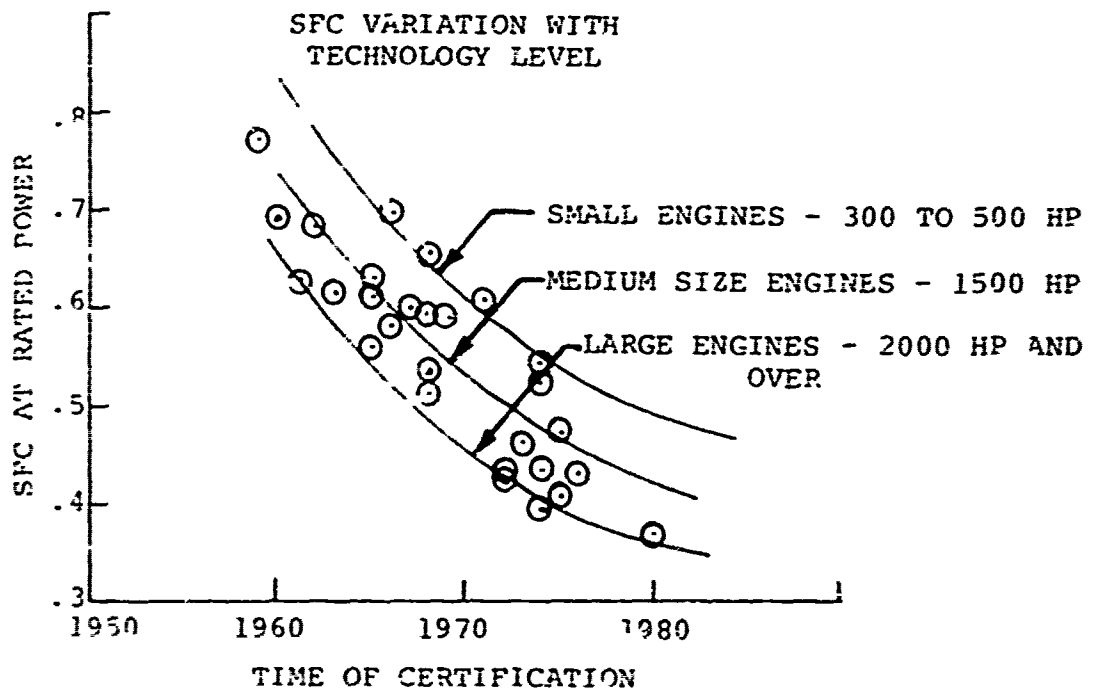


Figure 2. SFC Data Compiled for Aircraft Sizing Studies.

The SFC at rated power is determined by technology level, engine size, tradeoffs of engine simplicity versus engine efficiency, and development history of the engine. The smaller engines have higher SFC than bigger engines because bigger engines can be designed with lower percentage losses. Simplicity, such as the use of a fixed shaft, is achieved at the expense of efficiency. During the development cycle of an engine, SFC usually improves; however, growth usually occurs to obtain more power within a given engine size envelope, and SFC improvement is considered of secondary importance.

The technology level is identified mainly by turbine inlet temperatures used and pressure ratios employed. These factors seem to go up hand in hand and result in lower SFC's and lower engine specific weight. The temperatures with current values from 1600° to 2000°F will increase to 2400°F in the 1980-1990 period requiring advanced materials and turbine cooling in various degrees. Pressure ratios similarly will increase from the current 6:1 to 14:1 range to up to 20:1.

In treating engine statistical data, the rated power was selected as the highest thermodynamic, i.e., turbine inlet temperature limited, rating given, excluding any "emergency" ratings. Any derating due to gearbox limits was ignored. The highest, i.e., T.O. or maximum (10 minutes), ratings were used, if given, instead of the 30-minute limits, assuming that the time ratings only express limits imposed to achieve certain TBO. In effect, it was assumed that given engine would have the same SFC at the highest rating regardless whether it is a 5-, 10-, or 30-minute rating.

For fuel consumption determination at part power operation, the SFC versus referred power was "rubberized" by generalizing it in terms of SFC and power at rated conditions, i.e., SFO and PRA resulting in SFC/SFO versus PRF/PRA. From the study, two shapes appeared as shown in Figure 3. The flatter of the two curves appeared associated with some of the proposed (mostly paper) engines, indicating a possible new trend in turbine design optimization in which the engine manufacturer's seem to take into account the fact that a good portion of the time engines are operated at part power and that it is here where low SFC's pay off. However, it has been noted that some prototype engines, which were initially designed to have this flat trend, seem to have moved back toward the current trend, throwing some question as to the achievability (or the will to achieve) of the projected flat trends. Either curve may be used to determine SFC at any power level once rated power and the corresponding SFC have been selected.

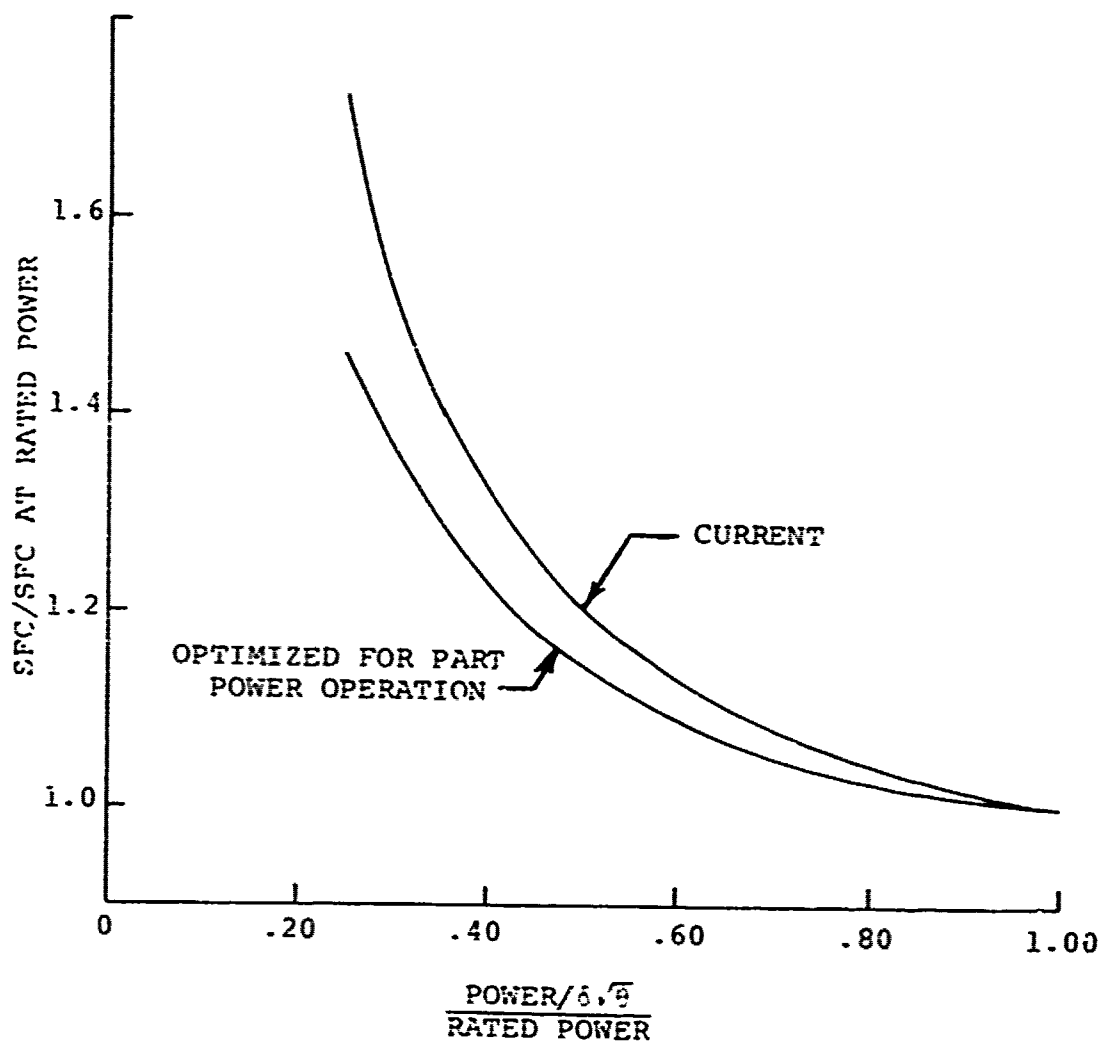


Figure 3. SFC Variation at Part Power.

The ram effect due to forward flight reduces the SFC slightly. Due to the relatively low forward speed of the helicopters studied, the ram may be ignored. The expression by which fuel consumption can be calculated is then:

$$W_{FL} = (P) (SFC) (SSF) KFF$$

where P is the given power at the desired airspeed, SFC is the SFC at rated power determined as a function of technology level and engine size, SSF is the SFC increase factor for part power operation determined as a function of PRF/PRA and KFF is any loss or allowance factor applied. Since in this study relative fuel loads are sought, application of a loss or allowance would not affect the conclusions of the study, and thus, for simplicity, none are applied.

Hover and Vertical Flight

A substantial body of statistics exists for various helicopters which establish a power required. Blockage losses, drive system losses, tail rotor and accessories power were not extracted from the statistics. Thus, the variables are gross weight and (total) power at the engine output shaft. Data form is GW/SHP vs DL/DR as is shown in Figure 4.

This is consistent with the traditional $C_D/\rho = f(C_T/\rho, \dots)$ presentation if the latter is expanded for a specified R and DL. The curve may be expressed in equation form as $SHP = (.051) (GW) (DL/DR)^{.41}$ at a specified rate, VRC.

Power to climb without forward speed can be calculated as power required to hover OGE plus an increment for the potential energy change. Assuming a climb efficiency of 1.25 results in a hover power adjustment as:

$$\Delta SHP = (VRC) (GW) / (33000) (1.25) = .00002424 (VRC) (GW)$$

If it should be desirable to size the engine or transmission to meet a given vertical rate of climb requirement with a specified margin of power, then the above may be combined to result in:

$$SHP = [(.051) (GW) (DL/DR)^{.41} + \Delta SHP] / (1 - PM/100)$$

where PM is the desired power margin in percent.

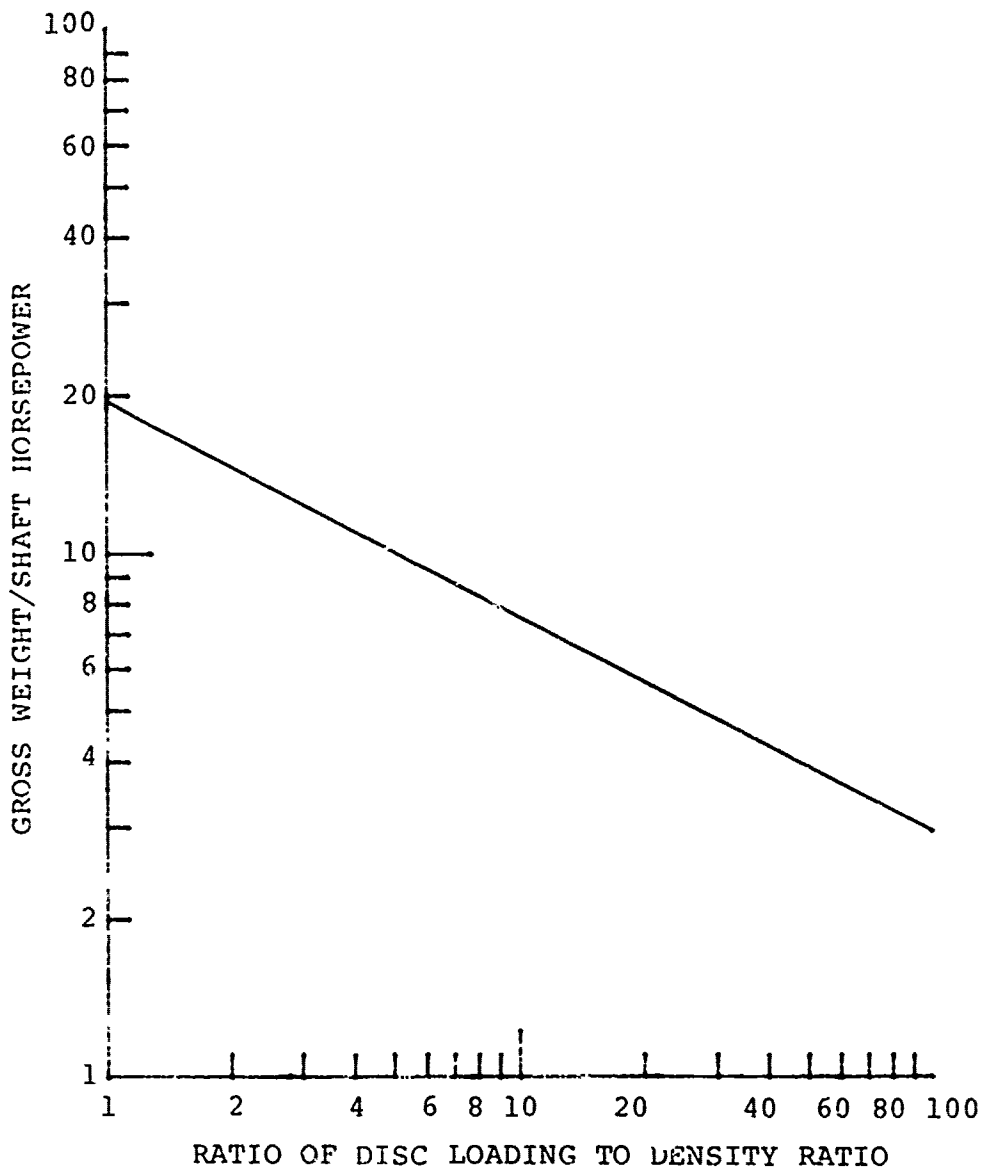


Figure 4. Empirical OGE Hover Power Required.

Speed-Power

The aircraft speed-power-weight-drag relationship is a function of rotor characteristics, such as airfoil sections used, taper, twist, disc and blade loadings (and thus solidity), tip speed schedule (and thus tip Mach number), etc.

For this study, data were generated for the following characteristics:

| | |
|-------------------|-----------------------|
| Airfoil: | NACA 23012 (constant) |
| Number of Blades: | 4 |
| Solidity, S | 0.1 |
| Tip Speed | 700 fps (constant) |
| Taper | None |

The airfoil selected is for a current state-of-the-art airfoil with good stall characteristics. The drag-lift characteristics are well established throughout the Mach number range. The other listed characteristics were chosen as typical for helicopters currently in use or in development. The data were obtained by a standard rotor performance program involving an iterative numerical solution of the blade flapping equations of motion.

The results are used in the model in a parametric form as illustrated in Figures 5-8. Data are entered into the program in two ways to allow determination of airspeed for a given power and determination of power at a given airspeed.

$$TAS = f(DLN, POW, FOW)$$

$$POW = \bar{f}(DLN, TAS, FOW)$$

These tables apply for speeds above speed for minimum power with accuracy improving as speed is increasing. Accuracy of the tables reduces at reduced airspeeds due to the shallowness of the slope of power vs airspeed. For this reason, separate data, as shown in Figure 9, are entered for speeds for minimum power to accommodate performance related to this speed such as loiter and maximum rate of climb. This data again are in two forms:

$$TAS = f(DLN, FOW)$$

$$MRHP = f(DLN, FOW)$$

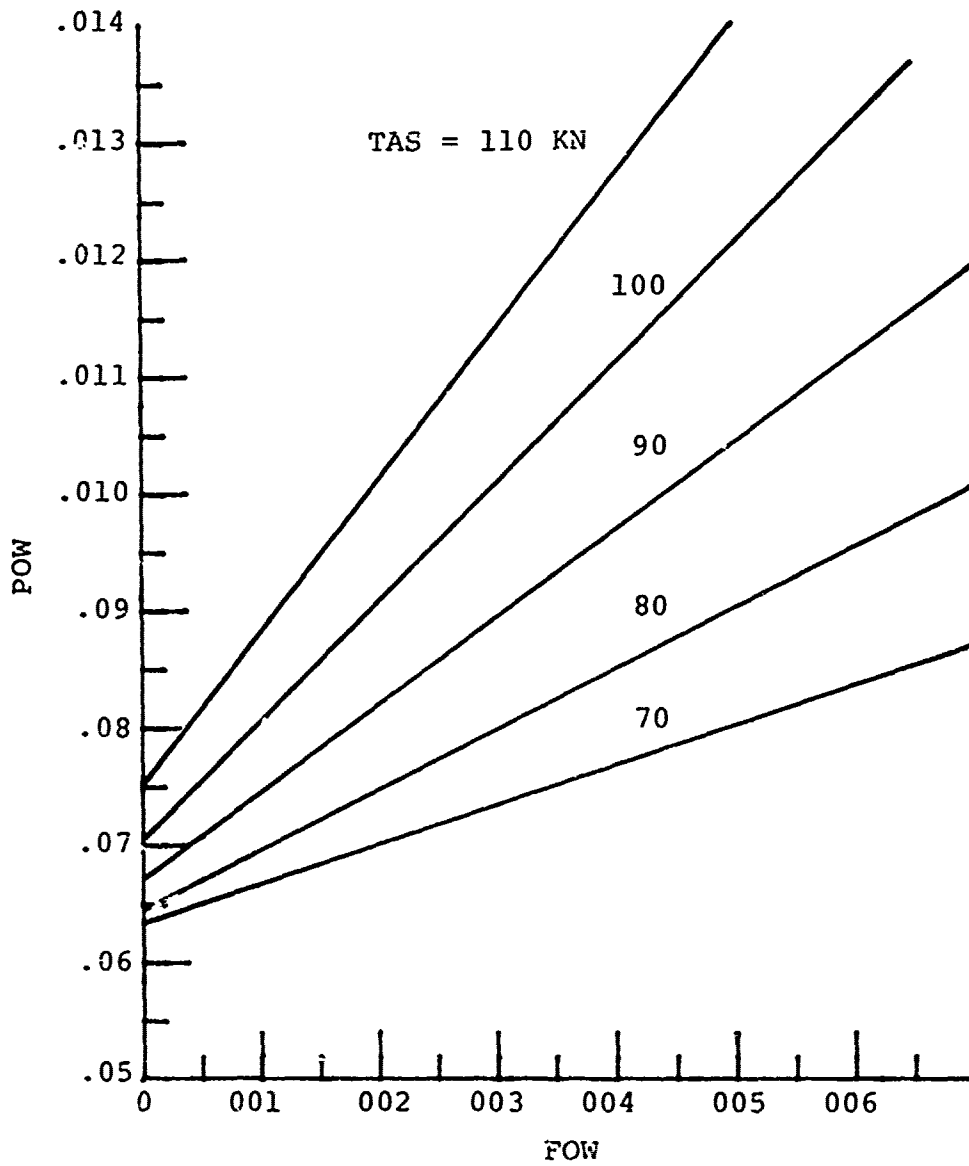


Figure 5. Speed-Power-Weight-Drag Relationship for $DLN = 4$, $S = .1$.

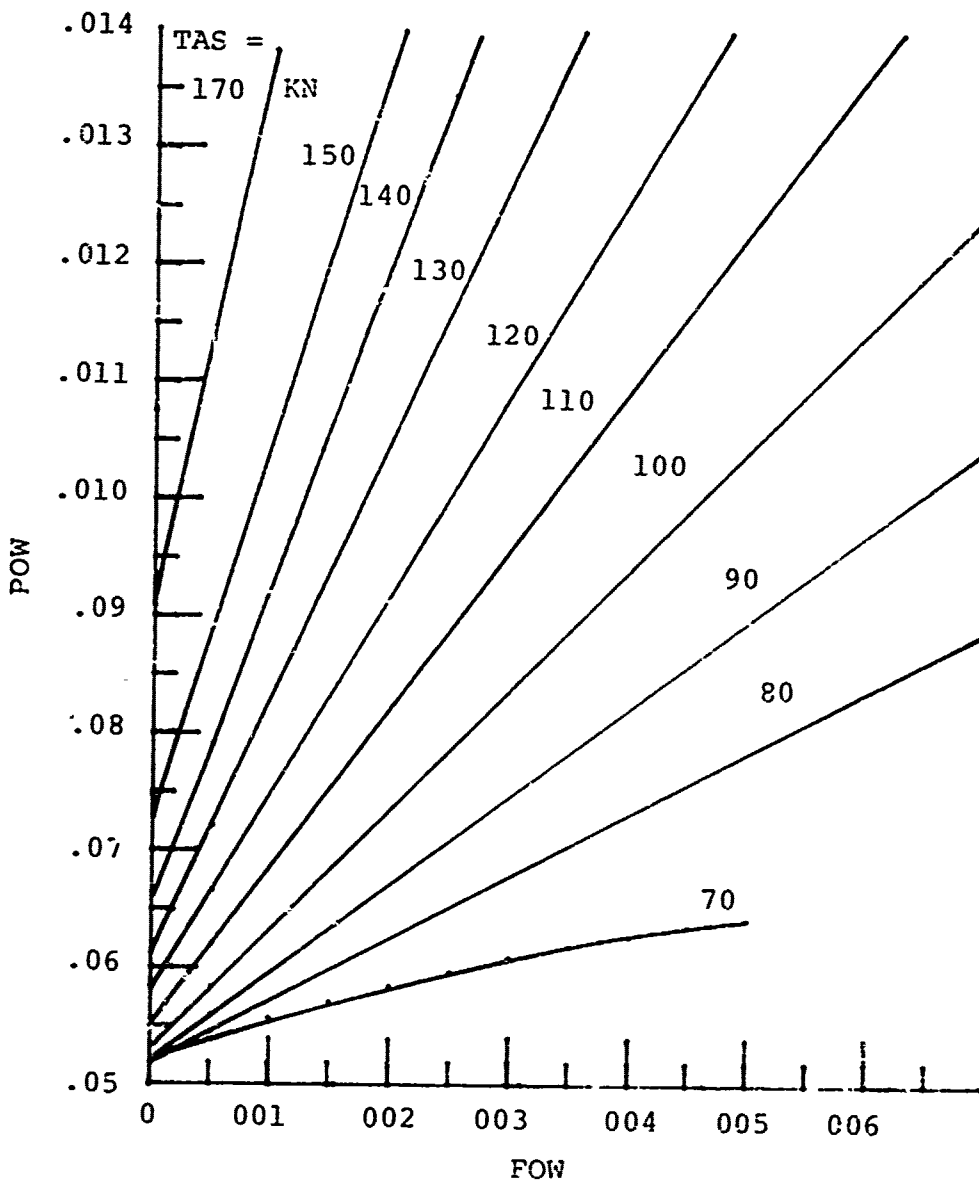


Figure 6. Speed-Power-Weight-Drag Relationship for $DLN = 6$, $S = .1$.

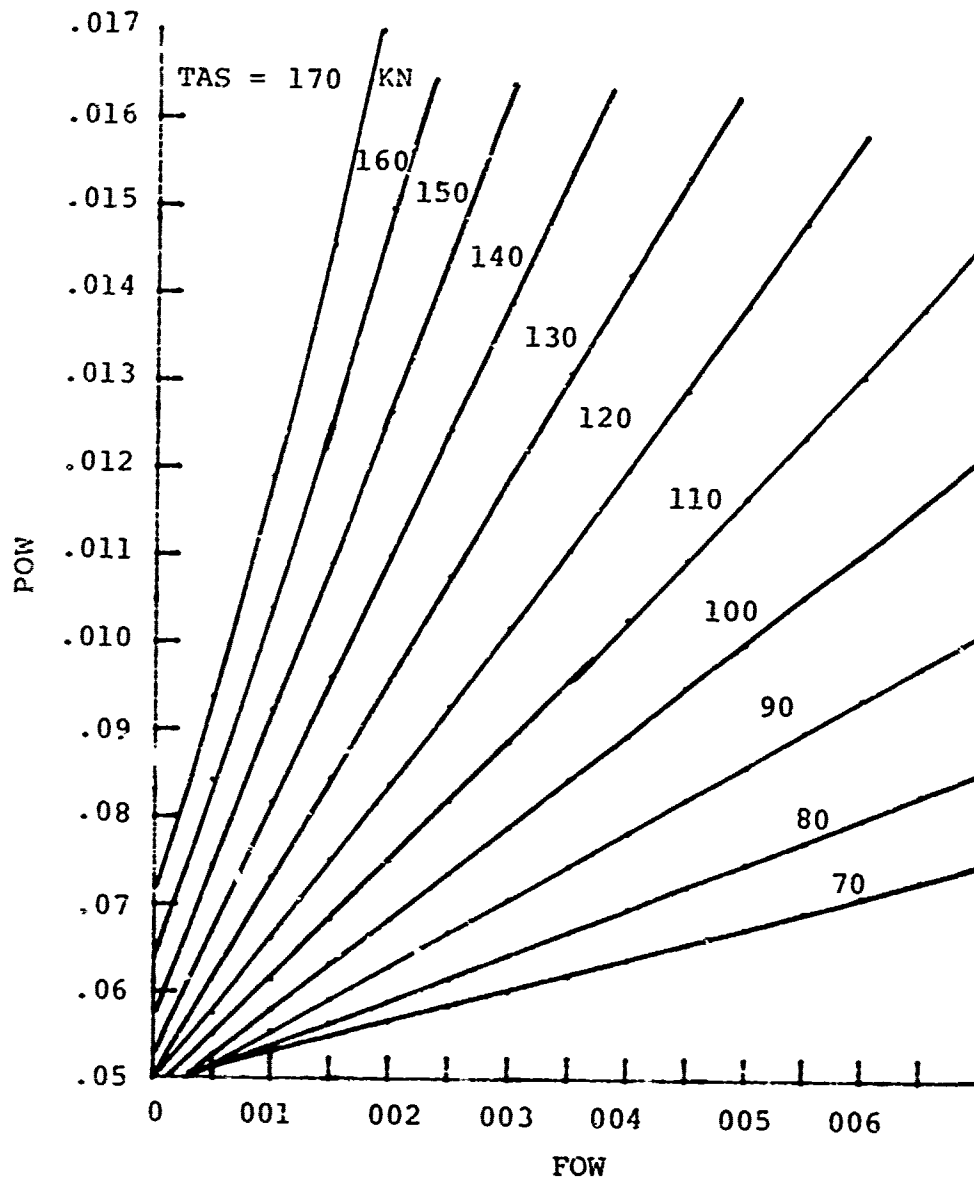


Figure 7. Speed-Power-Weight-Drag Relationship for DLN = 8, S = .1.

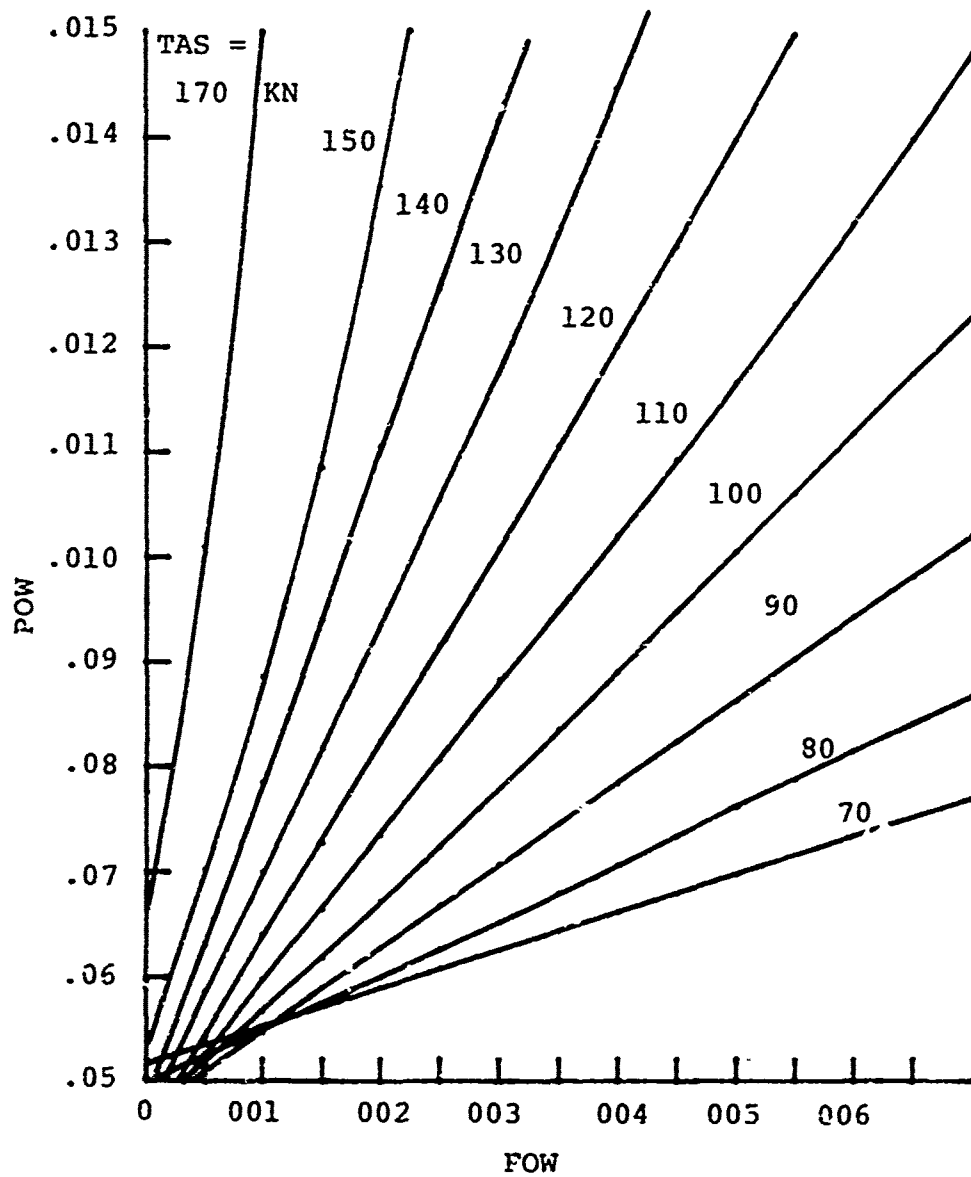


Figure 8. Speed-Power-Weight-Drag Relationship for $DLN = 10$, $S = .i$.

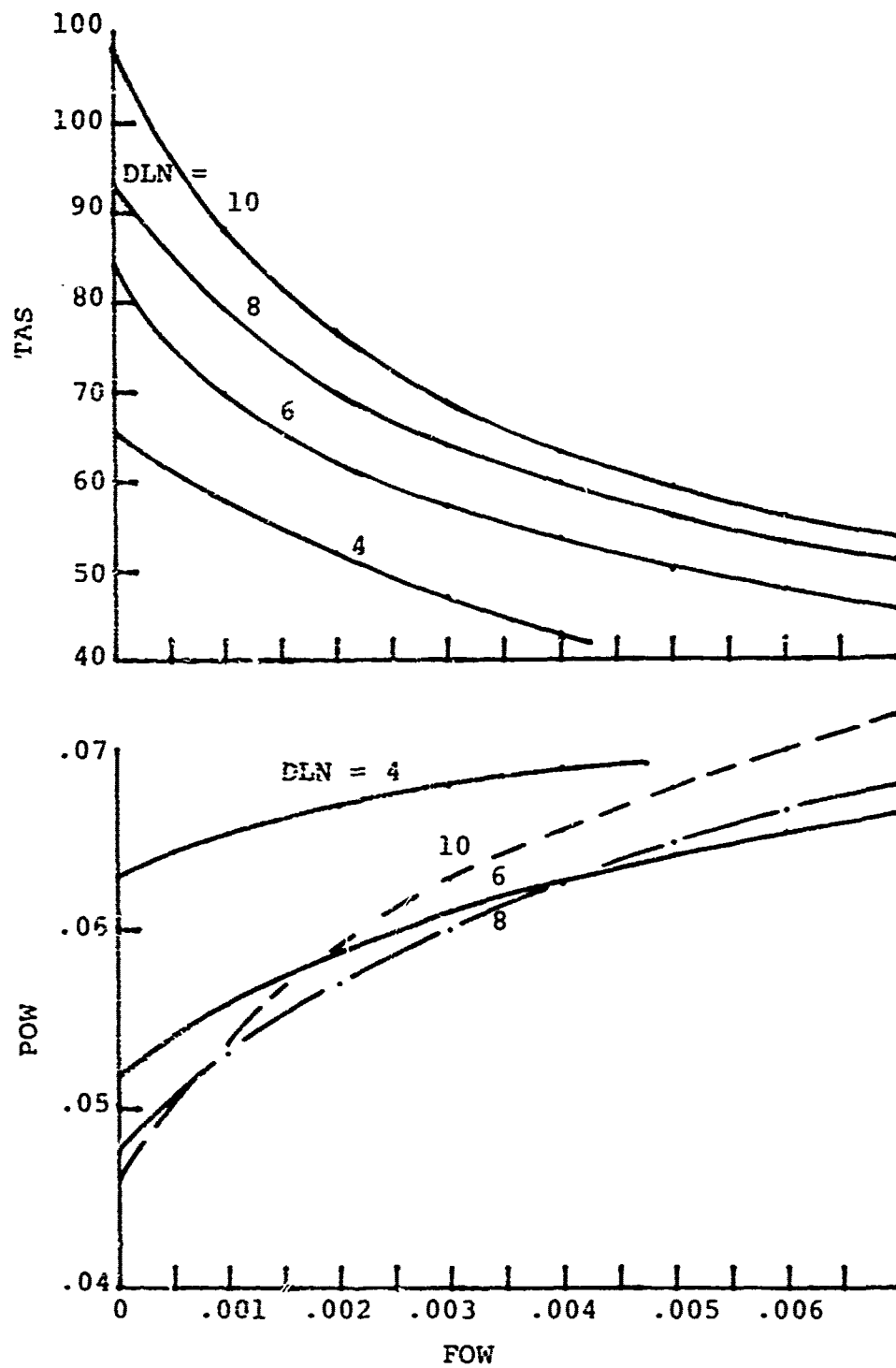


Figure 9. Minimum Power in Forward Flight and Corresponding Airspeed.

The parametric form used in the table is the result of determining the most meaningful way of presenting the power-speed-lift-drag relationship for a given rotor geometry. The early forms of $C_p - C_T - \mu$ types of presentation have lost some of their usefulness ever since Mach number effects have been taken into account. The form used, however, is consistent with $C_p/\sigma - C_x/\sigma - C_L/\sigma - V/\Omega R - \sigma - M$ relationship and has the advantage over the latter that it is closer to the dimensional form. In this semi-dimensional form, rapid comparisons can be made of data used with other estimates or test data and corrections made incrementally or percentage-wise as desired.

The relationship between the traditional coefficient type formulation and the used semi-dimensional form is illustrated by the following. C_p/σ is defined when C_x/σ , C_L/σ , σ , $V/\Omega R$ and M are given.

There is no increase in number of variables to define a condition if instead of $V/\Omega R$ and M , one would specify V and ΩR and assume a nominal speed of sound to relate these as

$$\Omega R = Mc / (1 + V/\Omega R)$$

$$V = (V/\Omega R) \Omega R$$

The remaining coefficients can be rewritten as:

$$POW = \frac{(C_p/\sigma) A \sigma \rho (\Omega R)^3 / 550}{(C_L/\sigma) A \sigma \rho (R)^2} = \frac{C_p/\sigma}{C_L/\sigma} \frac{\Omega R}{550}$$

$$q = .5 \rho V^2 = .5 (DR) \rho_0 (V/\Omega R)^2 (\Omega R)^2$$

$$FOW = \frac{F_x (DR)}{GWq} = \frac{(C_x/\sigma) A \sigma \rho (\Omega R)^2 (DR)}{(C_L/\sigma) A \sigma \rho (\Omega R)^2 \cdot .5 (DR) \rho_0 (V/\Omega R)^2 (\Omega R)^2}$$

$$= \frac{C_x/\sigma}{C_L/\sigma \cdot .5 \rho_0 (V/\Omega R)^2 (\Omega R)^2}$$

$$DLN = \frac{GW}{(A) (DR)} = \frac{(C_L/\sigma) A \sigma \rho_0 (R)^2}{(A) (DR)} = (C_L/\sigma) \cdot \rho_0 (R)^2$$

In the above, the use of a nominal speed of sound may, for some off-design condition, introduce a small error. With a 20°C change in the temperature, a 3-1/2-percent error in resulting Mach number is introduced. This, however, should be an acceptable penalty for a study such as this, and thus the data presented is generated for C = 1117 fps only.

Variation of solidity does not require separate charts but can be accommodated similarly to Reference 1. This reference substantiates the equivalence of a drag change to inflow change resulting from a solidity change. In this study the data was compiled for S = .1; performance for any other S can be obtained by entering the data with an adjusted equivalent flat plate drag area:

$$F = F_{\text{actual}} + \frac{(GW)(BL)(S - .1)}{4q^2}$$

The adjusted F is now used to calculate FOW as before. POW is determined from the data at the desired normalized blade loading BLN. The chart values in the presentation of this report must be used as DLN/S. For example, values shown for DLN = 6 lb/ft² and S = .1 are really for a BLN = 6/.1 = 60 lb/ft².

The tip speed in this study was chosen as 700 fps representing the current state-of-art average. The outcome of this study will not be significantly different if run at any other tip speed. However, if it should be desired to repeat the study for any other tip speed, new power required must be calculated. From this, either a new data table must be generated or a suitable adjustment found for the existing data.

Geometry of the rotor blade naturally affects the power levels and is an inherent part of any performance presentation. The characteristics used here, such as airfoil and twist, are current technology and should yield representative results. However, as in the case of tip speed, should it be desired to investigate some different geometry, then corresponding power data must be calculated, from which a new table can be generated or a suitable adjustment found for the data now used.

The tables yield main rotor power. To obtain total power, i.e., power at the engine output, a factor was determined which includes the effects of tail rotor power, accessories power, and drive system losses. The factor applies only to forward flight and is:

$$MRHP/SHP = KPP = .9174$$

Stall

The ultimate limiting factor on airspeed is stall of the retreating blade. For the purposes of this study, the stall boundary was determined consistent with the data generated for forward flight. Thus, they contain the same assumptions as the power required. Stall was defined at the airspeed when the angle of attack reached 12 degrees at the outboard section of the blade. The angle was found to be just below the stall caused break in power vs lift curves. The data is shown in Figure 10. The data are entered into the program in the form of an equation:

$$TAS = 70 + 15.7(15 - DLN)/(1000 FOW) \cdot 2598$$

For operational use, helicopter maximum airspeeds are limited to airspeeds below stall. The margin, SM, specified for this study is 10 knots.

Drag

Drag of aircraft is most conveniently represented as a function of gross weight to the two-thirds power, a relationship which assumes that a characteristic dimension exists which, when cubed, gives a volume proportional to gross weight, and when squared, gives an area proportional to the equivalent flat plate drag area. Statistics from various current and projected helicopters have led to the trends shown on Figure 11.

The statistical drag data is treated as a function of maximum gross weight of the helicopter. There is no assurance that helicopter cargo spaces are designed to carry the maximum structural weight limited payload. In fact, for many helicopters the maximum gross weight has grown by a third, without a corresponding increase in cargo space. However, since the cargo-containing fuselage, as a rule, makes up less than a quarter of the total drag, the cargo space is not a significant factor. It was felt that the total drag is more related to the maximum gross weight of the aircraft which dictates rotor size so that gross weight adequately represents the aircraft. In the case of helicopters with considerable development and growth behind them, the latest gross weight was used for correlation purposes. Then, helicopters at their maximum GW exhibit higher disc loadings than originally designed for. Thus, the statistics reflect the tendency for new aircraft to be designed for higher disc and power loadings.

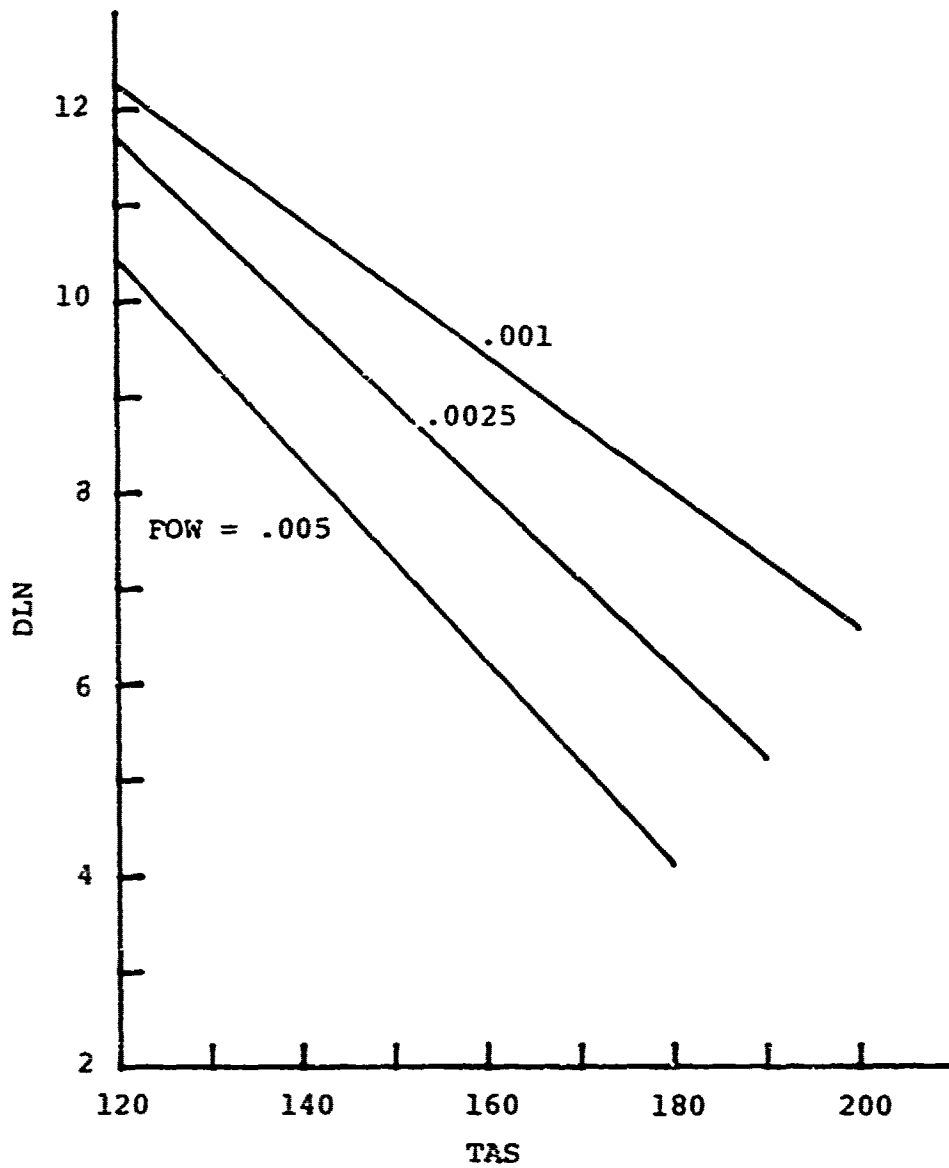


Figure 10. Stall Boundary as a Function of Disc Loading, Airspeed, and Drag.

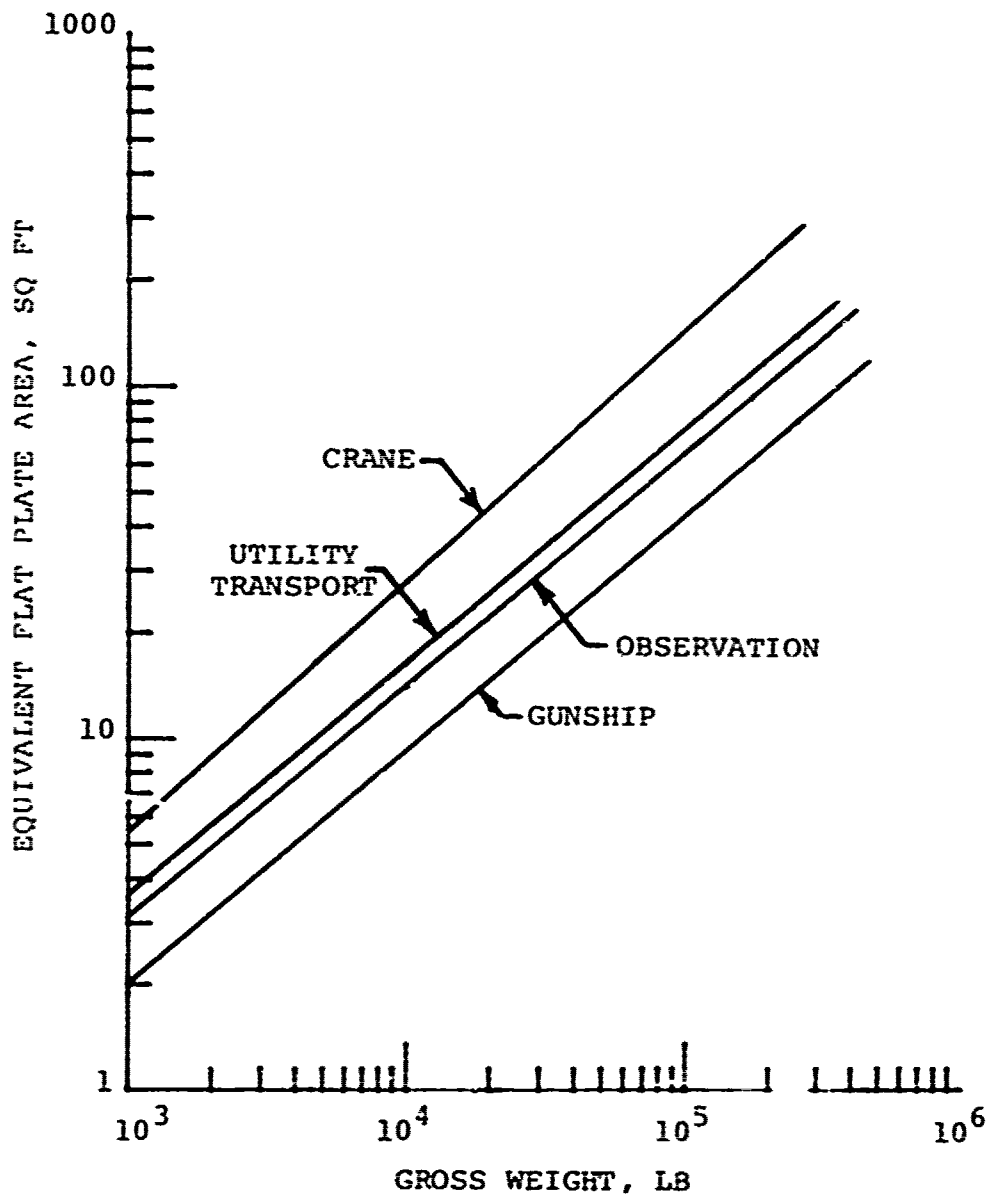


Figure 11. Drag Trends for Different Types of Helicopters.

Depending on the type of helicopter, the loading density varies and thus the volume-gross weight relationship. Therefore, different fairings were drawn for the various types of helicopters.

These expressions cover only the basic aircraft without external stores or cargo. These items have a characteristic of themselves and are treated as an add-on to the basic drag. In this study, it is assumed that all fuel is carried internally, i.e., no external fuel tanks are used. Furthermore, it is assumed that no external stores are carried by the observation-utility-transport categories of aircraft. The weapons drag of the gunship is assumed at an equivalent flat plate drag area of 5 ft², and the cargo drag area for cranes is assumed to be 100 ft². If desired by the user of the program, these add-ons can also be rubberized by use of suitable statistics.

The above resulted in the following relationships to be used in this study.

| | |
|--------------------|----------------------------------|
| Utility, transport | $f = .035 \text{ GW}^{2/3}$ |
| Observation | $f = .03 \text{ GW}^{2/3}$ |
| Gunship | $f = .02 \text{ GW}^{2/3} + 5$ |
| Crane | $f = .07 \text{ GW}^{2/3} + 100$ |

STATISTICAL WEIGHTS

The statistical weight model used for the estimation of conventional (single point) designs was developed to represent the five types of helicopters under consideration and to use relatively limited data such as would be available during a typical predesign situation. This model is a further development of that given and fully documented in Reference 2. The statistical trends were based on analyses of the following helicopters:

| | |
|--------|---------|
| CH-3C | HH-2D |
| CH-34 | HH-52 |
| CH-37 | UH-2A/B |
| CH-53A | UH-19 |
| SH-3A | UH-1B |
| S-52 | UH-1D |
| S-61 | UH-1N |

The equations are listed in the STAT WEIGHT module and are not repeated here. There are three types of data used in the parametric equations, as follows:

Basic Input Data - These data either define characteristics of the vehicle or are a result of performance calculations. Examples are: Number of engines and rotor radius. The required input data are listed in Table III.

Intermediate Data - Actual values may be used if known from design definition. If an actual value is not available, an intermediate data value can be calculated using input data and the appropriate equations. An example is Tail Rotor Radius. If not known from design definition, the tail rotor radius (in feet) is estimated, using input data only, by $.087 (\text{rotor radius})^{1.22}$.

Calculated Weight Data - The weight calculated by a weight equation is used in a subsequent weight equation. An example is Blade Weight, which is subsequently used to calculate Hub Weight.

ANALYTICAL WEIGHTS

The statistical weight model is appropriate for the single-point baseline vehicle. The modifications resulting from the additional design point will result in changes in the structure, drive system, and rotor. These changes are due to the changes in gross weight and engine and rotor torque. The other major elements (engine, fuel system, and fixed weights) of the vehicle are assumed to change only insignificantly since the basic mission is unchanged.

Structure

The various elements of the structure of a typical helicopter were examined from the point of view of whether the weight of the element was significant and what kinds of loads were the major design consideration. It is assumed that limit load factors, sink speed, and crash criteria are not changed with the changes in gross weight due to the second design point criteria.

The elements of the structure considered include the forward fuselage, center fuselage, tail cone, vertical tail (tail rotor pylon), horizontal tail, landing gear, engine and transmission mounts and carry through structure. In general, the items which contribute significant weight can be lumped together as the fuselage and tail and the landing gear. Some of the components are designed by steady flight loads, some by vibratory loads, some by landing loads, some by cargo loads, etc. The steady loads can be expected to be proportional to the gross weight. Landing loads also are proportional to gross weight. The vibratory loads are the

TABLE III. INPUT DATA FOR PARAMETRIC WEIGHT ANALYSIS

| Symbol | Data |
|--------|--|
| AG | = Number of Auxiliary Landing Gears |
| BF | = Blade Folding Option (= 1 if used, = 0 otherwise) |
| BRK | = Main Rotor Brake Option (= 1 if used, = 0 otherwise) |
| CAP | = Gallons of Fuel - Gal. |
| CB | = Blade Chord - Feet |
| EDS | = Engine Drive Shaft Option (= 1 if used, = 0 otherwise) |
| EN | = Number of Engines |
| HP1 | = Rotor Horsepower - hp |
| HP2 | = Installed Horsepower - hp |
| ITR | = Intermediate Tail Rotor Gearbox Option (= 1 if used, = 0 otherwise) |
| KLG | = Landing Gear Geometry - Values/Configuration .0157 - Skid Gear .0247 - Sponson Mounted .0280 - Quadricycle .0329 - Tricycle - Fuselage Mounted .0405 - Crane - Straddle Type |
| KNAC | = Nacelle Arrangement - Values/Configuration .96 - Twin Engines Mounted to Transmission Forward or Aft of Main Rotor 1.19 - Single Engine Mounted to Fuselage Forward or Aft of Main Rotor 1.23 - Twin Engines With Combining Gearbox 2.26 - Twin Engines Outboard of Main Fuselage Add Factors for More Than Two Engines |
| MOW | = Maximum Operating Weight - Lb |
| NMR | = Number of Main Rotor Blades |

TABLE III - Continued

| Symbol | Data |
|--------|--|
| NR | = Number of Main Rotors |
| NULT | = Ultimate Load Factor |
| P | = Number of Passengers |
| RM | = Main Rotor Radius - Feet |
| S | = Main Rotor Solidity |
| TAF | = Type of Aft Fuselage - Values/Configuration 8 - Full Fuselage Depth at Splice of Main Fuselage to Aft Fuselage. Example: SH3A 9 - Tailboom Configured for Rear Ramp. Example: CH53 10 - Tailboom Without Rear Ramp. Example: UH19 13 - Full Fuselage Depth at Splice of Main Fuselage to Aft Fuselage and With a Tail Wheel Full Aft. Example: HH2D 15 - Tailcone Upswept From Fuselage Splice. Example: UH1D |
| SW | = Total Wing Area |
| TAG | = Type of Auxiliary Gear - Values/Configuration 0 - Observation 0 - Gunship 1.0 - Utility 2.5 - Transport 15.5 - Crane |
| TAR | = Armament Provision and Plating - Values/Configuration 600 - Gunship (0 otherwise) |
| TEL | = Type of Electronics - Values/Configuration (Depends on A/C Designation) .42 - Observation .75 - Crane 1.00 - Utility 1.16 - Transport 1.25 - Gunship |

TABLE III - Continued

| Symbol | Data |
|--------|---|
| TPU = | Auxiliary Power Unit Option (= 1 if used, 0 otherwise) |
| TPY = | Type of Pylon Configuration - Values/Configuration (Depends on Type of Aft Fuselage) |
| | 14 - Tailcone Upswept From Fuselage Splice. Example: UH1D |
| | 25 - Tailboom Without Rear Ramp. Example: UH19 |
| | 45 - Tailboom Configured for Rear Ramp. Example: CH53 |
| | 48 - Full Fuselage Depth at Splice of Main Fuselage to Aft Fuselage. Example: SH3A |
| | 62 - Full Fuselage Depth at Splice of Main Fuselage to Aft Fuselage and With a Tail Wheel Full Aft. Example: HH2D |
| VM = | Main Rotor Tip Speed - FPS |
| WPL = | Desired Weight of Payload |

most difficult to generalize upon. The transition flight regime is when the highest vibratory loads can be usually expected. Experience indicates that the vibratory loads are proportional to GW, increasing by about 4 to 8 times the ratio of delta GW to GW.

Simple models of typical structures have indicated that the weight of the structure will be approximately proportional to ratios of the design loads. This is, of course, most true when relatively small changes are considered.

The types of loads which design the separate components will vary between types of helicopters and even between different helicopters of the same type. Some elements are not strictly designed by loads, for example, by the use of minimum gage skins and landing gear mechanisms.

Because of the great uncertainty in generalizing the structural weight changes a simple but reasonable approximation is made in the model used in this study. It is assumed that the change in weight of the fuselage, tail, and landing gear of the second design point vehicle is directly proportional to the change in gross weight from the first point design. Typically, the structure involved here represents about 10 percent of the gross weight, and a 50-percent increase in gross weight will result in a structural weight increase of about 5 percent of the gross weight.

The computer program allows easy modification of this approximation when it is considered necessary and when specific aircraft are being studied.

Drive System

The methods developed in Reference 2 were used to determine the rate-of-weight change with torque for the main transmission. The analysis includes the optimized weights of shafts, bearings, case, and all gears. For this study, the following gross weight helicopters were studied: 3000, 15,000, 25,000, 100,000, 200,000. These are considered typical of observation, utility, gunship, cargo, and crane helicopters.

Figure 12 illustrates the results of the analysis. While the data has been specifically obtained for the main transmission, the percentage change is assumed to apply to the entire drive system.

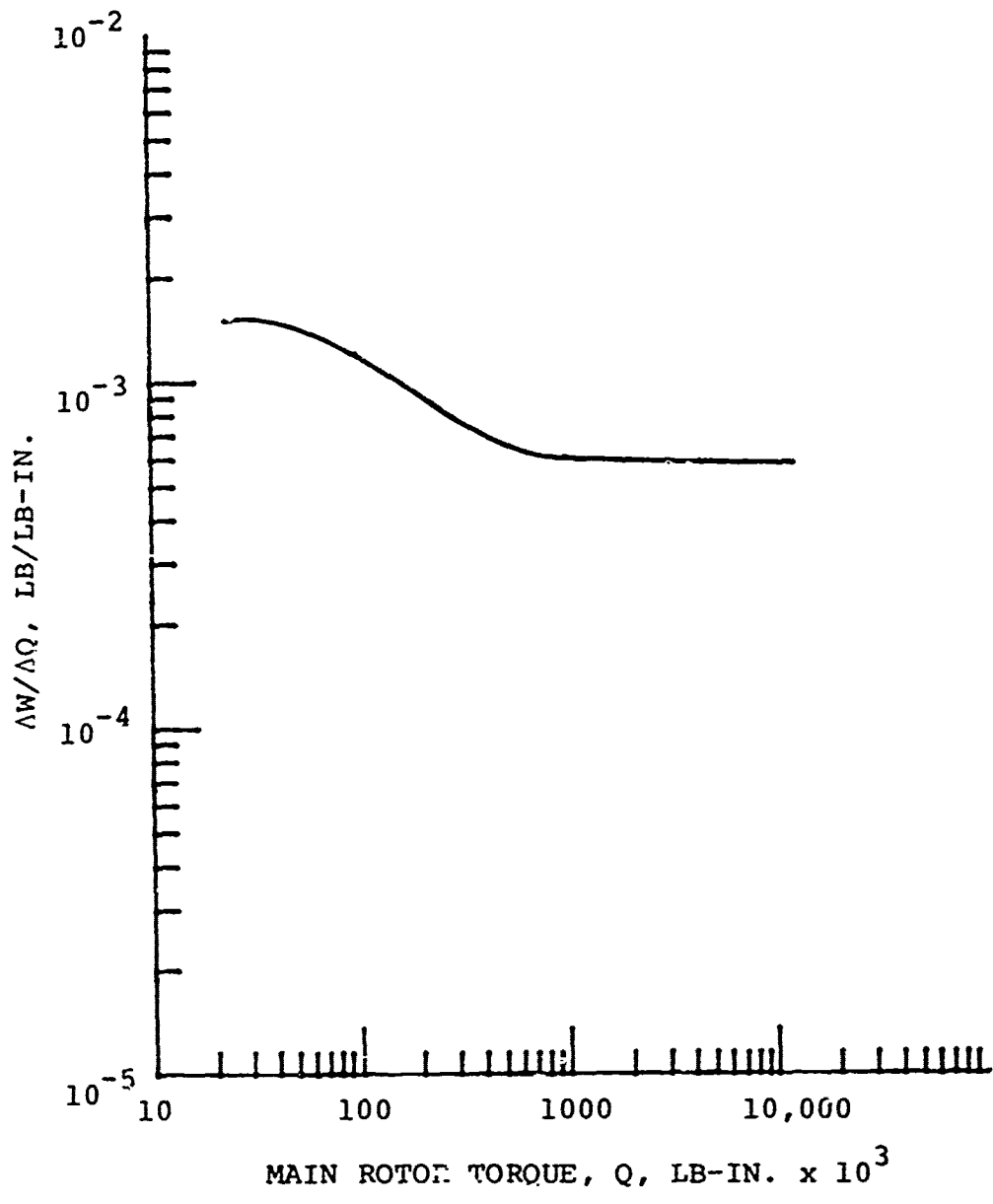


Figure 12. Main Transmission, Rate of Change of Weight Per Unit Change in Torque.

Rotor

The relationship between rotor torque and weight-change-with torque is determined. To facilitate this, it was decided to limit the study to the components which are more directly related to the imposed loads. These consist of the blades and the hub. The retentions, controls, bearings, etc., can be idealized structurally; however, because these items have so many mechanical configurations, the calculated component weights would vary directly from actual cases. It is assumed that the weights of these items vary identically as the analytically determined blades and hub.

The approach used here is as follows.

1. Assemble data providing design parameters (disc loading, tip speed, etc.) for various gross weight helicopters. Fit equations to these data.
2. Choose materials and appropriate working properties.
3. Define configuration to be modeled. Write equations defining structure.
4. Define load conditions.
5. Determine minimum weight configuration for each point chosen for analysis.
6. For each point, increase and decrease gross weight by five percent and determine optimum weights for each new point.
7. Analyze the hub in a similar manner.

Design Equations - The design equations were derived from the data of Table IV which is considered to be typical of the five types of helicopters.

TABLE IV. TYPICAL PARAMETERS

| Category | Observ | Utility | Gunship | Transport | Crane |
|------------------|--------|---------|---------|-----------|---------|
| Nominal G.W. | 3000 | 15,000 | 15,000 | 70,000 | 150,000 |
| Rotor | | | | | |
| Disc Loading | 4 | 8 | 9 | 9 | 9 |
| Tip Speed | 650 | 700 | 700 | 700 | 750 |
| Solidity | .05 | .1 | .1 | .1125 | .1 |
| Blade Loading | 80 | 80 | 90 | 80 | 90 |
| Number of Blades | 4 | 4 | 4 | 5 | 6 |
| Aspect Ratio | 25.4 | 12.7 | 12.7 | 14.14 | 19.1 |

From the foregoing data, the following equations are derived for rotor blades.

$$R = .564 (GW/DL)^{.5}$$

$$CB = R/AR$$

$$DL = 9.27515 - 15680.1/GW$$

$$QMR = .58296 (GW)^{3/2} / (DL)^{1/2}$$

$$\sigma = 11948 (DL/GW)^{.5}$$

Materials - Blade section materials were chosen as given in Table V.

Configuration - A typical configuration was selected as follows:

- (a) Symmetrical Airfoil 00 Series
- (b) Mass Balanced Blade at 1/4 Chord
- (c) Inboard Extension of Mass Balance to be a Variable
- (d) Thickness Ratio = .12
- (e) Trailing Edge Cap Length = .05 CB
- (f) Spar Wall = .08 x .12 CB = .0096 CB
- (g) Spar Width "x" is Variable

TABLE V. BLADE MATERIALS

| Element | Material | Lb-In. ³ Density | Design Static Strength | Design Fatigue Strength | Comments |
|--------------|-----------|--------------------------------|------------------------------|-------------------------------|----------------------|
| Spar | 2014 Al | .101 | 68,000 | 6000 | Structural Member |
| Mass Balance | Lead | .4 | - | - | - |
| Spline Cap | Al | .101 | - | - | - |
| TE Cap | Al | .101 | - | - | - |
| Spline | Honeycomb | .0018 | - | - | - |
| Bond | Glue | .0745 (Lb-Ft ²) | - | - | - |

The unit weights of the separate elements are found to be of the following form: (Weights in lb/in. of length, where CB is blade chord and X is spar width)

$$\text{Spar: } W_1 = .00097 \text{ CB} (2X + .17 \text{ CB})$$

$$\text{Core: } W_2 = .000108 (\text{CB}(\text{CB}-X) - .0025 (\text{CB}^3 / (\text{CB}-X)))$$

$$\text{Core Cap: } W_3 = .000024 \text{ CB} (.0036 \text{ CB}^2 + (\text{CB}-X)^2)$$

$$\text{Core Glue: } W_4 = .00103 (.0036 \text{ CB}^2 + (\text{CB}-X)^2)$$

$$\text{Trailing Edge Cap: } W_5 = .0000152 \text{ CB}^3 / (\text{CB}-X)$$

$$\text{Mass Balance: } W_6 = .0453(\text{CB}) x - .000435 \text{ CB}^2$$

The area of the spar:

$$A = .0192 \text{ CB}(X + .085 \text{ CB})$$

Load Conditions - The following load conditions were considered: Centrifugal loading, edgewise moment (starting torque with limit torque factor of 2), and droop bending moment (limit factor of 2.67). Because no general fatigue criteria due to flatwise bending could be developed, this condition was excluded.

Minimum Weight Configuration

The minimum weight blades meeting the strength requirements was obtained. This data is given in Table VI.

| TABLE VI. WEIGHT ANALYSIS - BLADES AND HUB | | | |
|--|-------------------------------|--------------------|-------------------------------|
| G.W. (lb) | Total Blade Weight (lb) | Hub Weight (lb) | Hub & Blade Weight (lb) |
| 3,150 | 147.56 | 15.00 | 162.56 |
| 3,000 | 130.33 | 14.31 | 144.64 |
| 2,850 | 120.67 | 13.73 | 134.40 |
| 15,750 | 870.96 | 70.16 | 941.12 |
| 15,000 | 796.51 | 65.16 | 861.67 |
| 14,250 | 724.16 | 61.24 | 785.40 |
| 26,250 | 1930.56 | 138.80 | 2069.36 |
| 25,000 | 1811.43 | 130.62 | 1942.05 |
| 23,750 | 1690.25 | 122.51 | 1812.76 |
| 73,500 | 8397.16 | 636.22 | 9033.38 |
| 70,000 | 7945.01 | 600.14 | 8545.15 |
| 66,500 | 7498.49 | 563.84 | 8062.33 |
| 157,500 | 22948.80 | 1970.38 | 24919.20 |
| 150,000 | 21967.50 | 1849.78 | 23817.30 |
| 142,500 | 21050.20 | 1739.41 | 22789.60 |

Vary Gross Weight - The gross weight was varied by ± 5 percent, and the blade weights were obtained as above and are also given in Table VI.

Analyze Hub - A similar analysis was performed for the hub. The results are given in Table VI.

The resulting data is given on Figure 13.

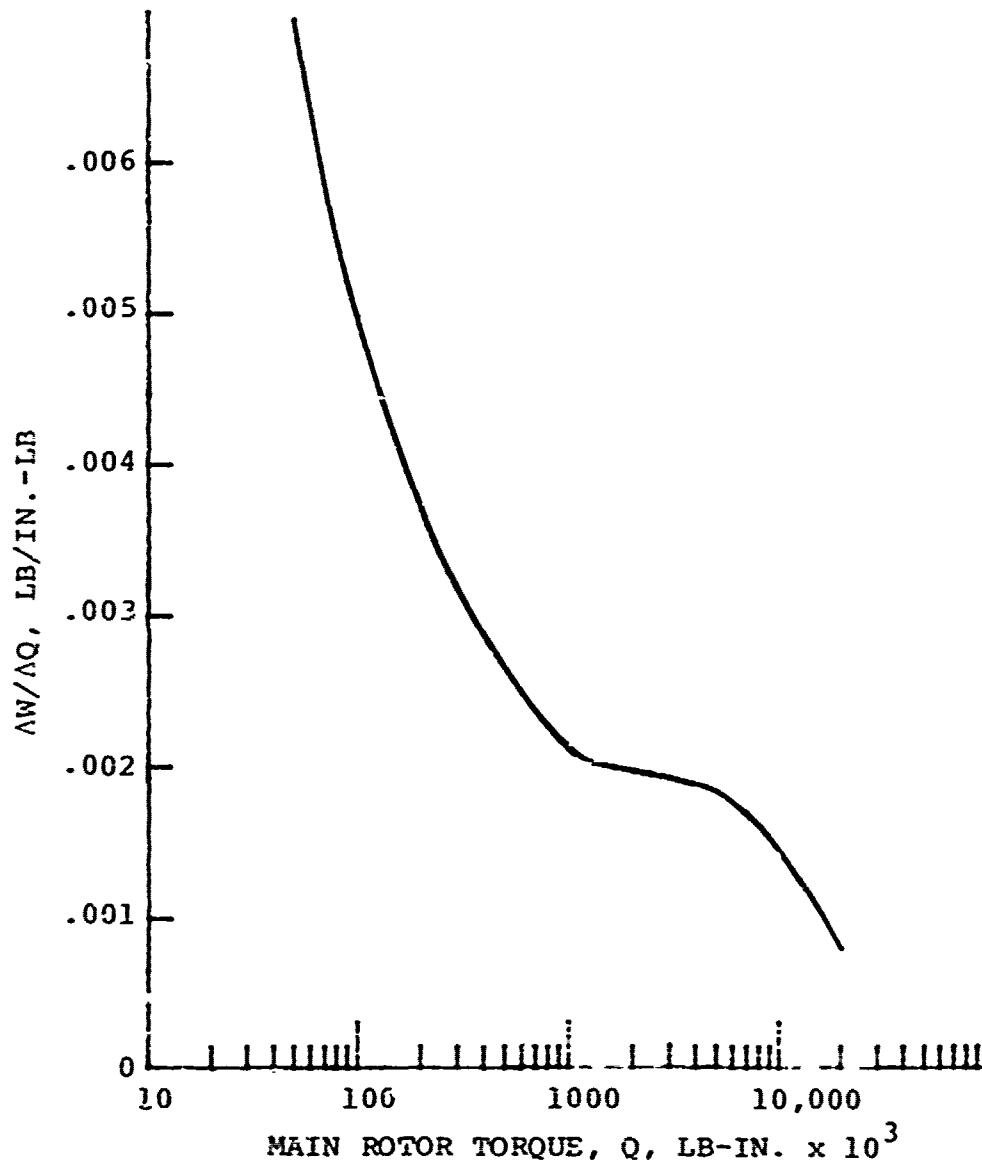


Figure 13. Main Rotor, Rate of Change of Weight Per Unit Change in Torque.

EFFECTIVENESS

It is the basic premise of the study that helicopters designed structurally for operation at off-design conditions will be heavier and costlier than those whose structure is designed at the same point at its powerplant. However, it is believed that when the entire operating spectrum of a helicopter is examined, it will be found that the extra capacity of the oversized helicopter will more than compensate for its additional size, weight, and cost. Thus, each of the helicopter types analyzed - utility, cargo, crane, observation, and gunship - is analyzed for its overall effectiveness in performing its intended functions at both design and off-design conditions.

Mission Parameters

As in other parts of the model, the primary emphasis of sub-models used to calculate mission effectiveness is on determining the differences in effectiveness between a helicopter designed with a single, arbitrary design point and a helicopter designed with an additional, more structurally demanding design point. Hence, the mission effectiveness measures are those which concentrate on evaluating these differences, once a suitable base is established. The base or reference level mission effectiveness for each type of helicopter is established by its design point requirements. These requirements are the performance parameters and associated data derived from mission analyses. The mission analyses translate operational requirements (numbers of troops to be airlifted, distance from troop bases to the forward edge of the battle area (FEBA), weapons compliments, supply levels and resupply rates, etc.) into design requirements for the helicopters (payload, range, speed, OGE hover requirements, etc.). And these design requirements are specified such that under the most severe, or nearly most severe, conditions, the helicopter will be able to perform its required mission.

In the case of a transport helicopter for example, the payload may be specified as so many troops and/or equipment and cargo, the range as that necessary to move the payload from staging areas to the FEBA, the speed as that required to achieve the required reaction time or resupply rate, and so forth. To permit sizing of the powerplant, it is necessary to specify a stringent combination of hover altitude, temperature, climb rate, and power margins that the aircraft must be able to perform with its design payload. For either a single-point design helicopter, or a helicopter with two design points, this requirement would be the same.

Similarly, for either a single- or two-point design helicopter, the required cruise speed would be the same. When the transport helicopter is operating at off-design conditions, its cruise speed could be modified, or its range, or any other pertinent parameter within its capabilities. In general, however, it is more appropriate to fix these values at their required levels and to examine the change in the helicopter's "essential" operational parameters. In the case of a transport helicopter this would be payload. Thus, the appropriate measure of mission effectiveness to be analyzed in this study for the transport helicopter would be its payload.

For the purposes of comparing helicopters with two design points to those with a single-point design, payload is an excellent mission measure of effectiveness (MOE) for all of the helicopter types to be analyzed by the model except for the observation helicopter. Both utility and crane helicopters have payload as their primary variable requirement, with range, speed, etc., set by operational requirements that must be met (but not necessarily exceeded) under any payload conditions.

For the armed helicopter, performance at high speeds is a primary design requirement, along with weapons load. But again, payload has been selected as the variable design parameter for the mission MOE; the assumption has been made that the design value of speed (and the associated maneuver load criteria) was selected after trading off payload versus rapidly increasing component weights, particularly the rotor, at higher speeds. At these conditions, there is much more leverage in increasing payload than there is in increasing speed, because of the design limitations of the helicopter. In addition, only a small portion of the helicopters' flight time will be spent at the maximum conditions, thus arguing that increasing capability (payload) at lower speeds is the preferred way to increase overall mission effectiveness.

For the observation helicopter, the primary performance parameter is time-on-station or time on patrol which can be expressed simply as endurance at stated conditions (best speed for range, best speed for endurance, etc.). Since payload is relatively fixed (observer, tracking equipment, etc.), and other performance parameters like speed are not dominating requirements, endurance at a nominal patrol speed has been selected as the appropriate mission MOE for the observation helicopter.

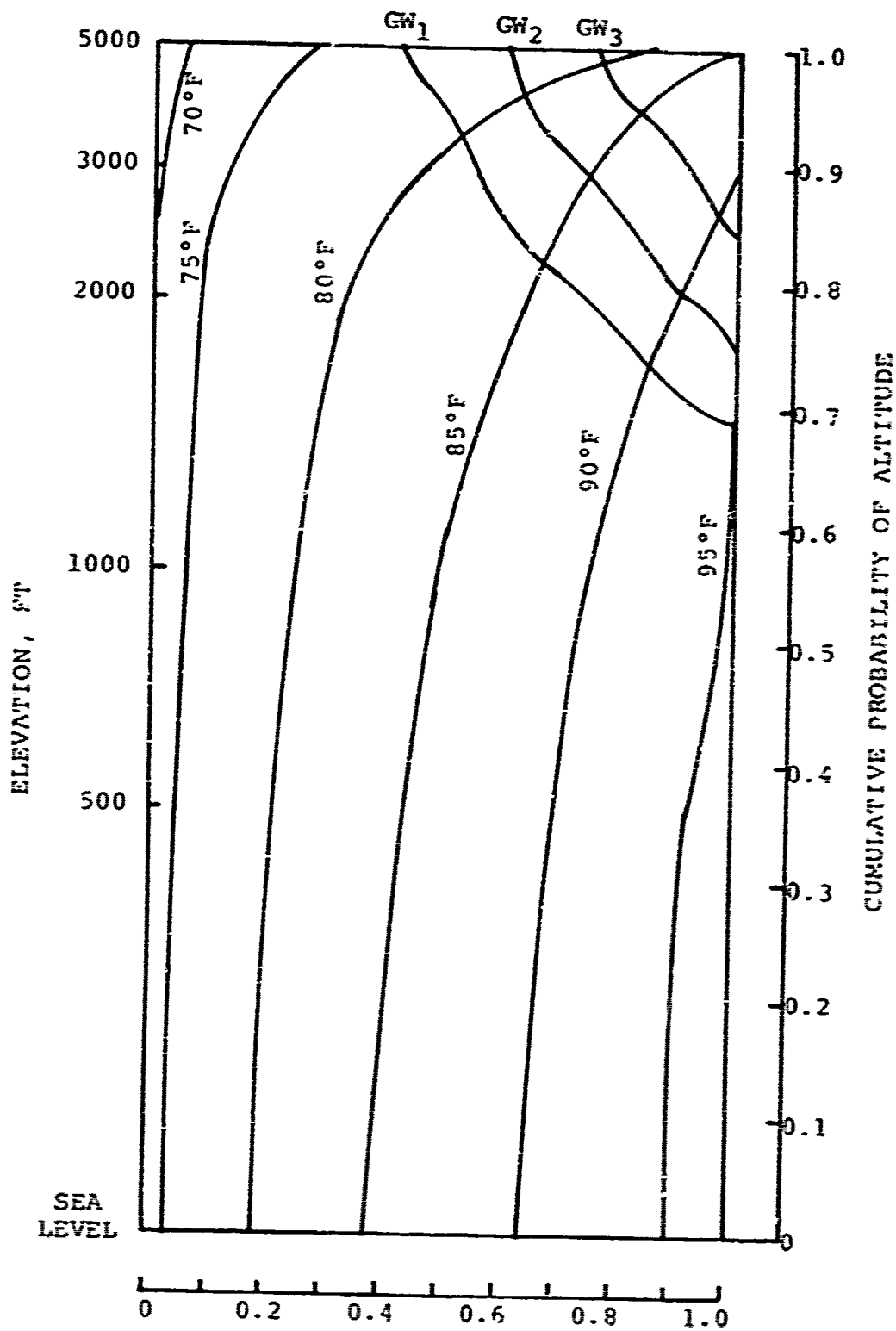
Operational Parameters

Operational parameters are those parameters which define the total environment, both natural and man-made, within which the helicopter will operate. These parameters are included in the analyses defining the helicopter design requirements and can significantly influence the intended operation of the helicopter if they are different from those designed for.

In this study, the only environmental parameter which must be included in the two-point design analysis is the altitude-temperature profile that the helicopter must operate in. However, this combined parameter is extremely important since it determines the off-design capability of the power system of a helicopter, and hence, its overall mission effectiveness parameter (payload or endurance).

A helicopter designed to hover with a specific payload at a specific altitude and temperature has a specific design horsepower powerplant requirement. At different altitudes and temperatures, its powerplant will deliver different power, and hence, its payload (or fuel load) capacity will also vary. Thus it will achieve different levels of mission effectiveness (payload or endurance) depending on the conditions under which it must hover during the course of a mission. The most concise and unambiguous method to analyze this problem is presented in Reference 3, and is the method used in this study. In this method, a joint temperature - altitude probability distribution for a given geographic area is prepared first. An example of such a distribution is shown in Figure 14. The data for both altitude and temperature for this study were taken from the above reference, and an explanation of how the data are obtained and processed is given there.

The data shown in Figure 14 are used to calculate the overall probability that a given helicopter carrying a given payload and fuel load can hover in the specified environment. This is done by determining the maximum temperature that the aircraft can hover at for a given gross weight at a given altitude. This point is plotted on the graph, and after several more points are calculated, a line, such as that labeled "GW", can be drawn. The process can be repeated for any other gross weight as well (GW_2 , GW_3). This line represents the combination of altitudes and temperatures above which (higher altitudes and/or higher temperatures) the helicopter cannot hover, and hence, cannot perform its mission. The proportion of area of the chart below this line, compared to the total area of the chart, is then numerically equal to the probability that the helicopter can



CUMULATIVE PROBABILITY OF TEMPERATURE FOR VIETNAM

Figure 14. Typical Altitude - Temperature Data.

perform its mission in the given environment at the specified gross weight.

The process described above derives the probability of hover, or the probability that the helicopter can perform its mission under given conditions. To measure overall effectiveness, several different combinations of payload and environment must be considered. The method of handling several different payload levels is discussed in the next section. The method used in the model to account for operations in several different environments is discussed below.

To simplify the computation of overall hover probability in the areas of the world of prime interest to the Army, the characteristics of 19 countries contiguous to the Sino-Soviet block were combined. These are the same areas used in the analysis referenced above, and are listed in Table VII. The altitude and temperature profiles of the countries were combined to form an overall "world" altitude-temperature profile.

For combining altitude data, the probability of being at or below a given altitude is equivalent to the percentage of land at or below that given altitude if it is equally likely that one could or would be placed anywhere in the total land area. Thus,

$$f_j \text{ cum} = P_j \text{ cum} = \frac{\sum_k P_{jk} A_k}{\sum_k A_k}$$

where:

f_j is the frequency of occurrence or cumulative probability of being placed at the j-th altitude within the combined area of the k countries.

P_{jk} is the frequency of occurrence or cumulative probability of being placed at the j-th altitude within the k-th country.

A_k is the area of the k-th country.

TABLE VII. AREAS USED IN HOVER PROBABILITY CALCULATIONS

1. West Germany
2. France
3. Italy
4. Spain
5. Turkey
6. Syria - Lebanon
7. Saudi-Arabia
8. Iraq
9. Iran
10. Afghanistan
11. West Pakistan (Pakistan)
12. India
13. East Pakistan (Bangladesh)
14. Burma
15. Thailand
16. Laos
17. Cambodia
18. Viet Nam (North and South)
19. South Korea

For temperature, it is necessary to combine the temperature/probability data in such a way as to preserve the relationship between temperature and altitude. Hence, temperature should be derived on a weighted basis for each altitude investigated. Treating the probability of a temperature occurring as its frequency of occurrence:

$$f_{ij \text{ cum}} = P_{ij \text{ cum}} = \frac{\sum_k P_{ijk} A_{jk}}{\sum_k A_{jk}}$$

where:

f_{ij} is the cumulative frequency of occurrence of temperature T_i at altitude h_j within the combined areas of the k countries.

P_{ijk} is the probability of T_i occurring at h_j in each of the k countries.

A_{jk} is the area of each country at the altitude h_j .

For altitude, the simple calculation can be performed by multiplying the percentage of total area represented by a country and the cumulative percentage of area in that country at or below a given altitude to obtain the fraction of the total area of all of the countries at or below a given altitude represented by that country. For a given altitude, when this is done for each country and the results added, the total represents the cumulative percentage of the total area at or below the given altitude. Thus:

$$P_{\text{cum } j} = \sum_k P_{\text{cum } jk} \times (A_k/A)$$

For combining temperature data, the process is more complicated. Here, it is necessary to weight a given temperature value by both its frequency of occurrence in a given country at a given altitude and by the percentage of area of a given country at that altitude. Cumulative frequencies of temperature for a given temperature level, multiplied by the fraction (not cumulative) of area represented at a given altitude yields the cumulative frequency of occurrence of the temperature at the altitude of interest. Thus:

$$P_{i(\text{cum})j} = \sum_k P_{i(\text{cum})jk} \times (A_{jk}/A_j)$$

Since the altitude/fraction data is given on a cumulative basis for each country, a method to derive a frequency distribution histogram must be devised so that area fractions can be assigned to each altitude for each country. If a very large number of altitudes were being investigated, the histogram would closely approach the actual frequency distribution. However, only a limited number of altitudes were calculated in the current calculation. Applying the histogram approach to the entire altitude distribution curve might result in a rather gross histogram where much area would be represented by a single altitude. However, since the accuracy of the source cumulative frequency distributions for temperature (and altitude to some extent) is somewhat questionable (as indicated by the methods used to derive these data in Reference 4), extreme care with development of a histogram is probably not warranted considering the overall temperature accuracy.

To derive a consistent weighting function for the temperature data at each altitude, a sampling approach was used. Here, a narrow band of altitudes was selected around each altitude for which weighting data were required. This number was used as the weighting factor. The size of this number depends on

two things: (a) the size of the country; and (b) the slope of the altitude distribution curve in the band selected. Obviously, the size of the country should have an effect on the weighting of the temperature. The local slope indicates how rapidly area is being added to the cumulative distribution and thus reflects the percentage of area considered as representative at a given altitude.

After performing the necessary computations, the cumulative joint probability distribution for altitude and temperature was obtained. These data are shown in Figure 15 and were prepared in tabular form for use in the computer model.

Utilization Parameters

The previous sections discussed the choice of payload or endurance as mission effectiveness parameters, and how environmental conditions of hover altitude and temperature affect the helicopter's ability to perform its mission. The latter factor is dependent upon the amount of payload or endurance required, which in turn, depends on how the helicopter is utilized. Thus, a third factor to be considered in determining the effectiveness of a helicopter is the relative frequency with which it will operate with a given payload or endurance (fuel load) over its operational lifetime.

An example of utilization data is shown in Figure 16, which was prepared using data from Reference 5. These data illustrate typical utilization patterns for utility transport observation, crane, and gunship helicopters. Unfortunately, many assumptions would have to be made to derive a relationship between the gross weight distributions shown in Figure 16 and the corresponding payload/fuel load distribution. Since this analysis was beyond the scope of the current study, this effort was not conducted. However, it was recognized that this could be an important factor in determining overall effectiveness and in optimizing selection of a second design point. Hence, provision was made in the effectiveness model, and the computer program, for including this factor in the effectiveness calculation.

Effectiveness Equations

The basic equation used to calculate the effectiveness of a helicopter is:

$$MEI = (PL) (PHOV) (PUF)$$

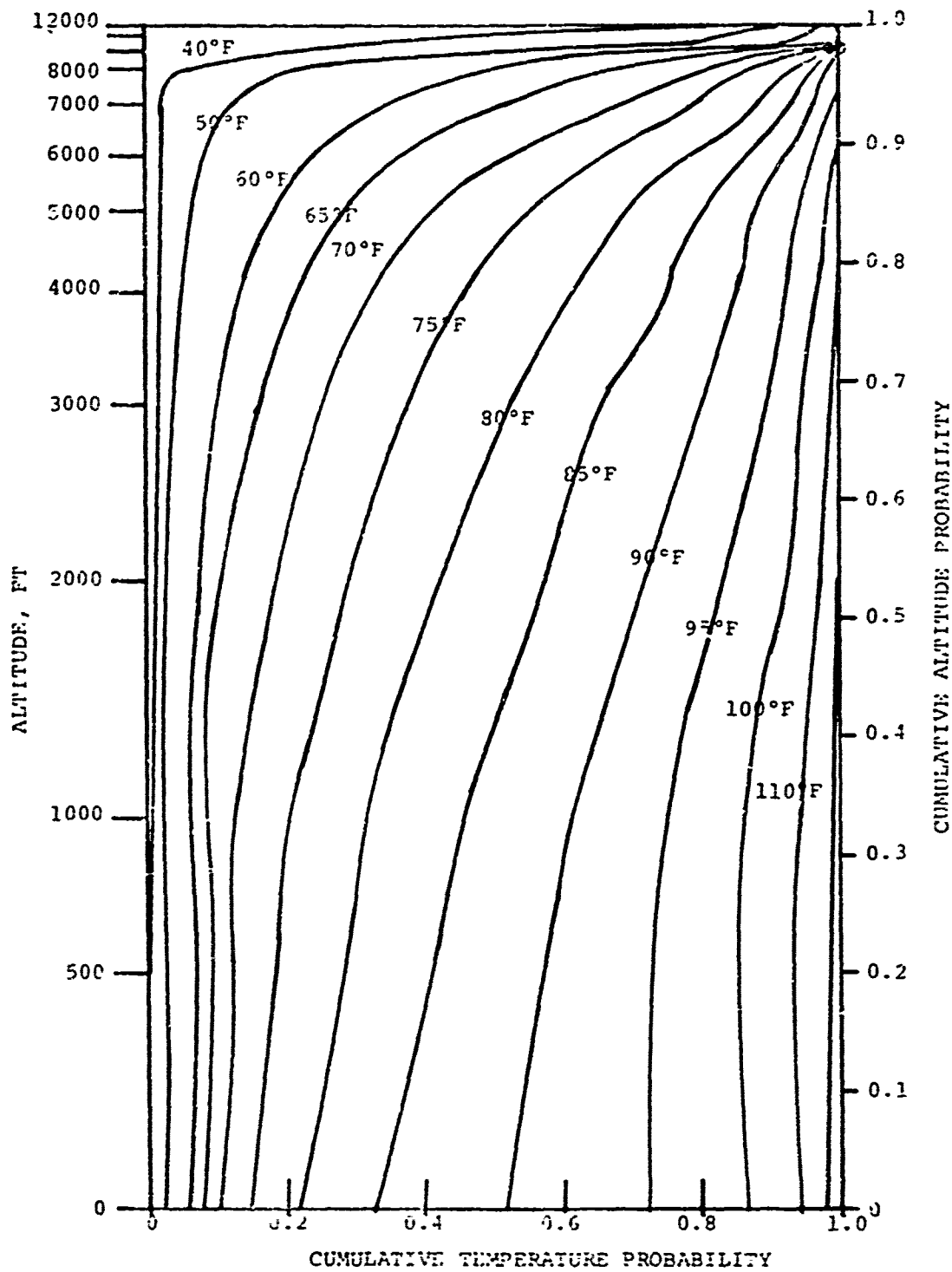


Figure 15. Combined Altitude - Temperature Data.

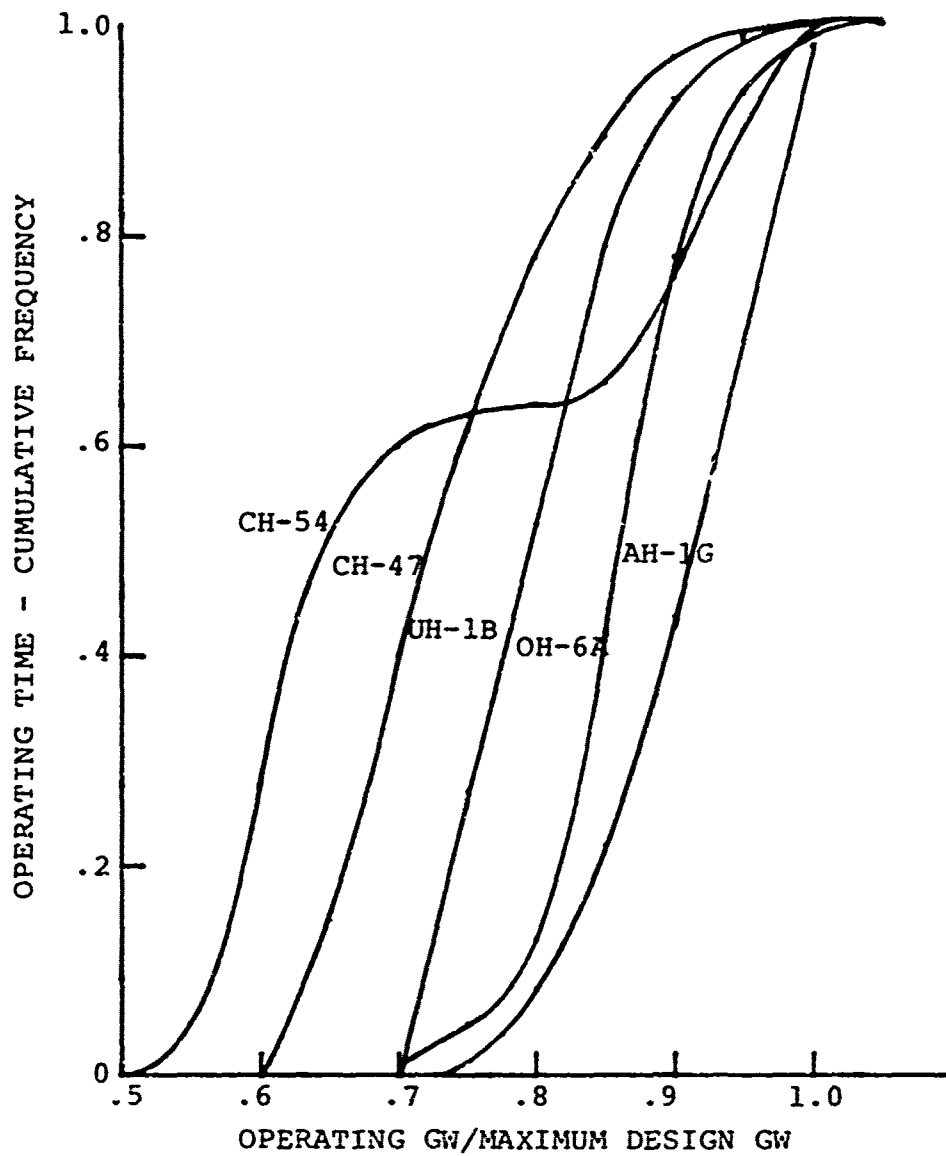


Figure 16. Sample Utilization Data.

The use of this effectiveness index is illustrated below.

It is desired to determine the optimum two-point design of a transport helicopter with a given design payload requirement at a hover condition of 4000 ft, 95°F, 500 ft/min rate of climb. The ship must have a range of 300 NM, a cruise speed of 160 knots, etc. Using the techniques described in previous sections, two helicopters are "designed": a helicopter with a single-point design (4000 ft/95°F) and a helicopter with two design points (4000 ft/95°F, 2000 ft/75°F). These helicopters have different gross weights and empty weights, but a common design payload.

To compare their respective effectiveness levels, representative payloads spanning their range of capabilities will be used, from 0 payload up to a payload that overloads the helicopter, say 10 percent over design payload. Using these payloads, a utilization frequency is obtained for each level. These are the same for either helicopter, since the payload increments match. However, the gross weight level associated with each payload level is different, depending on which helicopter is examined. This results in a different probability of hover, which in turn, affects the effectiveness index. After the effectiveness index is calculated for each payload increment, the sum yields the overall effectiveness index for each helicopter.

A sample calculation illustrating this technique is shown in Table VIII. Included in the table is a cost factor covering life cycle costs for each helicopter. A detailed explanation of how these costs are calculated is given in the next section. If costs are included, a cost effectiveness index can be calculated rather than just a simple effectiveness index. Thus

$$OCE = \sum_{j=0}^k \frac{(PL) (PHOV) (PUF)}{CPFH}$$

where:

CPFH is the total cost per flight hour for the helicopter.

After examining the case for the two-point design helicopter described above, another calculation can be performed for another one (say 4000 ft/95°F, 3000 ft/75°F). Several of these calculations then lead to a series of optimization curves, from which the optimum second design point for the helicopter with the given mission requirements can be determined.

TABLE VIII. SAMPLE COST EFFECTIVENESS CALCULATION

| Payload (lb) | Single Design Point Helicopter | | | | | Two Design Point Helicopter | | | | | | | |
|------------------|--------------------------------|-------------|------------|--------------|--------------|-----------------------------|------------|--------------|--------------|-------------|------------|--------------|--------------|
| | Utilization Frequency | Weight (lb) | Hover Prob | Index of Eff | Cost (\$/hr) | Weight (lb) | Hover Prob | Index of Eff | Cost (\$/hr) | Weight (lb) | Hover Prob | Index of Eff | Cost (\$/hr) |
| 0 | .05 | 14,840 | .1 | 0.0 | 285 | 17,090 | .1 | 0.0 | 285 | 17,090 | .1 | 0.0 | 310 |
| 500 | .05 | 15,340 | .1 | 25.0 | 286 | 17,580 | .1 | 25.0 | 286 | 17,580 | .1 | 25.0 | 311 |
| 1000 | .05 | 15,840 | .1 | 50.0 | 288 | 18,070 | .1 | 50.0 | 288 | 18,070 | .1 | 50.0 | 312 |
| 1500 | .05 | 16,300 | .995 | 74.6 | 291 | 18,600 | .995 | 75.0 | 291 | 18,600 | .995 | 75.0 | 314 |
| 2000 | .05 | 16,760 | .990 | 99.0 | 294 | 19,070 | .990 | 100.0 | 294 | 19,070 | .990 | 100.0 | 316 |
| 2500 | .05 | 17,220 | .985 | 123.1 | 298 | 19,560 | .985 | 123.8 | 298 | 19,560 | .985 | 123.8 | 319 |
| 3000 | .10 | 17,700 | .975 | 292.5 | 302 | 20,050 | .975 | 296.7 | 302 | 20,050 | .975 | 296.7 | 322 |
| 3500 | .05 | 18,220 | .973 | 170.3 | 306 | 20,560 | .973 | 172.0 | 306 | 20,560 | .973 | 172.0 | 326 |
| 4000 | .20 | 18,780 | .968 | 774.4 | 310 | 21,070 | .968 | 780.8 | 310 | 21,070 | .968 | 780.8 | 330 |
| 4500 | .10 | 19,350 | .962 | 432.9 | 315 | 21,440 | .962 | 436.5 | 315 | 21,440 | .962 | 436.5 | 335 |
| 5000 | .15 | 20,000 | .950 | 712.5 | 320 | 22,200 | .950 | 712.5 | 320 | 22,200 | .950 | 712.5 | 340 |
| (Design) 5500 | .10 | 20,600 | .891 | 490.0 | 340 | 22,755 | .891 | 506.0 | 340 | 22,755 | .891 | 506.0 | 345 |
| | | | | | MEI = 3244 | | | | MEI = 3278 | | | | |
| | | | | | OCE = 10.33 | | | | OCE = 9.86 | | | | |

COST MODEL

The cost model is a statistical approach to aircraft cost estimating. The cost estimating relationships utilize empirically derived cost functions. The costs have been functionally related to basic aircraft parameters such as empty weight of airframe and installed power of engine. The model is sufficiently detailed to distinguish cost differentials between two-point design and single-point design helicopters. This approach allows cost estimates to be made based on primary aircraft parameters before a detailed design is actually completed. The cost model is broadly divided into initial and operating costs as illustrated in Figure 17.

Initial Costs

Initial Production costs are based on a model evolved by E. H. Yates (References 6 and 7). The production costs are subdivided into airframe, engines, and government-furnished aircraft equipment (GFAE).

Airframe direct labor costs were derived from direct labor man-hour data contained in Aeronautical Manufacturers Planning Reports (AMPR). The costs were estimated on a per-pound basis at production number 1000. The average labor learning curve as a function of production number, NP, is:

$$C = 43.12(NP)^{-.39}$$

The airframe labor cost, in dollars, is given in terms of AMPR weight*, WA, in pounds:

$$\text{Labor Cost} = 17.63 WA^{.85}$$

Thus, when combined with the learning curve, the airframe labor cost is

$$CL = 760.2 WA^{.85} (NP)^{-.39}$$

where CL is in dollars and WA is expressed in pounds.

* AMPR weight is Aeronautical Manufacturers' Planning Report weight which is empty weight of aircraft less (1) wheels and brakes, (2) engines, (3) starter, (4) cooling fluids, (5) instruments, etc.

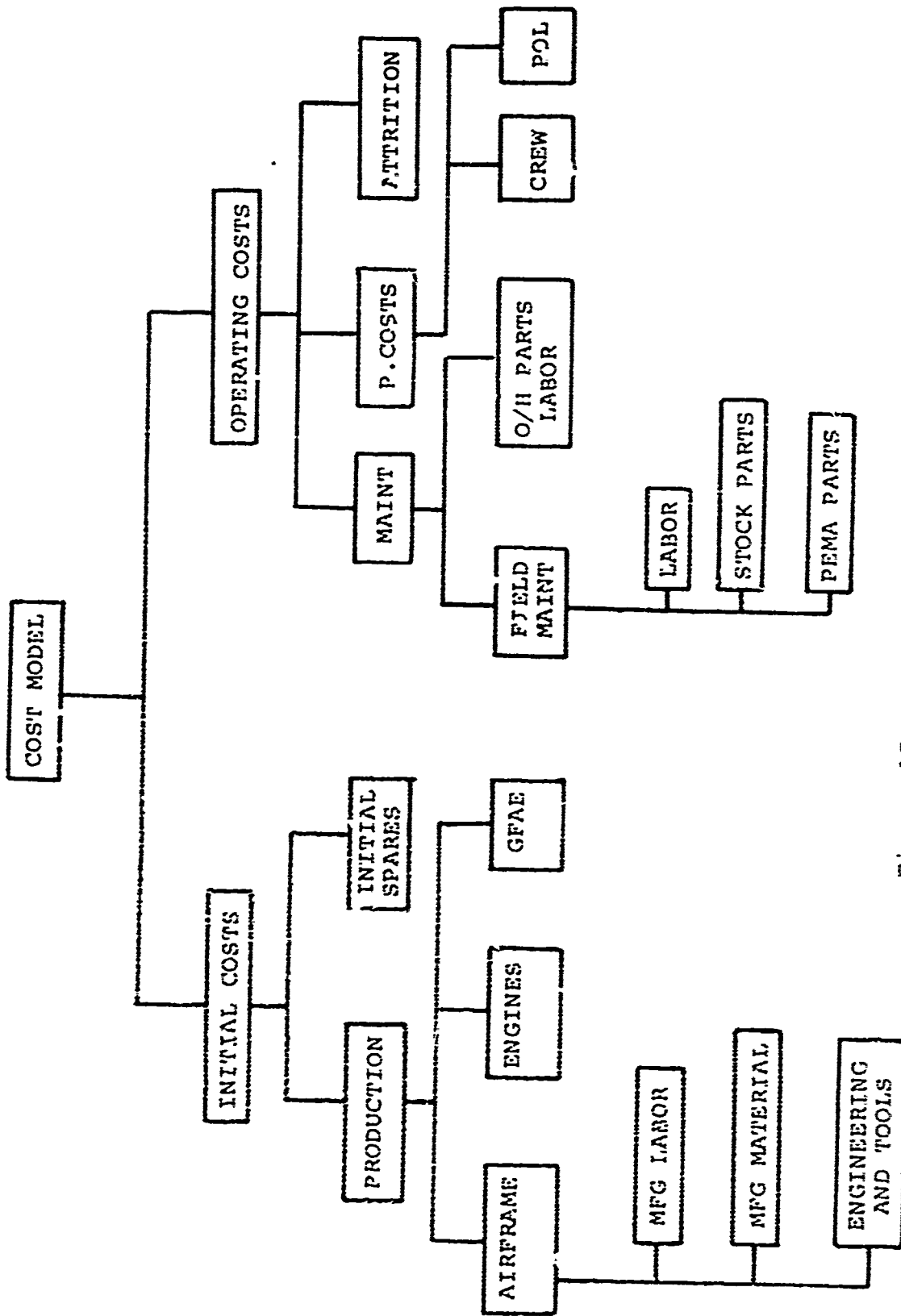


Figure 17. Cost Model.

The cost for airframe materials for subsonic aircraft was found to be a function of airspeed as well as weight and number produced. The following relationship is for fixed-wing aircraft, but since its effect is small and a better relationship was not found, airframe material cost is defined as:

$$CM = .007(WA)/(NP)^{-1.2} (TAS)^{1.24}$$

where TAS is the aircraft speed in knots.

Cumulative average engineering and tooling costs per airframe are related to the total number of units planned for production. Based on post World War II aircraft the relationship for engineering and tooling costs is:

$$CET = WA(220/NP + 7.5/NP^{-1.5})$$

where NP is the number of units planned for production.

There are additional costs which must be added to the above costs. These are general and administrative expense (GA), engineering change proposals (ECP), and profit (P). The following relations apply:

$$GA = 0.1(CL + CM)$$

$$ECP = 0.1(CL + CM + CET + GA)$$

$$P = 0.1(CL + CM + CET + GA + ECP)$$

In the equations above, the AMPR weight, WA, is related to the empty weight, WEM, by

$$WA = .749 WEM + .126$$

The correlation coefficient of this equation is .997 with a standard error of .356 kilo-pounds (Reference 7).

Data for 17 turboshaft engines were analyzed. The best least-squares fit was made to obtain the following relationships:

$$CE = PRA(58 - .006 PRA/NEN) \quad PRA \leq 3500 \text{ HP}$$

$$CE = NEN(129,500 + 37(PRA/NEN - 3500)) \quad PRA > 3500 \text{ HP}$$

where PRA is in horsepower per engine and CE is in dollars.

The GFAE category usually includes the cost of ordnance and armament and electronics that are not an integral part of the airframe and engines. This cost item is highly dependent on mission objectives and type of helicopter, and therefore, is quite sensitive to the function of the aircraft. For this cost model, insufficient data exists to derive a cost estimating relationship for the various types of helicopters, i.e., utility, observation, gunship, etc. An estimation equation with limited data was found to be:

$$CG = -3760 + 4.79 WA$$

The initial costs are plotted in Figure 18 for production number of 100 of a 120-knot helicopter.

The cost of production (CP) is then defined by:

$$CP = 1.331 CL + 1.331 CM + 1.21 CET + CE + CG$$

To simplify the model, the constants are included in the individual terms to yield:

$$CL = 1011 (WA)^{.85} / (NP)^{.39}$$

$$CM = .00931 (WA) (TAS)^{1.24} / (NP)^{.12}$$

$$CET = 1.21 (WA) (220 / (NP) + .75 / (NP)^{.15})$$

and

$$CP = CL + CM + CET + CE + CG$$

The costs of attrition (CA) and initial spares (CI) are defined as:

$$CA = (YAR) (CP) (SL) / (NP)$$

and

$$CI = .1 (CP)$$

The production, spares, and attrition costs are summed to form:

$$CPIA = CP + CI + CA$$

Operating Costs

The operating cost portion of the model is broken down into three main categories, as is shown in Figure 17: maintenance, direct operating costs, and attrition.

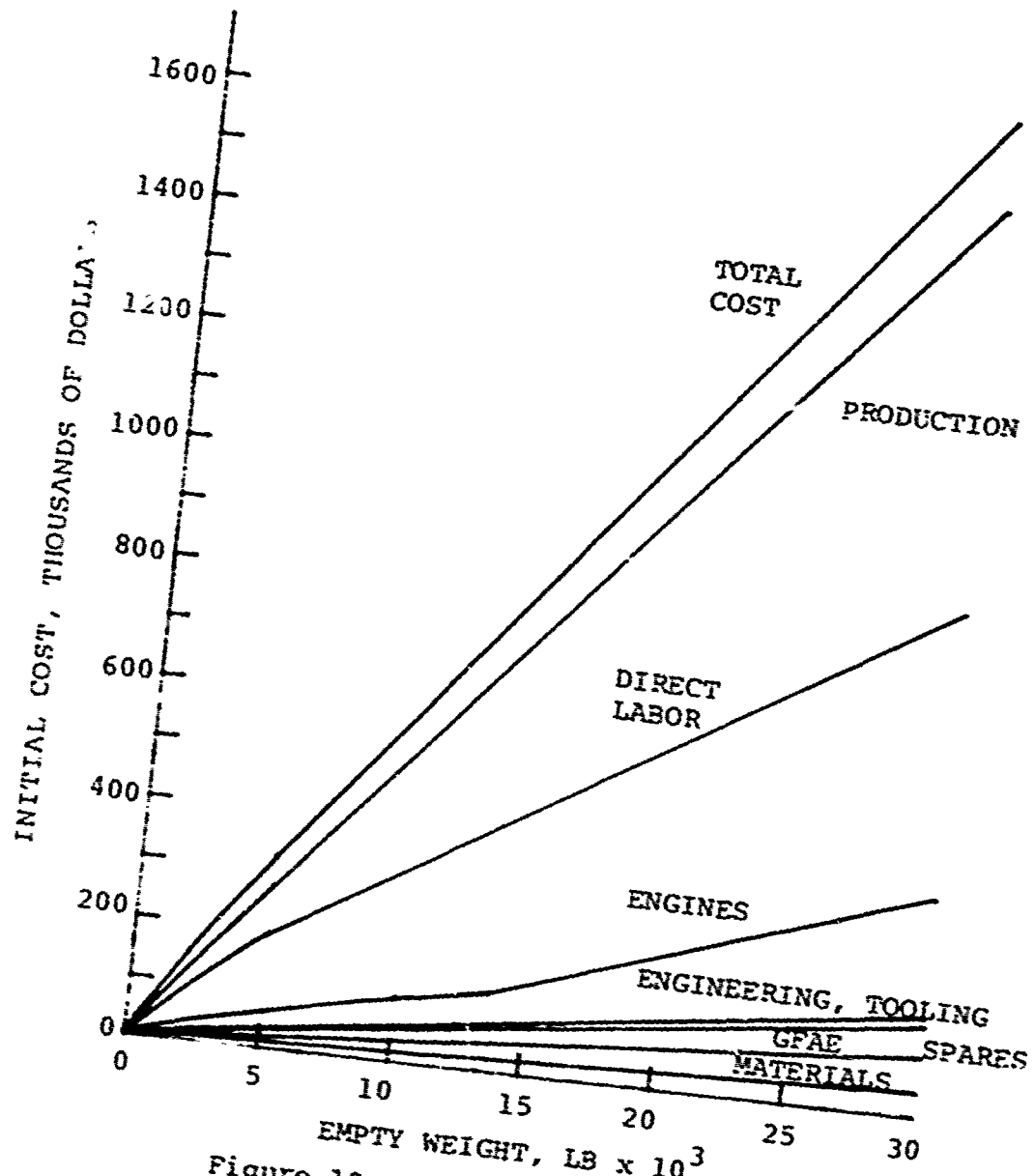


Figure 18. Helicopter Initial Costs.

Maintenance costs consist of overhaul parts and labor and field maintenance. The field maintenance category includes labor, stock fund parts, and PEMA (Procurement of Equipment and Missiles, Army) parts. The direct operating costs are composed of crew costs and petroleum, oil and lubrication (POL).

A regression analysis was performed on the operating costs (Reference 9) of 17 Army helicopters to determine cost estimating relationships. The correlations are based on the empty weight, WE, of the helicopter. These operating cost estimating relationships are given below:

$$\begin{array}{l}
 \text{CFM} = .00191 \text{ WEM}^{1.323} \text{ TN/T} \\
 \text{COPL} = 1.016 \text{ WEM}^{-.4} \text{ TN/T} \\
 \text{CPOL} = .0038 \text{ WEM}^{-.89}
 \end{array}
 \left. \vphantom{\begin{array}{l} \text{CFM} \\ \text{COPL} \\ \text{CPOL} \end{array}} \right\} \text{WE} \leq 3200 \text{ lb}$$

$$\begin{array}{l}
 \text{CFM} = -87.6 + .05362 \text{ WEM (TN/T)} \\
 \text{COPL} = 18.16 + .00233 \text{ WEM (TN/T)} \\
 \text{CPOL} = -2.5 + .00235 \text{ WEM}
 \end{array}
 \left. \vphantom{\begin{array}{l} \text{CFM} \\ \text{COPL} \\ \text{CPOL} \end{array}} \right\} \text{WE} > 3200 \text{ lb}$$

$$\text{CC} = 101 + .0033 \text{ WEM}$$

The fuel costs can be described by the above statistical relationship but since the actual fuel load is calculated, the fuel cost can be calculated using:

$$\text{CFUL} = .25 \text{ WFL}/6.5$$

The expression for the maintenance operating (CFM) costs is for average operating conditions. If the helicopter is operated at an overloaded or underloaded condition, the maintenance costs will differ from these. This comes about due to a change in the average failure rate of components of the helicopter system. Maintenance costs are inversely proportional to the mean time between failures. To determine the mean time between failure, the probability of failure as a function of loading was related to the probability of failure as a function of time.

The probability of failure, $P_F(L)$, as a function of load, L, is typically of the form (References 10 and 11):

$$P_F(L) = 1 - \exp \left\{ - \left(\frac{L + a}{b} \right)^c \right\}$$

The probability of failure as a function of time shown is of the form:

$$P_F(t, T) = 1 - \exp(-.693 \frac{t}{T})$$

where T is the mean time between failure.

When the elapsed time $t = T$, the probability of failure is .5; i.e., at the mean time between failure the probability of failure is 50%. This corresponds to an average loading of the helicopter ($L = 1$). If the loading is increased to $L = 1.4$ for example, the probability of failure increases to .9. A failure probability of .9 at time T_1 determines a new failure curve and thus defines a new MTBF which is T_2 . In other words

$$P_F(L) = P_F(T_1, T_2)$$

resulting in

$$\frac{T_2}{T_1} = \frac{.693}{\left(\frac{L + \alpha}{\beta}\right) \gamma}$$

Thus, the new MTBF, T_2 , is determined from the load factor L and T_1 .

The mean-time-between-maintenance action, T_1 , was determined from data in Reference 12. Failure rates per flight hour were determined for 35 systems included in helicopters. From this data, the average flight hours per failure was determined and was correlated to the empty weight, WE , of the helicopter. The relationship is

$$T = .6778 + \frac{5544}{WE}$$

where T is the average mean time between failures in hours and WE is the empty weight in pounds.

The loaded maintenance costs are then obtained by multiplying the above equation for CFM by the inverse ratio of the mean time between failures.

The above relationships result in the relationship

$$T/TN = .693 / \left((OLF + .017) / 1.15 \right)^3$$

where T, TN are the actual and the normal mean time between failures. OLF is the overload factor and is the ratio of the gross weight to the design gross weight. In practice, it is found that in effect that OLF is never less than .5, corresponding to T/TN of 7.6. This implies that maintenance is still performed even if the helicopter is not flown. When $OLF \geq 1.5$, catastrophic failure occurs.

The costs are all reduced to cost per flight hour using the following equation:

$$CPFH = CPIA / (12(MFH)SL) + CD + CMT + 60 CFUL / TTIM$$

where TTIM is mission time in minutes and CPFH is in \$/hr.

COMPUTATIONAL METHOD - USER'S GUIDE TO ZODIAC II

The elements of the analytical model described above must, of necessity, originate in several different sections of an Engineering Department. Each of these model elements is subject to minor or major changes due to variations in mission and helicopter type under study, technology level, design philosophy, data available, or budgetary considerations. The overall logic is similarly subject to changes for these reasons and, in addition, because of the particular parameters to be varied and because of variations in the purpose of the study.

The conventional approach to this modeling study would range from a simple computer program which would have to be re-programmed for each of the many modifications in the model to a complex program which includes prior provisions for all the possible modes of operation. The objections to these methods include the high cost of many changes (for the simple program) or high initial costs (for the complex program), the difficulty of varying modes of operation; changing criteria; and expanding capabilities. The most serious disadvantage, however, is the fact that the engineer is left out of the decision loop. Typically, the engineer would describe his requirements to a programmer (or make major program changes himself), or he would select options from a coded table. In this environment of continual change, the risk of getting meaningless data is significant.

The approach selected here for implementation is an outgrowth of a computer program originally devised at Kaman primarily for weights analyses, where typically the analytical models are continuously changing. This program, called ZODIAC, is described in Reference 13.

The primary motivation in the development of this program was that it should be a tool which is completely meaningful to, usable, and changeable by an engineer with no or little programming experience. It is believed that this objective has been achieved in ZODIAC II.

PROGRAM FEATURES

Prior to describing the program usage in detail, some of the features and the organization will be discussed. Examples of all these features can be found in the listings of the model formulations in Appendix II.

Modular Organization

The analytical model is divided into separate computational units called "modules". Each module generally is used to carry out one logically self-contained computation. Examples were discussed in the previous section on the Analytical Model. Typically, individual modules will represent computations like statistical weight, mission fuel requirements, initial costs, mission effectiveness, etc. Many of the quantities involved in the module will not be used any place else in the model. Only these variables which are shared in common with other modules must be specified. The module will consist almost entirely of the equations which define the computation. Each module must have a name so that it may be referred to by the "control module". Modules may be easily changed by adding, removing, or changing equations or the entire module.

Control Module

The overall logic of the analytical model is carried out by the "control module". This portion of the program consists mainly of instructions specifying which module to run next. The same module may be run more than one time by the control module.

Logical Operations

The number of types of logical operations has been limited to true operational decision making functions. It is preferred that the engineer change his model to reflect changed ground rules rather than include several possibilities and choose between them with pseudo-logical input codes. In this manner the engineer is always fully cognizant of his model and it is always under his full control. This approach is possible because of the ease and safety with which such changes can be made. The two major logical operations included are: (1) automatic iteration within a module or around several modules (as is commonly used in weight estimation or in determining the power for maximum range); and (2) a conditional evaluation of a variable (as might be used to prevent a power required computation from exceeding some torque limitation).

Equation Form

The actual equations make up almost all of the model. The equations are written in algebraic form (consistent with FORTRAN) and allow all arithmetic operations including exponentiation. See listings in Appendix II for many examples.

Table Look Up

Since tabular data will normally make up a substantial portion of the input data to any modeling program, ZODIAC II has an automatic table look up feature. Linear interpolation of tables with up to three independent variables is automatically performed.

Input Data

Input of data is extremely simple. The program does not presuppose any point of input or any particular data. Data is always self-identified and may be freely input with the modules. Additional input may be called for during the running by the simple statement, READ. At this point, any desired data may be input or changed.

Output of Data

Output is also extremely simple. All that is required is the simple statement PRINT, followed by a list of the variables. On output each quantity is automatically identified.

The input and output procedures are especially convenient when compared to more formal languages, like FORTRAN, where typically many programming hours are spent deciding on all the input options and output formats.

Checks

Because of the free form of computation allowed, it is necessary for the program to include a number of built-in automatic checks. If a variable used in an equation has not been previously input or calculated, a warning message is printed. If it is necessary to extrapolate during a table look up, a warning message is also printed. If the equations in a module cannot be evaluated in the order presented, they are automatically rearranged and an error is indicated if appropriate.

USERS RULES

The rules for using ZODIAC II are quite simple, and all one needs to know is specified in detail in the following pages. In some cases comments meant for FORTRAN programmers are included in parenthesis. These comments should be ignored by engineers not familiar with FORTRAN. There are a few definitions required prior to discussion of the allowable statements:

- Statement - meaningful (to the computer) contents of a punched card
- Variable - an algebraic quantity whose name has from 1-4 letters or numbers, the first of which must be a letter. Examples: A, QMR, B123, A7L6. If the variable is common (see below) its name may be preceded by a \$.
- Constant - a number. It may be positive or negative, it may or may not have a decimal, and it may contain an exponential. Examples: 12, 15.7, $1.73E-5 (= 1.73 \times 10^{-5})$, 6.54E16, 2E10.

The following codes are used in the following sections.

v \equiv variable

c \equiv constant

vc \equiv variable or constant

n \equiv name

Capital letters indicate precise words required as part of the statement. Blanks are ignored and may be used in place on cards for clarity (with the single exception of input table data).

All statements may be followed by comments on the same card provided a semicolon (11-8-6 punch) is used to separate the two.

There are three groups of statements: Control Module Statements, Module Statements, and Data Statements. These will be discussed separately.

Control Module Statements

The control module is used to specify the order of computation and includes the major logic of the simulation. Unless otherwise instructed the statements are carried out in the order shown. The allowable statements are listed and then described immediately following.

RUN MOD n

v = simple expression

POINT n

ITERATE ON v, ATOL = vc, PTOL = vc, TIMES = c, FROM n

COMMON v, v, v...

(LT)

IF vc IS EQ vc, GO TO n

(GT)

GO TO n

READ

PRINT v, v, v...

RUN MOD n (1-20 characters) - This statement causes the named module to be run. The name specified must also appear on a Module Name statement in the module which is to be run. (This is similar to a call statement in FORTRAN, but no argument list is used.)

v = simple expression - This statement is used to perform simple arithmetic in the control module. A simple expression is one which involves addition or subtraction of two terms, or a single term. The two forms which this type statement can have are shown below.

$$v = vc \pm vc$$

$$v = vc$$

Point = n - This statement specifies a point in the control module which may be referenced by an ITERATE, IF or GO TO statement. The point name specified must follow the same rules as a variable name and it may not appear in the control module as a variable name. Its use will be clear when the mentioned statements are discussed.

ITERATE ON v, ATOL = vc, PTOL = vc, TIMES = c, FROM n - This causes the program to iterate on the statements which are located between the POINT specified by FROM n and the iterate statement. Iteration will continue until two successive values of the variable specified by ON v are within the limits set by ATOL or PTOL or until the number of iterations exceeds the amount specified by TIMES. The details for each specification are as follows.

ON v - The variable which is specified is the variable on which iteration will occur. This specification is optional, if it is omitted the computations will be repeated the number of times specified by TIMES.

ATOL = vc, PTOL = vc - Both ATOL and PTOL are used as a test for convergence of the variable specified in the ON specification. ATOL is an absolute tolerance and PTOL is a percent tolerance. Both ATOL and PTOL are optional, but both are omitted, PTOL is set equal to 5 percent. For convergence, one or both of the following must be true:

$$|v_i - v_{i-1}| < ATOL$$

and/or

$$100 \frac{|v_i - v_{i-1}|}{|v_i|} < PTOL$$

Note that PTOL is put in in percent not decimal.

TIMES = c - This specification is used to specify the maximum number of iterations to be allowed. If convergence is not obtained before the number specified by TIMES is exceeded, iteration stops and an error message is printed out.

FROM = n - This specifies from which POINT in the program iteration is to occur. The point name specified must be on a POINT statement which must precede the ITERATE statement.

COMMON v, v, v - A COMMON statement is used to specify variables which are used in other modules. The order in which variables appear on the card is not important, but the variable name must be the same in both modules. A \$ preceding a variable name has the same effect as placing the variable name in a COMMON statement. A common statement must appear in a module before any of the variables on it are used. This statement is normally placed at the beginning of the module. Each card may contain up to 40 variables. As many COMMON cards as necessary may be used. (As distinguished from FORTRAN the order of the names is immaterial, only the names themselves are important.)

(LT)
IF vc IS EQ vc, GO TO n - In this statement a test is (GT)
made to determine if the left variable or constant is less than (LT), equal to (EQ), or greater than (GT) the right variable or constant. If the statement is found to be true, then the module branches to POINT n. If the statement is not true, the next statement following the IF statement is executed.

GO TO n - This statement causes a branch to POINT n. The next computation to be performed immediately follows the POINT n. Note that a GO TO should be followed by a POINT statement or be at the end of the module since there is no way of getting to a statement which follows a GO TO unless it is a POINT statement.

READ - This statement will cause data to be read into the next module before it is run. The rules for the data statements are specified elsewhere. (No specification is made as to what or how much data is to be read, this is defined on the input cards.)

PRINT v, v, v - This statement causes the values of the variables to be printed and identified in a standard format, five to the line.

Module Statements

The module contains primarily computation and a minimum of logical instructions. The allowable statements and their descriptions are as follows:

```

MODULE NAME = n

v = general expression

v = TABLE table name (vc, vc, vc)

ITERATE ON v, ATOL = vc, PTOL = vc, TIMES = c

INITIALIZE v = c, v = c

COMMON v, v, v...

      (LT)
IF VC IS EQ  vc, vc = general expression
      (GT)

PRINT v, v, v

NO ORDER

```

MODULE NAME = n - This statement gives a name to the module. Every module must contain this statement. The name can consist of from 1 to 20 alphanumeric characters. This card is usually the first one in a module but it can be placed anywhere.

v = general expression - This is the basic statement and as such, there is a whole section devoted to it. But a few rules are: the minimum requirements are a variable, an equals sign and either a variable or a constant. Usually, the general expression is any algebraic expression which conforms to standard mathematical usage and consists of addition, subtraction, multiplication, division, and exponentiation. See the section titled Syntax Rules for Expressions.

v = TABLE table name (vc, vc, vc) - This statement is used for table look up. Up to three arguments are allowed but only one is necessary. The number of arguments must coincide with the size of the table. The value returned is a result of a linear interpolation. When an argument exceeds the limits of a table, a warning message is printed. The rules for a table name are the same as for a variable. All tables are essentially in COMMON and thus can be shared by all modules.

ITERATE ON v, ATOL = vc, PTOL = vc, TIMES = c - This statement is the same as used in the Control Module with the single and very important exception of the absence of the FROM specification. In a module the whole module is iterated upon except the INITIALIZE statement. The location of this statement in the module is not important.

INITIALIZE v = c, v = c...up to 17 variables per card - The initialize statement may be used in a module which contains an ITERATE statement. Before the first iteration the variables specified are initialized to the specified values.

COMMON v, v, v... - This statement is used to designate variables which are used in or come from other modules. The rules are the same as for the Control Module statement. Note that only variables which are used in the module need to be listed and that the order is not significant.

(LT)

IF vc IS EQ vc, v = general expression - This statement

(GT)

is similar to the IF statement of the Control Module except that a general algebraic statement is evaluated if the logical statement is true. This statement is often used for limiting conditions: for example, a stall limit might be imposed by the following statements

VMAX = TABLE VEL (POW, FOW)

IF VMAX IS GT VSTL, VMAX = VSTL

which says that VMAX will not be greater than VSTL.

PRINT v, v, v... - up to 40 variables per card - The statement is the same as above except that regardless of where it is located in the module the data is not printed until the module has been run.

NO ORDER - Normally a module is run with the statements in the same order as they were read, and if the sequence must be changed an error message is produced. This statement allows the sequence to be changed without producing an error message.

Data Statements

Data can be entered following any of the modules (including the Control Module) when the model is first loaded into the computer. This is done with no special instruction. For data to be read by a module during the running of the program, the RUN MOD n statement is preceded by a READ statement. At no time does the user have to specify in the model how much or what data is to be read.

For input of variables the following form is used on the cards:

v = c, v = c, v = c...

There may be up to twenty variables per card. The commas are required to separate the statements. The following example is an illustration of two cards of data.

ALT = 2000, OAT = 35., GW = 10,000
DL = 8.5, VRC = 500.

Only variables which are referred to in a module (or in its COMMON statement) may be entered.

Input of tables requires somewhat more care. The first card must be of the form:

TABLE NAME = n, SIZE = (c, c, c)

This statement is used to assign a name to a table and to define its size. This statement must be followed by the data for the table. The name must conform to the same rules as a variable name. The size need only contain the number of arguments needed to specify the array size; for instance, if a table has 10 "x" values and 3 "y" values, the size would be (10,3). The order in which the data is input is given below. The data cards are of the form:

c c c c

Each card contains up to 8 constants. This form is used only for table data input. This card is the only one with a specific format. Each constant must be contained in a field of 10 columns, 1-10, 11-20, etc. Each constant must also contain a decimal point. Otherwise the rules are the same as for a normal constant. The order in which the data is input will now be described. x, y and z correspond to the first, second and third arguments in a $v = \text{TABLE } n(x,y,z)$

statement. Consider a TABLE NAME statement with SIZE = (i, j, k). The first thing to be input would be i values of x followed by j values of y and then k values of z. Then the table is read in with the first index varying first, then the second, then the third. That is, the elements of a (3,4) table would be read in this order: (1,1), (2,1), (3,1), (1,2), (2,2),... A new card must be started whenever one of the indices returns to 1. The values of x, y, z must be in ascending order. They may be positive or negative and the increments need not be constant.

The following is an example of a table which has three x values and four y values.

| | | | | |
|---|-----|-----|------|-----|
| | 5 | 2.6 | 3.4 | 5.8 |
| | 2.5 | 2.1 | 3.2 | 5.5 |
| Y | 1 | 1.9 | 2.85 | 5.4 |
| | 0 | 2.0 | 3.0 | 5.5 |
| | | 0 | 10 | 20 |
| | | | X | |

The data cards would be as follows:

| <u>Card #</u> | <u>Contents</u> | | | | <u>Comments</u> |
|---------------|-----------------|----------------------------|------|-----|-----------------|
| 1 | TABLE | NAME = EXMP, SIZE = (3, 4) | | | |
| 2 | 0 | 10.0 | 20.0 | | x values |
| 3 | 0 | 1.0 | 2.5 | 5.0 | y values |
| 4 | 2.0 | 3.0 | 5.5 | | |
| 5 | 1.9 | 2.85 | 5.4 | | |
| 6 | 2.1 | 3.2 | 5.5 | | Table |
| 7 | 2.6 | 3.4 | 5.8 | | |

SYNTAX RULES FOR EXPRESSIONS

The rules for general expressions are essentially the same as for any algebraic expression (and are compatible with FORTRAN). Two things to keep in mind are that for multiplication, the multiplication operator must separate the two variables, and since equations are written on one line extra parentheses are sometimes required when dividing.

There are five operations which are allowed, the operation and their symbols are as follows:

| <u>Operation</u> | <u>Symbols</u> |
|-------------------|----------------|
| 1. Addition | + |
| 2. Subtraction | - |
| 3. Multiplication | * |
| 4. Division | / |
| 5. Exponentiation | ** |

There are two other symbols which are allowed in a general expression. They are left and right parentheses which are used for associations and must be used in pairs.

The following are the rules for general expressions (these are a formalization of ordinary algebraic form):

1. All variables and constants, except the first must be preceded by an operator or a left parenthesis. The first may be preceded by a left parenthesis or a sign.
2. All variables and constants, except the last, must be followed by an operator or right parenthesis. The last may be followed by a right parenthesis.
3. A left parenthesis must be preceded by a left parenthesis or an operator unless it is the first symbol in the expression, in which case it may be preceded by a sign.
4. A left parenthesis must be followed by a left parenthesis, a variable, a constant, or a sign.

5. A right parenthesis must be preceded by a right parenthesis, a variable, or a constant.
6. A right parenthesis must, unless it is the last symbol on the card, be followed by a right parenthesis or an operator.
7. An operator must be preceded by a variable or a right parenthesis.
8. An operator must be followed by a left parenthesis or a variable.

The following are examples of general expressions which conform to the rules.

$$A + B$$

$$A*B + C**D$$

$$(A + B)**1 3 + (2*(3 + B - C))**(2*K)$$

$$(A + B + C)/(D + E + F)$$

$$(TIM + PHSE)* PIE*2$$

$$(((X + 3)*6 + 2)*B + C)**.5$$

$$6*A + 3*B + 5/C$$

The order in which operations are performed are:

1. Exponentiation
2. Multiplication and Division
3. Addition and Subtraction

The order of evaluation is from left to right, with parenthetical expressions being evaluated first and then the expression as a whole. Note that the division operator applies only to the variable or parenthetical expression immediately following it, i.e.,

$$A/B*C = \frac{AC}{B}$$

PROGRAM OPERATION

The first deck to be loaded must be the control module. This is followed by any appropriate data. Then the individual modules are loaded, each optionally followed by a block of data. These modules may be loaded in any order. The order in which they are used is solely determined by the statements of the control module. After the last module is input, appropriate blocks of data follow in the order in which they will be called by READ statements during execution of the program.

Each of the above units must be separated by an "end-of-file" card which contains an /* in columns 1 and 2. Thus the input deck will appear as follows:

```
(Control Module)
/*
(Data)
/*
(Module)
/*
(Data)
/*
(Module)
/*
:
:
(Last Module)
/*
(Data)
/*
/*
(Data)
/*
(Data)
/*
:
:
```

Data input is assumed after each module. Even if no data are entered then the two /* cards must still appear:

```
:
:
(Module)
/*
/*
(Module)
:
:
```

After the last module is entered, two /* cards instruct the computer to start running the model. If the last module is not followed by input data, then:

```
      :  
      (Module)  
      /*  
      /*  
      /*
```

PROGRAM LIMITATIONS

The following limits exist in the present version of ZODIAC II.

| | |
|---------------------|---------------------------|
| Common variables | - 200 maximum |
| Noncommon variables | - 200 maximum in a module |
| Constants | - 200 maximum in a module |
| Equations | - 100 maximum in a module |
| Tables | - 20 maximum |
| Modules | - 30 maximum |
| Iterate statements | - 4 maximum in a module |

Constants may not contain more than fifteen characters.

ERROR CODES

During operation of the program, certain violations of rules or apparent violations of logic may occur. When this happens a coded error message is printed. The codes are given in Table IX.

TABLE IX. ERROR CODES

| Code | Meaning |
|------|---|
| 1 | Number of common variables exceeds 200 |
| 2 | Number of constants exceeds 200 in module |
| 3 | Number of equations exceeds 100 in module |
| 4 | Missing parenthesis |
| 5 | "=" missing or incorrectly placed |
| 6 | Name length on data card too long |
| 7 | Constant exceeds 15 characters |
| 8 | Number of noncommon variables exceeds 200 in module |
| 9 | Undefined variable in module |
| 10 | Equations reordered - possible error |
| 11 | Name of argument in table lookup too long |
| 12 | More than 3 arguments in a table lookup |
| 13 | Invalid character |
| 14 | Incorrect symbol |
| 15 | More than one "=" on card |
| 16 | --- |
| 17 | Undefined "FROM" on iterate card |
| 18 | No name on a MODULE NAME card |
| 19 | Incorrect argument on IF card |
| 20 | Incorrect operation on IF card |

TABLE IX - Continued

| Code | Meaning |
|------|---|
| 21 | Incorrect format on IF card |
| 22 | More than 4 ITERATE statements in a module |
| 23 | More than 30 modules |
| 24 | Illegal command |
| 25 | Number of iteration exceeds allowed number |
| 26 | Illegal statement in control module |
| 27 | More than 20 tables |
| 28 | Number of arguments in a table lookup is inconsistent |
| 29 | Table lookup requires extrapolation |
| 30 | Error on table input |
| 31 | More than 18 variables initialized in module |
| 32 | Invalid operator on a control module card |
| 33 | Name too long |
| 34 | Undefined variable in control module |

In general, the program will continue to run even though errors are found. Invalid variables are ignored and other assumptions are made which will allow the completion of the computation. Care must be exercised since some computations with errors will be valid, some will be completely invalid, and some will have limited meaning. This approach, however, is expected to minimize the time required to verify a program.

The only error which will terminate a run is no. 34.

SUGGESTIONS FOR THE NEW USER

Gaining Experience

A good way for the new user of ZODIAC II to gain familiarity with the usage of the program is to first modify existing models, rather than attempting to develop a complete new analytical model.

Changes within individual modules corresponding to mission definition changes, effectiveness criteria, statistical weight analysis, etc., are especially straightforward. It is recommended that each equation be identified by making use of the comment capability on each card.

A next step in the familiarization process would be to add or delete modules and make the appropriate changes in the control module statements.

Making changes in the logic within the modules and especially in the control module will complete the process of familiarization. While these modifications are being performed, computer runs using various combinations of data variations should be conducted.

User Techniques

One of the major objectives of ZODIAC II was to make the model formulation virtually self-explanatory to the engineering user. This has been achieved providing the user does not artificially complicate his model by allowing numerous artificial choices between options, only one of which will be used at one time. For example, it would be tempting to a conventional programmer, when developing a module to estimate drag, to include the relationship for all the types of helicopters and selecting the appropriate one by a coded input such as "1" = cargo helicopter, "2" = utility helicopter, etc. This kind of programming is to be discouraged because it tends to obscure the analytical model.

It is strongly suggested that, when analyzing different helicopters, the proper equations are placed in the proper modules. These changes are easy to make and the engineer will always know what model he was using. This, of course, is the objective of this program.

One of the great advantages of this program is that computations can be easily performed that were not envisioned by the original programmer. It is suggested that the engineering users do not hesitate to increase the sophistication of the computations by adding new modules, modifying old ones, using new types of data.

Another advantage of this program is that it is possible to vary any parameters without having made prior provision in the basic program. For example, suppose it were desired to study several combinations of number produced (NP), monthly flight hours (MFH) and yearly attrition rate (YAR). In this case the control module could be preceded by a POINT and READ statement and followed by a PRINT and an ITERATE statement as follows:

```
POINT NEW  
READ
```

Original control module

```
PRINT NP, YAR, MFH  
ITERATE TIMES = 10, FROM NEW
```

This will cause data to be read in ten times and the complete computation repeated. In reading data, note that the last used values are in effect until a new value is computed or read in as data. Thus, the data package following this modified program could be as follows:

```
:  
/*  
/* (end of model input)  
NP = 1000, YAR = 0, MFH = 100  
/*  
MFH = 300, NP = 100  
/*  
YAR = 10  
/*  
YAR = 50, NP = 100  
/*  
NP = 500  
/*  
YAR = 10, MFH = 200  
/*  
etc.
```

Thus, it is seen that by adding the few cards shown above, it is possible for the engineer to vary any parameters he wishes and in any manner he wishes.

There is an area where the user must use some caution. It was intentional in the design of ZODIAC II that no argument list be used (as in FORTRAN), and that all interchange of data between modules be carried out through the common variables. This technique helps to minimize the risk of making local changes in modules. However, if the same module is used at more than one point in the control module, some of the same variables will change their values more than once during the computation. This is no problem unless it is desired to use one of the results of an early use of a module after the module has been run again. The same effect occurs if the same variable is computed in different modules. For example, consider the computation of fuel load, WFL, at different points in a mission where each segment makes a computation of the form $WFL = WFL + \text{DELTA}$.

```
RUN MOD TAKE OFF
RUN MOD CLIMB
RUN MOD CRUISE
etc
```

If it is desired to know at some later point the fuel used after takeoff but before climb, this can be accomplished by naming a new variable and inserting the simple equation as follows:

```
RUN MOD TAKE OFF
  WFLO = WFL
RUN MOD CLIMB
etc
```

WFLO will retain its value as desired. WFL must be in a COMMON statement in the control module.

Techniques such as suggested above will be found to be readily picked up by engineers without any conventional programming experience in a short time.

METHOD APPLICATIONS

UTILITY MISSION

As an application of the techniques and computer program discussed, a number of conditions have been analyzed. Most of the data presented here is for the utility mission as described in Tables I and II. In addition to the data discussed previously, the following parameters have been used in these computations:

NP (no. of ship produced) = 1000
YAR (yearly attrition rate) = 40
SL (system life) = 10 years
WCR (crew weight) = 400 lb
MFH (average monthly flight hours) = 100 hr
PM (power margin) = 5 percent
NEN (number of engines) = 2
DL (disk loading) = 8 lb/ft²
TS (main rotor tip speed) = 700 ft/sec
BL (blade loading) = 80 lb/ft²
NRM (no. of main rotor blades) = 4
SM (airspeed margin to stall) = 10 kt
RCP (fuel reserve) = 10 percent

The first design point was taken as 4000 ft, 95°F, 500 ft/sec rate of climb. "Current" SFC data was used (See Figure 3).

For the statistical weight analysis the following assumptions were made (see Table III):

AG = 1 (no. of auxiliary landing gears)
BF = 1 (blade folding included)
BRK = 1 (main rotor brake included)
ITR = 1 (intermediate tail rotor gearbox included)
KLG = .0329 (tricycle landing gear)
KNAC = .96 (nacelle for twin engines mounted to transmission)
NR = 1 (no. of main rotors)
NULT = 4.5 (ultimate load factors)
TAF = 13 (type of aft fuselage (see Table III))
TPU = 0 (no auxiliary power unit)
TPY = 62 (type of pylon configuration (see Table III))

The ground rules used are as follows:

1. The disc loading at the second design point is the same as for a single-point design helicopter. This results in a reduced disc loading at the first design point for the two-point design helicopter.
2. The rate of climb specified for the single-point design helicopter is also obtained for both the second and first design points of the two-point design helicopter.
3. The "probability of hover" calculation includes the requirement to achieve the above vertical rate of climb.
4. All designs include the fuel load required for the standard mission.

The second design points studied included all combinations of altitude from 0 to 4000 ft in increments of 1000 ft and temperatures from 20°C to 35°C in increments of 5°C.

Payload Utilization

A payload utilization function was used as follows:

| <u>Payload</u> | <u>% Utilization</u> |
|---------------------------------|----------------------|
| <u>(% of 2nd Point Payload)</u> | |
| 40 | 15 |
| 60 | 25 |
| 80 | 30 |
| 100 | 25 |
| 110 | 5 |

The model listing is given in Appendix II.

Weight Variation

The variation of the gross weights of the two-point design helicopters is shown in Figure 19 for combinations of design altitude and design temperature. This figure shows the gross weight at point two, which is the maximum gross weight at the second design point making use of all the power available at this condition. At this point, the helicopter can hover and carry out the specified vertical rate of climb (500 ft/sec).

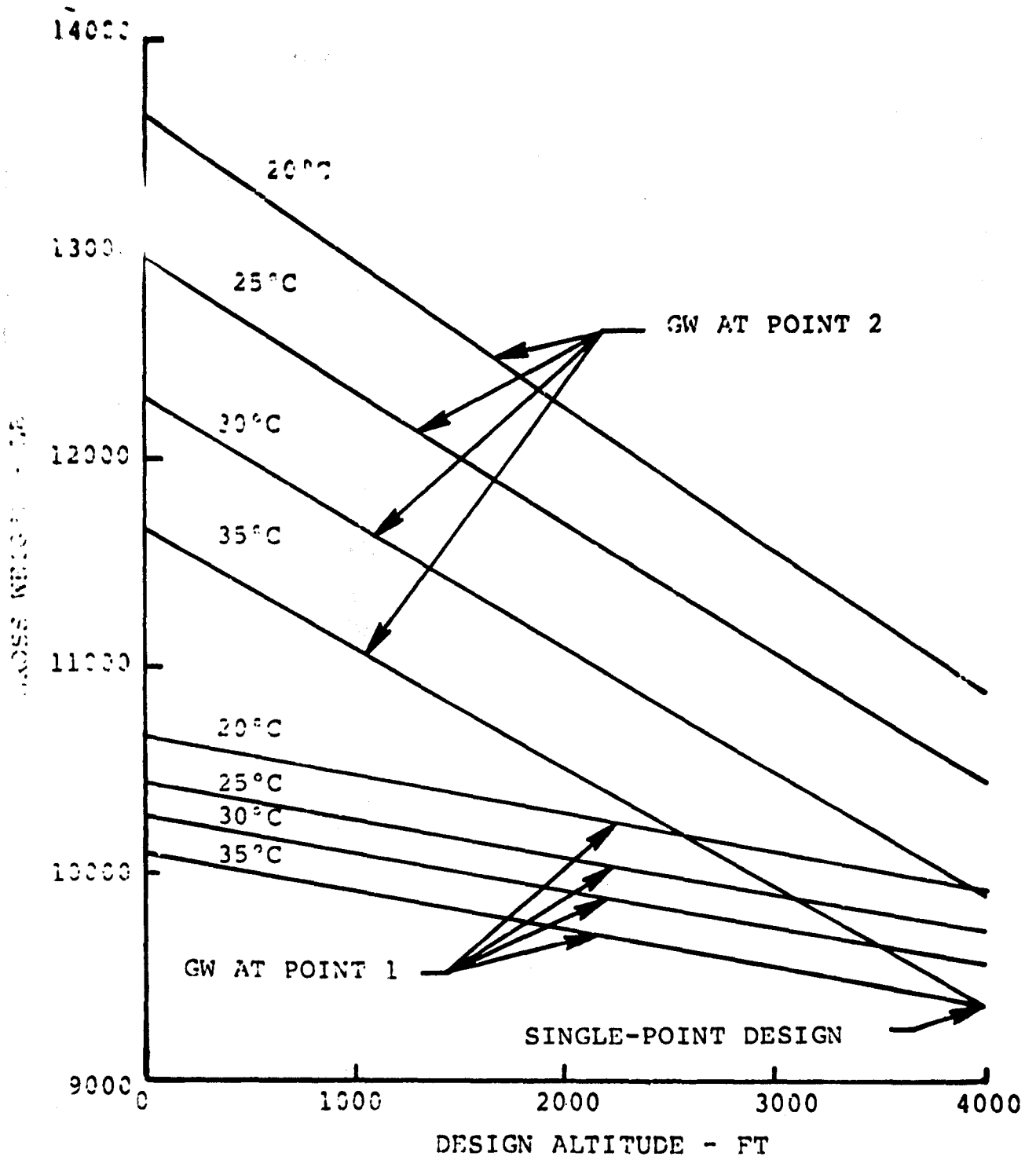


Figure 19. Two-Point Design Gross Weights for Utility Mission.

Also shown in Figure 19 is the resulting gross weight at point one, that is, with the mission payload. The changes in these weights are due to the changes in empty weight and mission fuel requirements. The gross weight at the second design point includes, in addition, the increased payload.

Figure 20 illustrates the payload capability as a function of the second design point. Note that at point one, the standard mission payload applies to all second design points.

Engine and Transmission Ratings

Figure 21 illustrates the effect of second-point design selection on transmission limits. As the second-point design temperature and altitude are reduced, the engine power available at the second design point is increased. The transmission rating is increased to match this power level, and the engine is derated less and less.

Figure 21 also indicates an effect of second-design point conditions on required power rating. This is a secondary effect and results from empty weight changes as the second-design point capability is added to the helicopter. As the second-design point temperature or altitude are decreased, the empty weight increases, and the first design point requirements can no longer be met with the single-point design engine.

Cost Variation

The computed cost per flight hour is shown in Figure 22 for several payloads. This cost includes initial costs which are primarily a function of empty weight and operating costs which reflect the effect of the ratio of actual gross weight to design (second point) gross weight. For small payloads the costs are only slightly sensitive to the second design point; however, as the payload increases this sensitivity also increases. This figure shows typical data obtained.

Hover Probability

The cumulative joint probability of hover is an extremely important factor in the overall cost effectiveness computation. It is a factor which is very sensitive to the assumed environmental operating conditions of the helicopter. It is also a quantity which tends to reduce the cost effectiveness of more stringent design conditions. As an illustration of this effect, at a 100-percent payload condition the single-design point helicopter can hover (and climb) 84 percent of the time. That is, 84 percent of the time the environmental

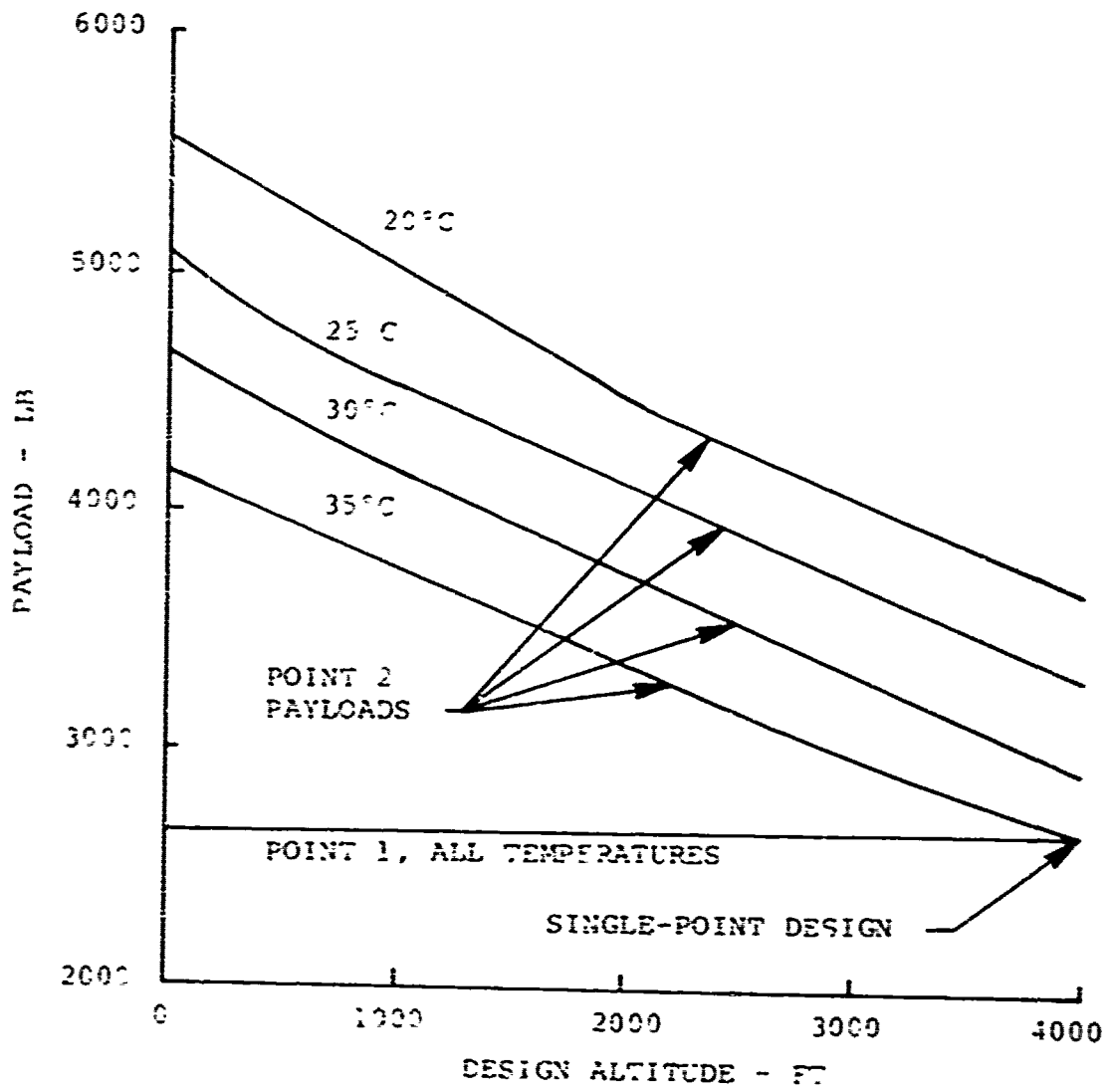


Figure 20. Two-Point Design Payloads for Utility Mission.

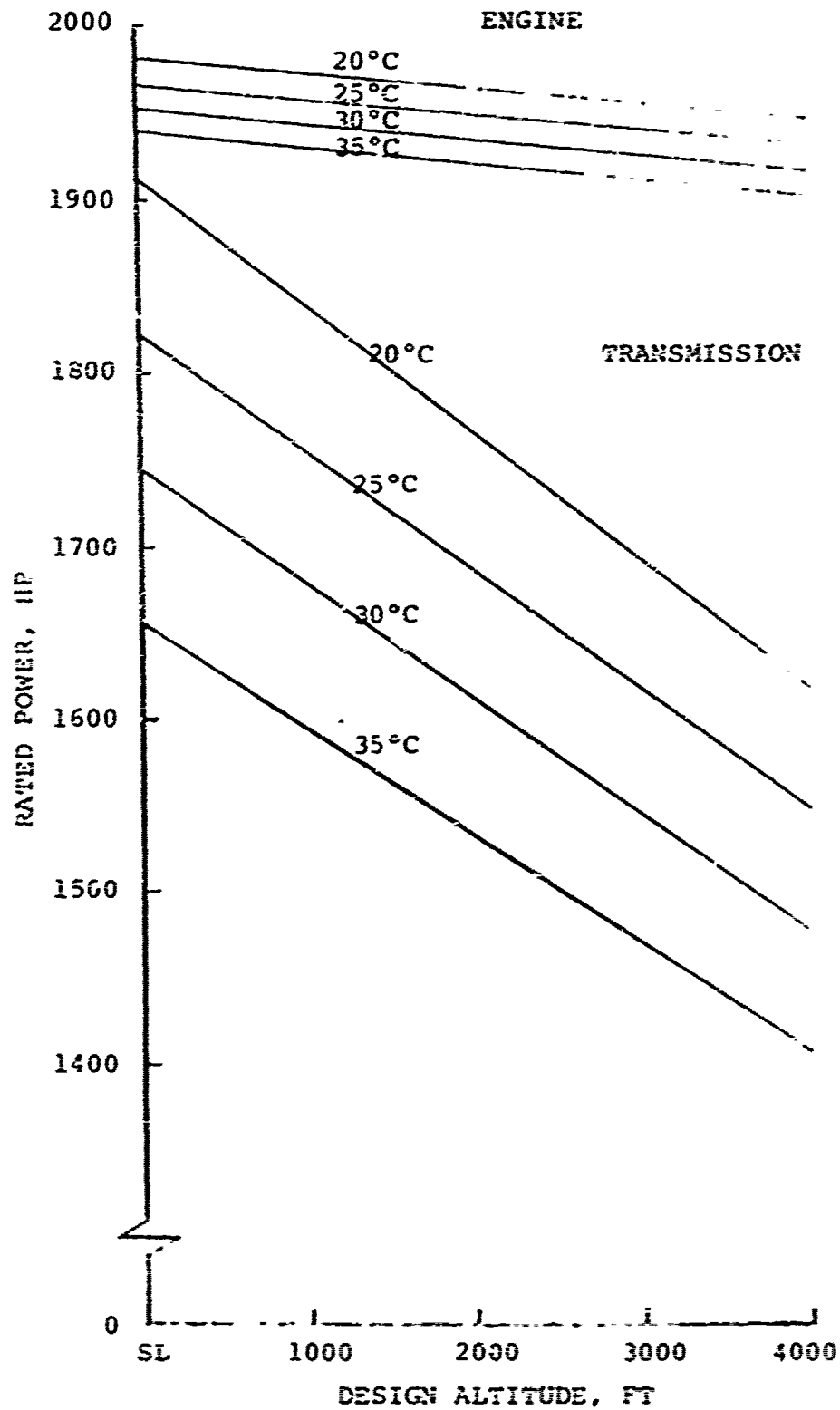


Figure 21. Engine and Transmission Ratings for Two-Point Design Helicopters.

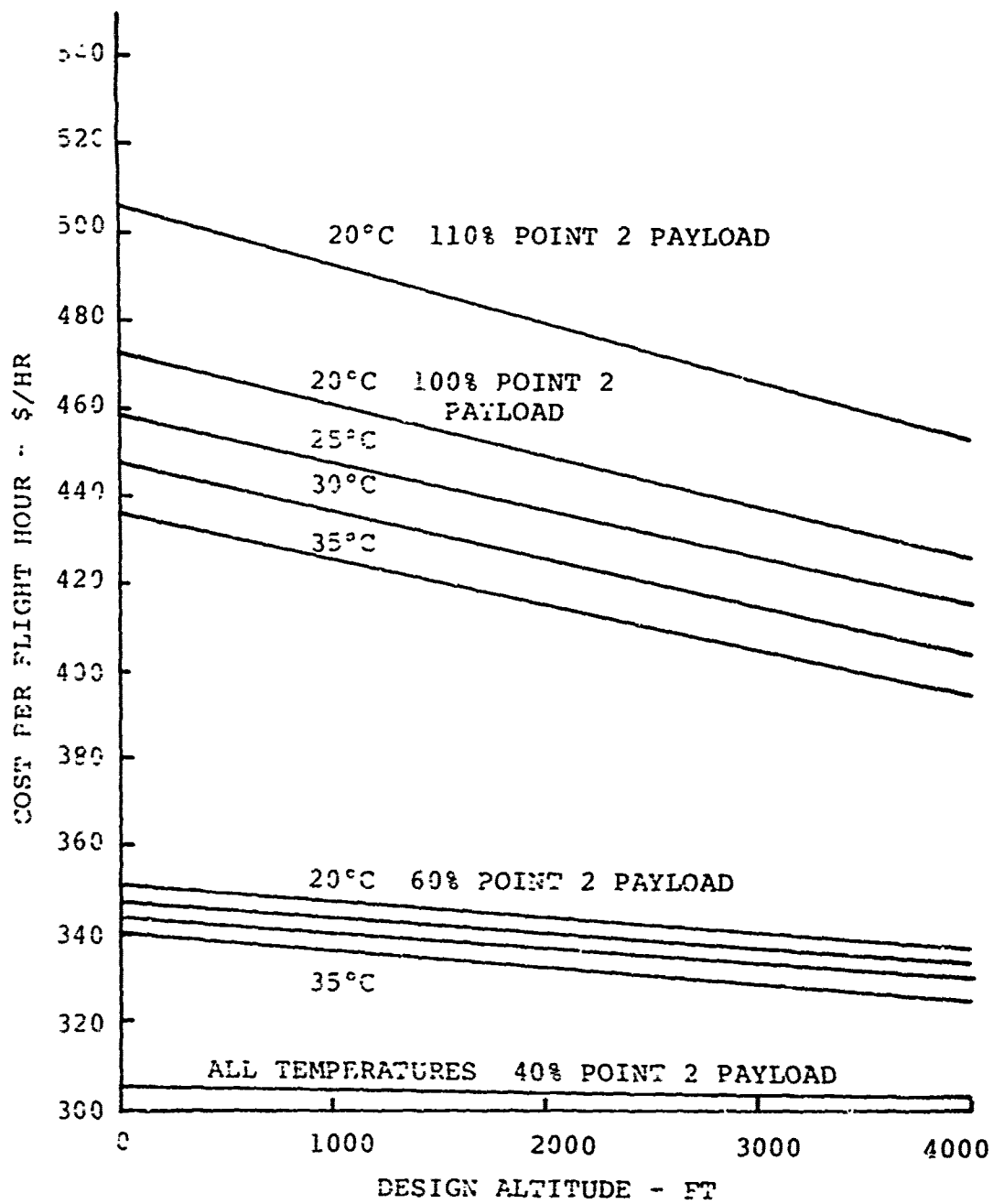


Figure 22. Typical Cost Per Flight Hour Results for Utility Mission.

conditions can be expected to be less stringent than 4000 ft, 35°C. However, a single-point helicopter designed for 2000 ft, 25°C, for example, will be able to hover with its design payload only 34 percent of the time since over much less of the area and time will the operating conditions be less stringent than this design point. Of course, the two-point design helicopter will be carrying larger payloads so there is a rather delicate balance between these two factors. Figure 23 (a-d) presents the probability of hover obtained.

Overall Cost Effectiveness

The final results, including the effects of assumed payload variation, costs, and hover probability, are given in Figure 24. It is seen that local peaks occur at certain temperatures. The optimum point calculated appears to be at 4000 ft, 20°C representing about a 10-percent increase in cost effectiveness compared to the single-point design.

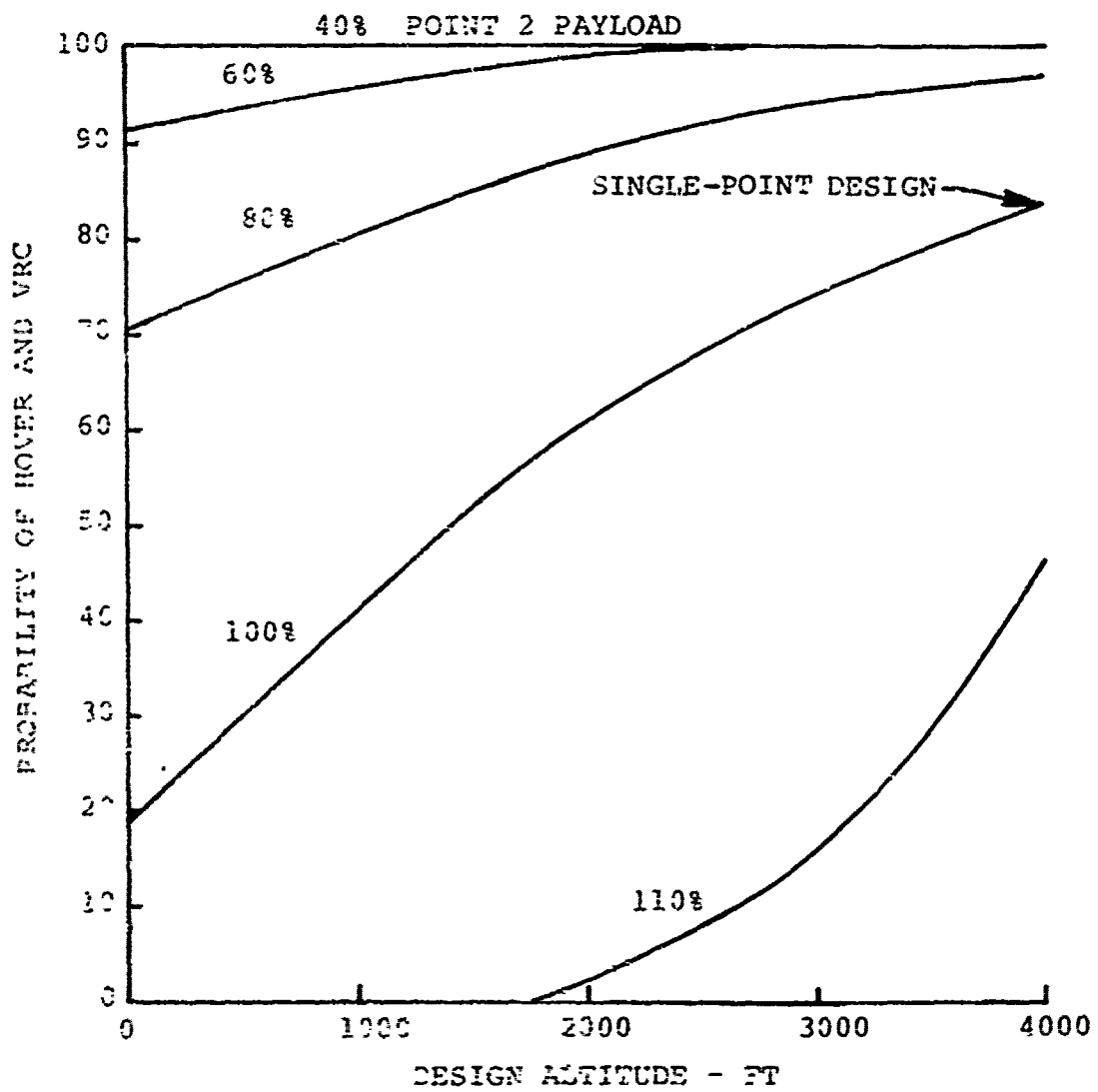
This "optimum" helicopter has an increased design gross weight of about 15 percent and an increased payload at the second design point of about 40 percent.

It must be emphasized, however, that these results are sensitive to the predefined mission, assumed number of production units, assumed payload utilization, environmental statistics, and numerous other factors which will vary with the particular requirements for the vehicle under study.

WEIGHT SENSITIVITY

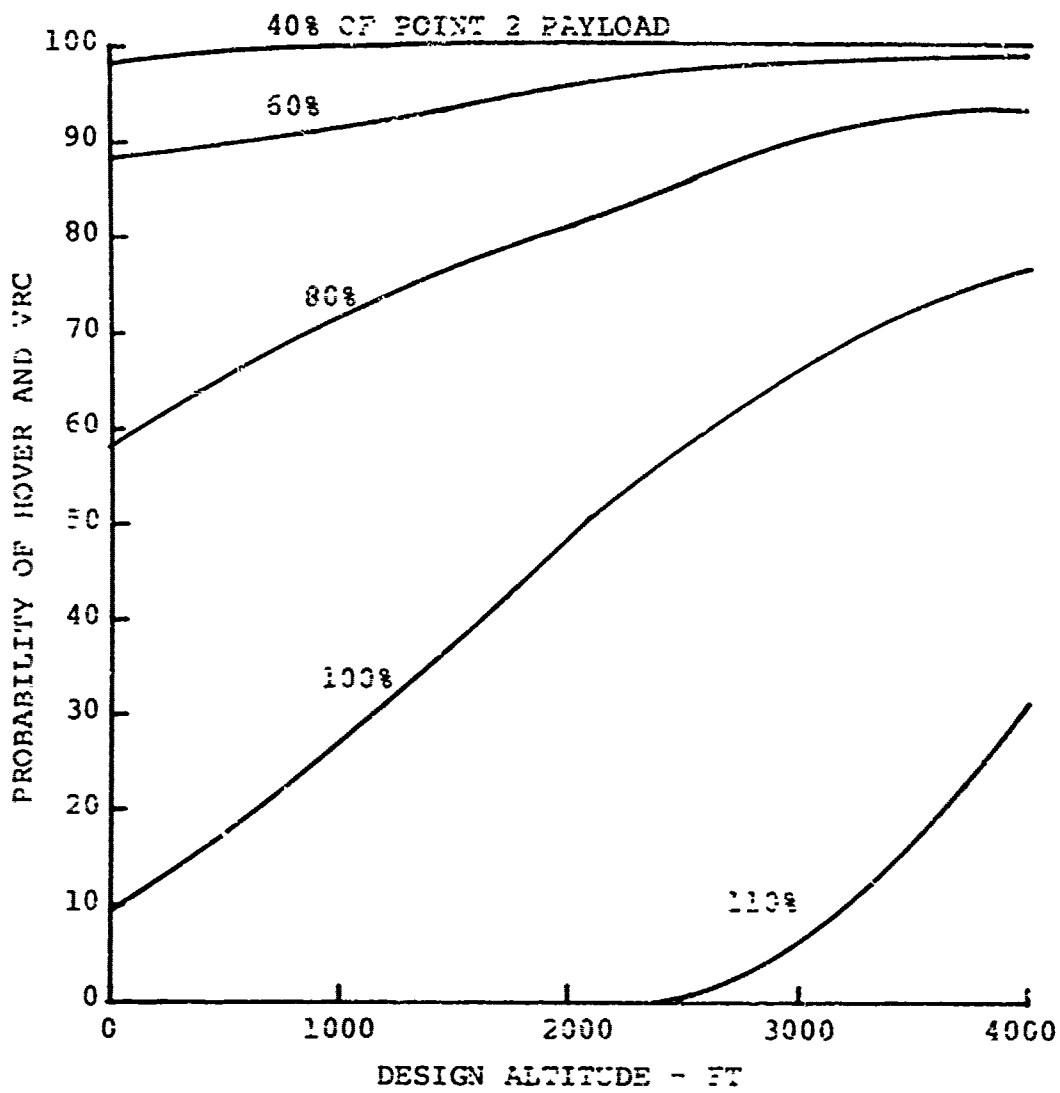
One of the most significant portions of the analytical model is the statistical weight model. In order to gain some insight into the sensitivity to the empty weight, some of the previous computations were repeated with an arbitrary 20-percent increase in predicted empty weight. For comparative purposes the payloads are shown in Figure 25. A comparison of the cost per hour is shown in Figure 26.

The change in probability of hover with increased weight is interesting. At payloads below 100 percent, the heavier helicopter has lower probability of hovering. At 100 percent payload (note that the payloads are not the same), the probabilities are equal. At over 100 percent the heavier helicopter has increased probability of hover. This effect is illustrated in Figure 27 for 25°C. The effect is the same at other temperatures.



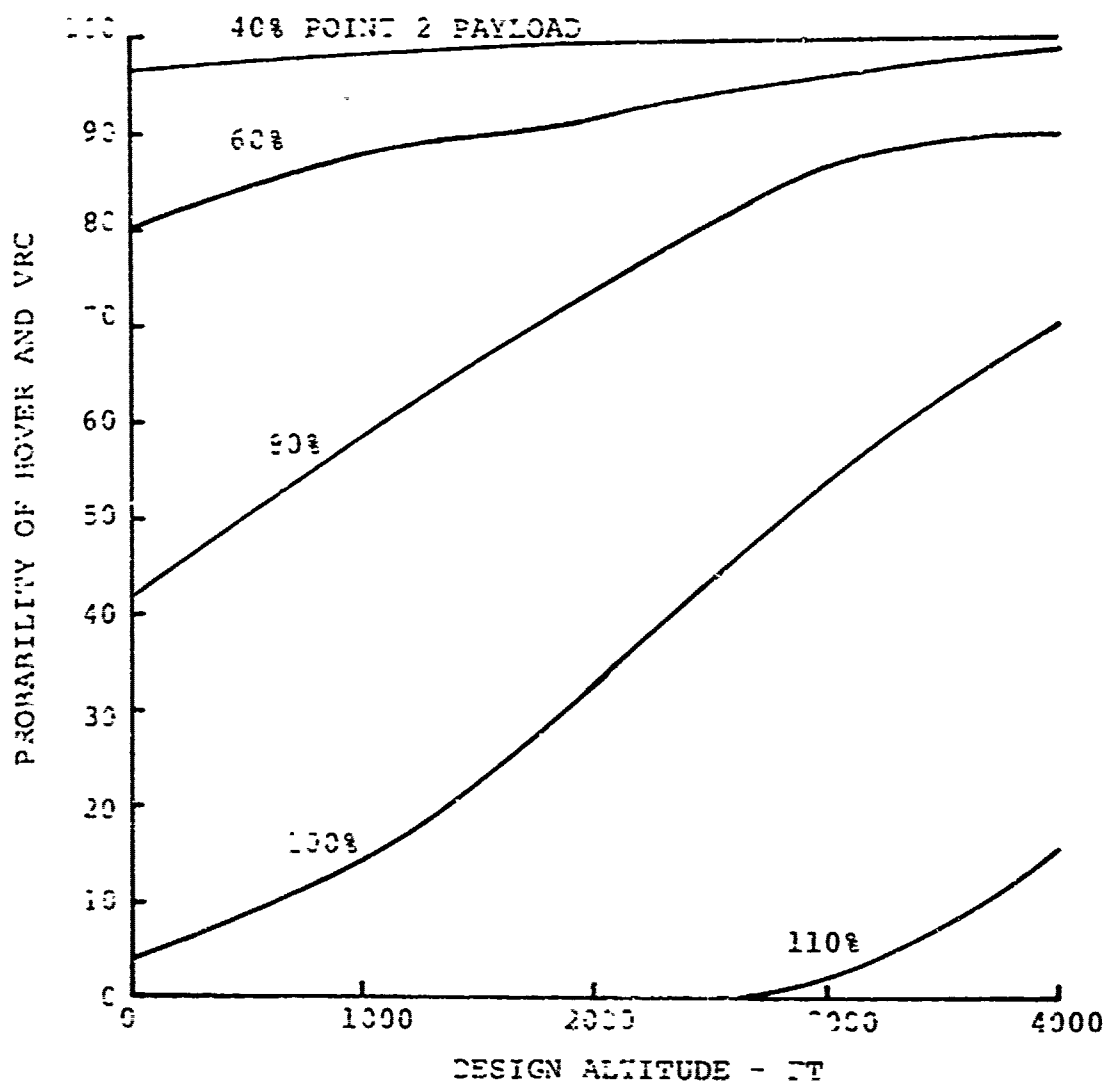
a. Design Temperature = 35°C

Figure 23. Probability of Hover and VRC for Utility Mission.



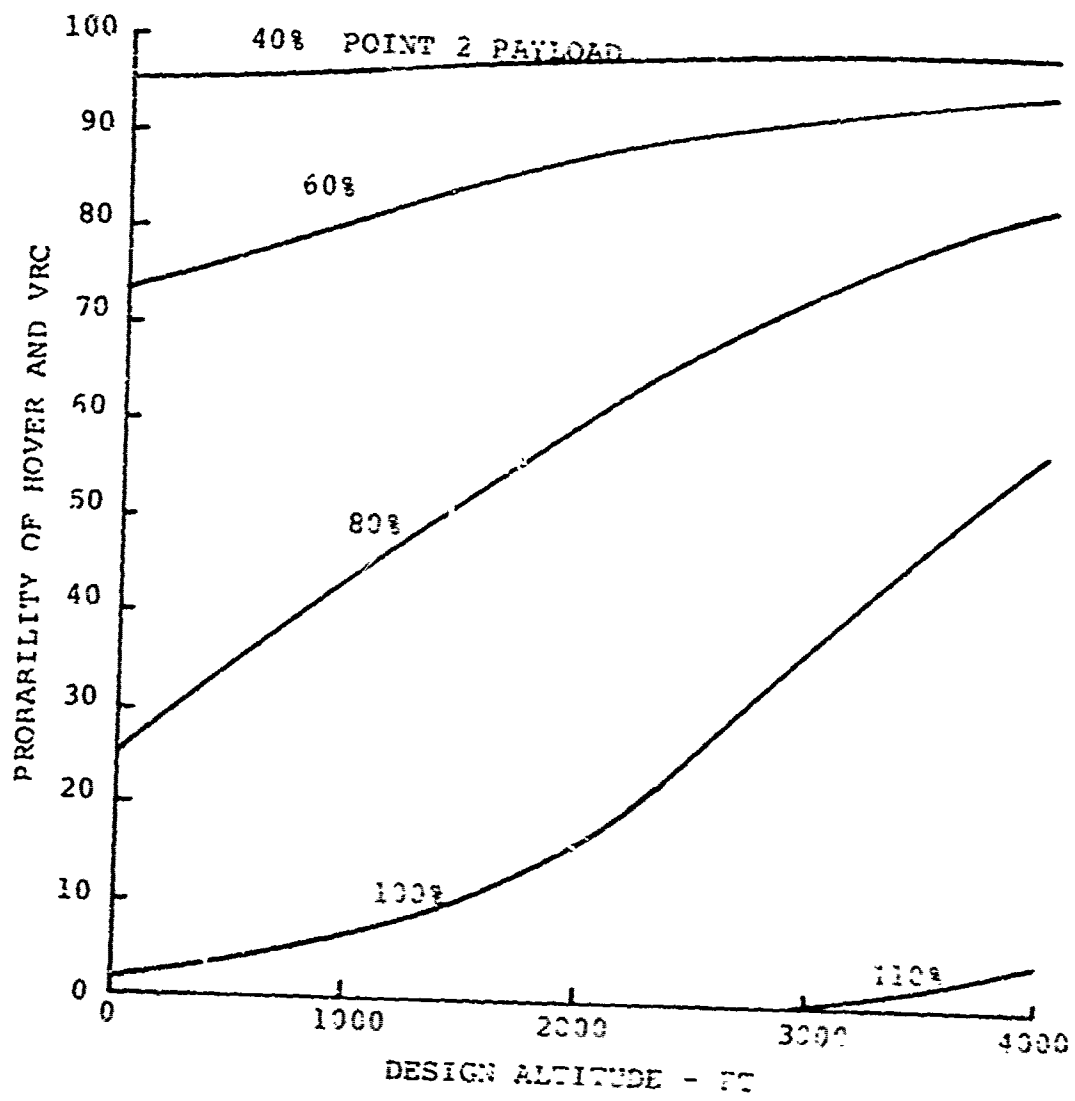
b. Design Temperature = 30°C

Figure 23 - Continued



c. Design Temperature = 25°C

Figure 23 - Continued



d. Design Temperature = 20°C

Figure 23 - Continued

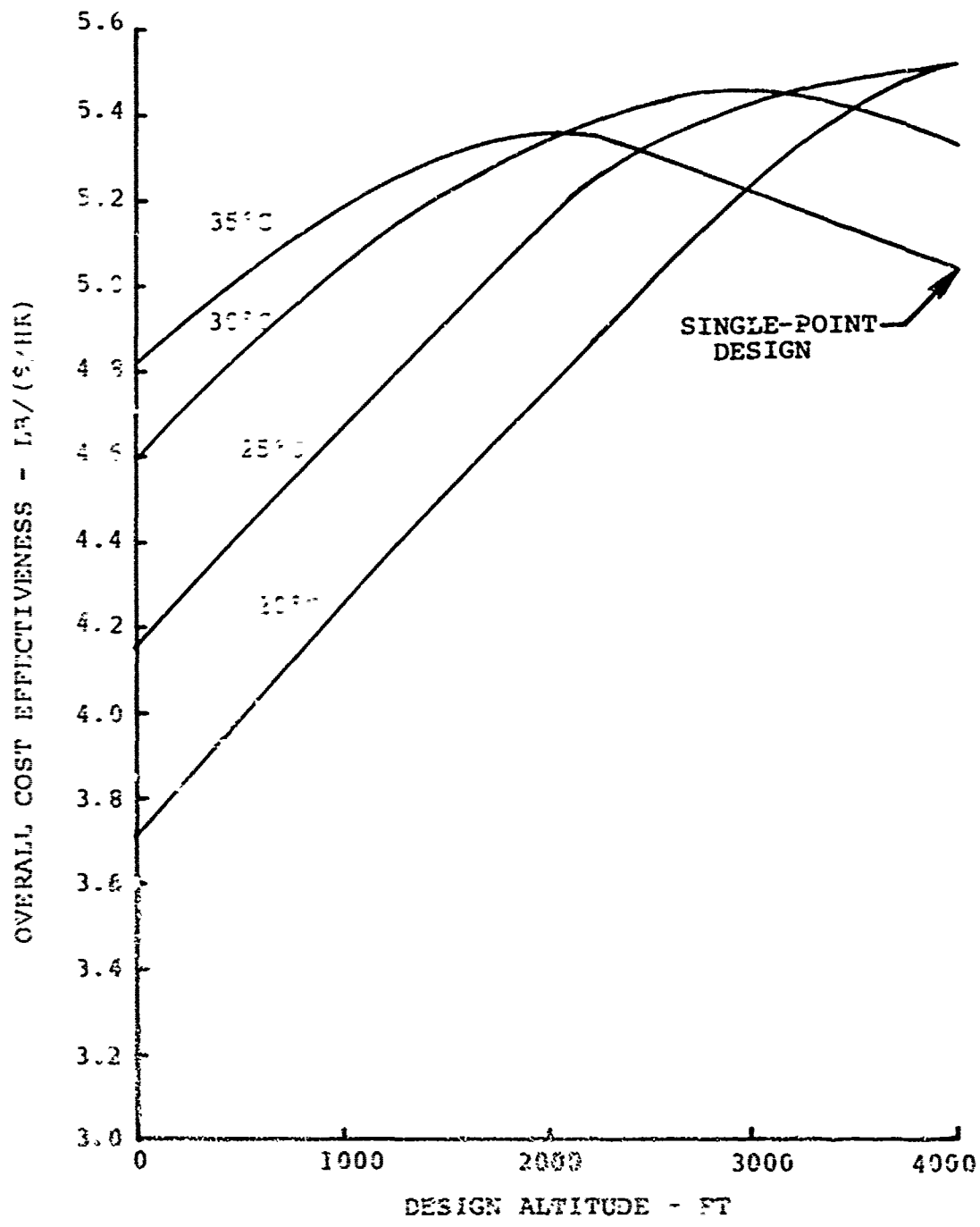


Figure 24 Overall Cost Effectiveness for Illustrative Utility Mission.

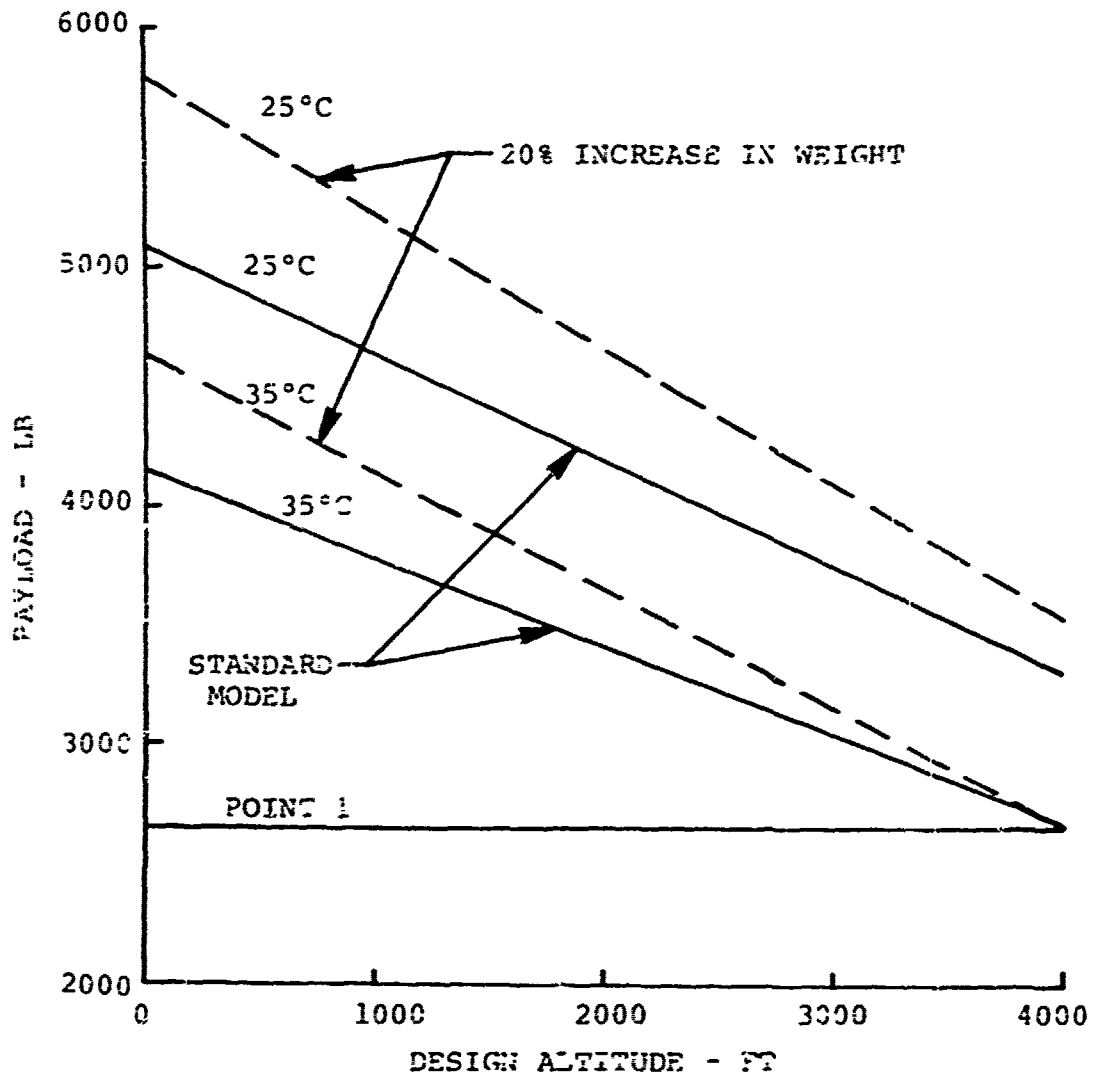


Figure 25. Effect of 20% Increase in Empty Weight Model on Payload - Utility Mission.

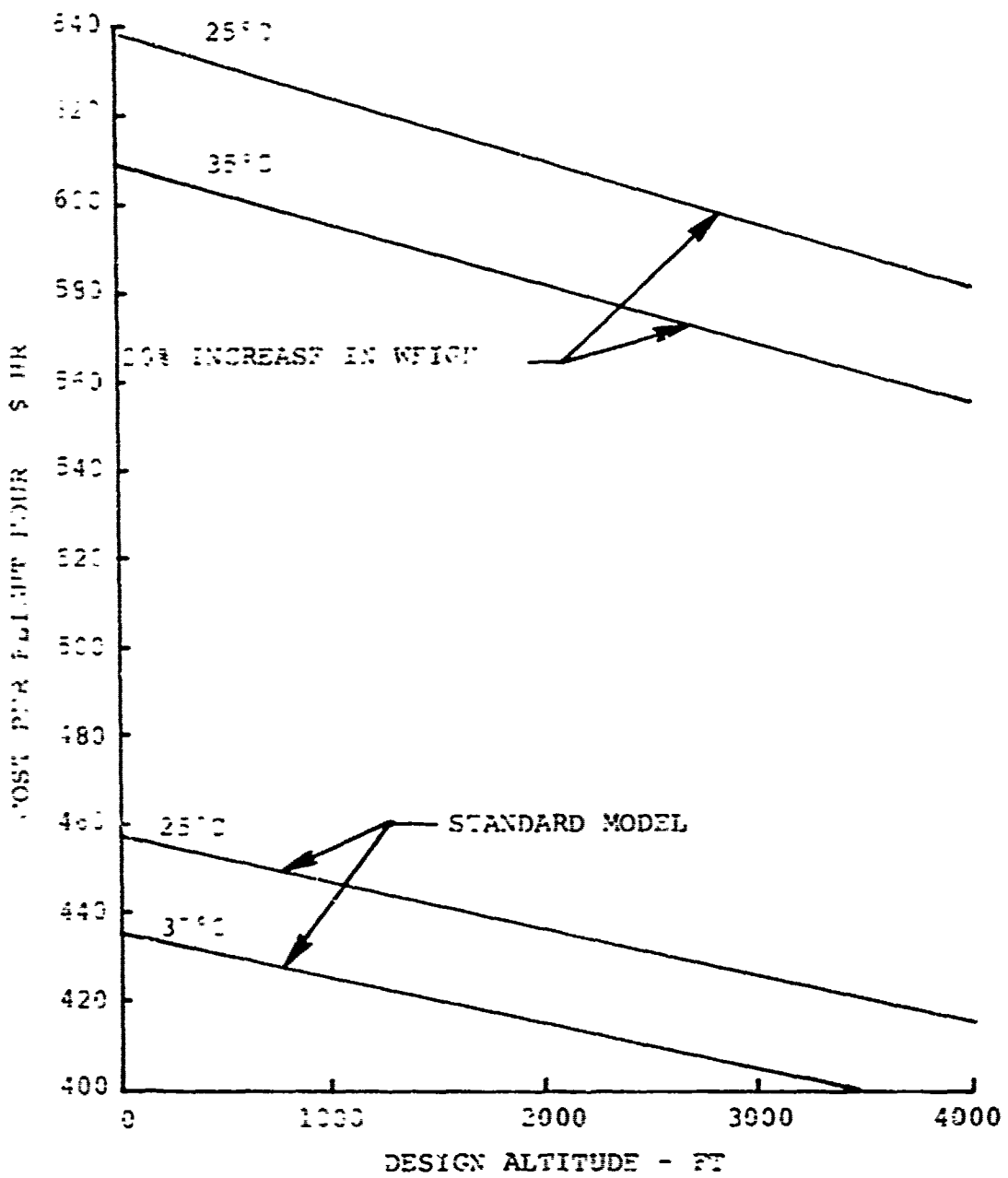


Figure 26. Effect of 20% Increase in Empty Weight Model on Cost Per Hour - Utility Mission.

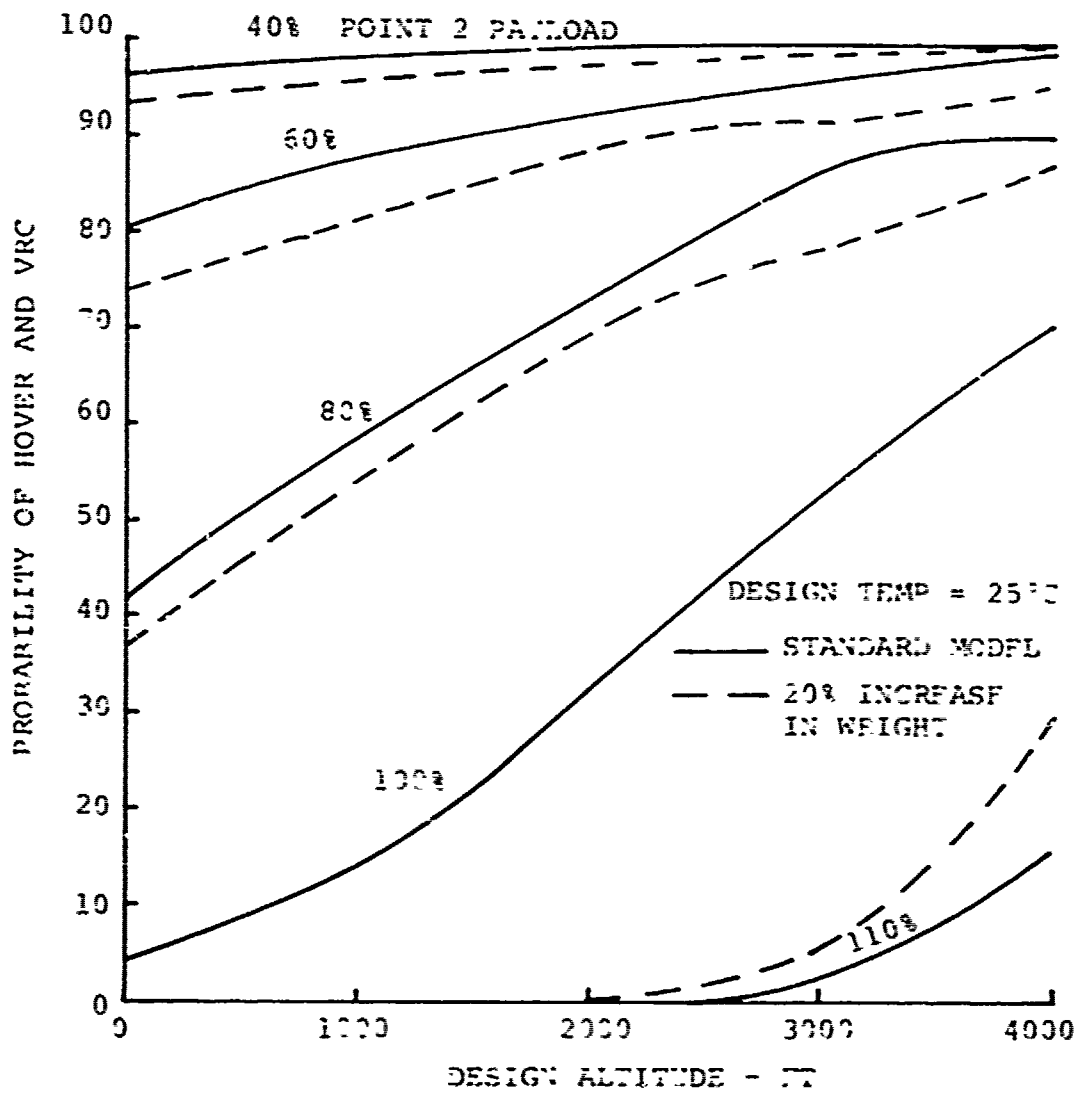


Figure 27. Effect of 20% Increase in Empty Weight Model on Probability of Hover - Utility Mission.

The overall cost effectiveness is shown in Figure 28. While the effectiveness is reduced because of increased costs and reduced probability of hover (for 70 percent of the time), the curves have very similar shapes.

PAYLOAD UTILIZATION EFFECTS

The previous analysis used a payload distribution based on percentages of the maximum. This implies that the size of the payload will always depend on the capability of the helicopter. At the opposite extreme is the concept of missions having no relationship to the maximum capability of the helicopter but having a requirement for the transportation of specific payloads. To consider the effect of such a payload distribution the same schedule of payload was used, except that the payload was a percentage of the fixed first point design payload rather than the variable second point payload.

While the first approach resulted in a highly loaded helicopter, this approach results in lightly loaded helicopters. In general, the probability of hover is significantly increased and the costs are reduced because of reduced maintenance. Since the same payloads are carried at reduced operating costs, the cost effectiveness tends to increase at the more stringent design points. This effect is illustrated in Figure 29. Note that the data of Figures 19 and 20 also apply to this condition.

This result, in effect, says that for a given fixed payload, the larger the helicopter the less the cost will be because the reduced unscheduled maintenance is the dominating factor. This appears unrealistic and suggests a flaw in the cost model.

In actuality, a distribution which is partially fixed and partly dependent on the helicopter's capability is probably more realistic. If we take as an example a 50-percent mix of the two types discussed, the curves on Figure 29 are the result. A comparison of the curves of Figure 29 and Figure 24 illustrates how sensitive the optimization can be to the predicted payload schedule.

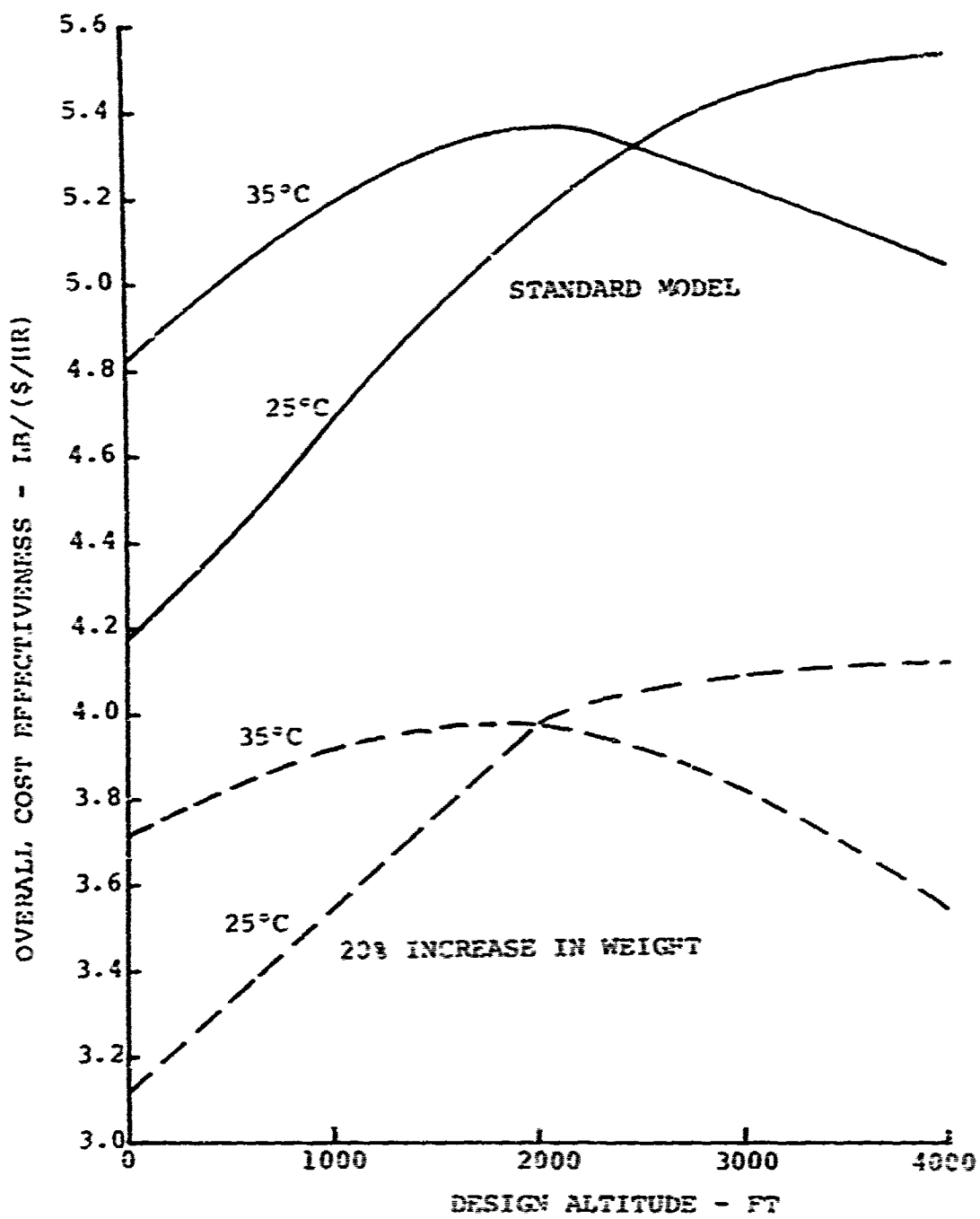


Figure 28. Effect of 20% Increase in Empty Weight Model on Overall Cost Effectiveness of Utility Mission.

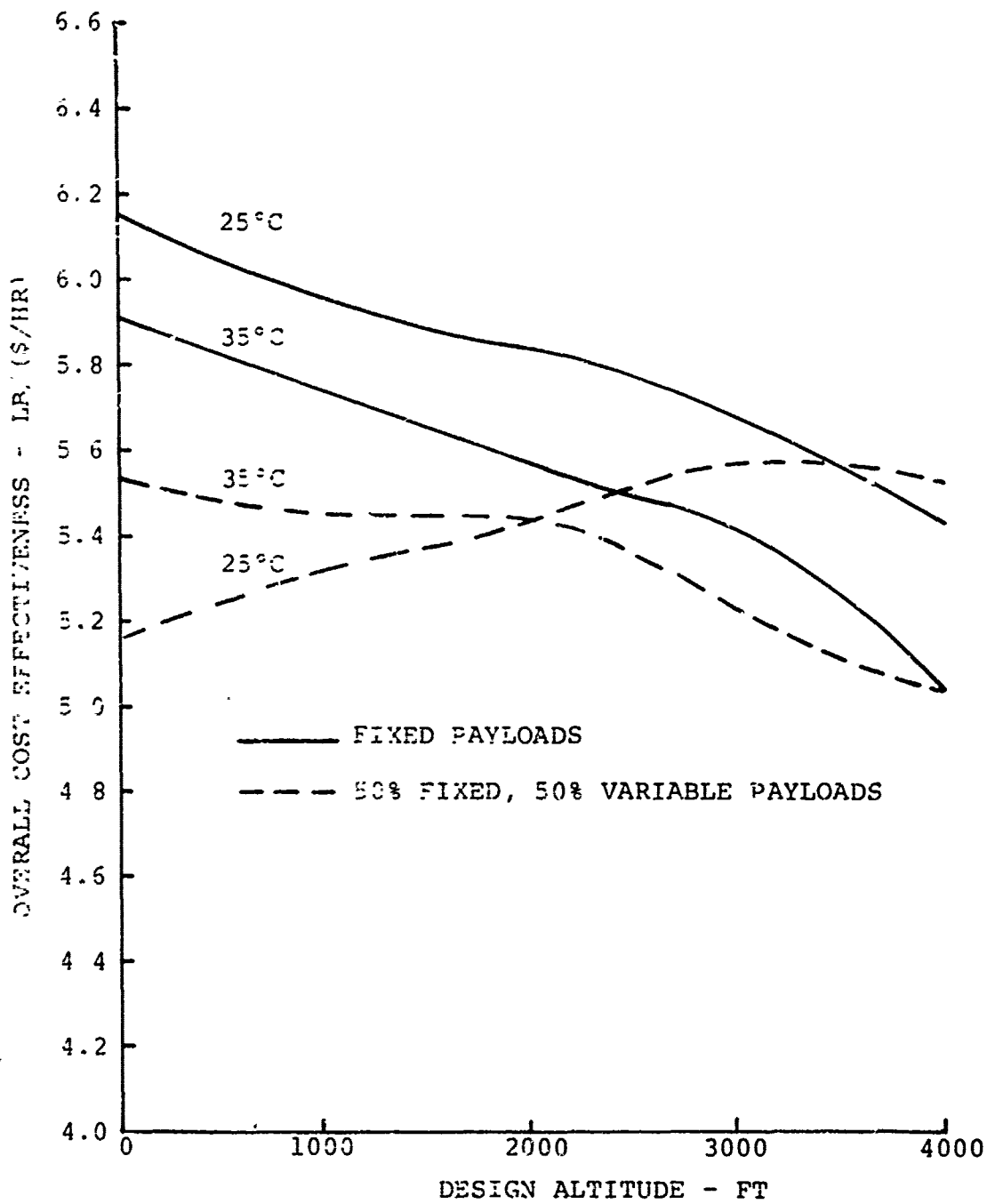


Figure 29. Overall Cost Effectiveness for Fixed and Variable Payload for Utility Mission.

GUNSHIP

Sample computations were carried out for the Gunship Mission. The input is the same as for the Utility Mission except as follows:

DL (Disc Loading) = 9 lb/ft²
BL (Blade Loading) = 90 lb/ft²
TAF = 15 (See Table III)
TPY = 14 (See Table III)

The gross weights and the overall cost effectiveness results for 35°C are shown in Figures 30 and 31.

CRANE

Computations for the Crane Mission were performed for the mission as described in Tables I and II. The input is the same as for the utility ship except for the following:

NEN (no. of engines) = 4
DL (disc loading) = 9 lb/ft²
TS (tip speed) = 750 ft/sec
NMR (no. of main rotor blades) = 6
BL (blade loading) = 90 lb/ft²
ITR = 0 (See Table III)
KLG = .0405 (See Table III)
KNAC = 2.26 (See Table III)
TAF = 10 (See Table III)
TPU = 1 (See Table III)
TPY = 25 (See Table III)

The gross weights and payloads and the overall cost effectiveness are shown on Figures 32 and 33.

TRANSPORT

The results of a sample run of the transport model are presented in Figure 34. The mission for the transport is described in Tables I and II. The transport model differs from the Utility in the following manner:

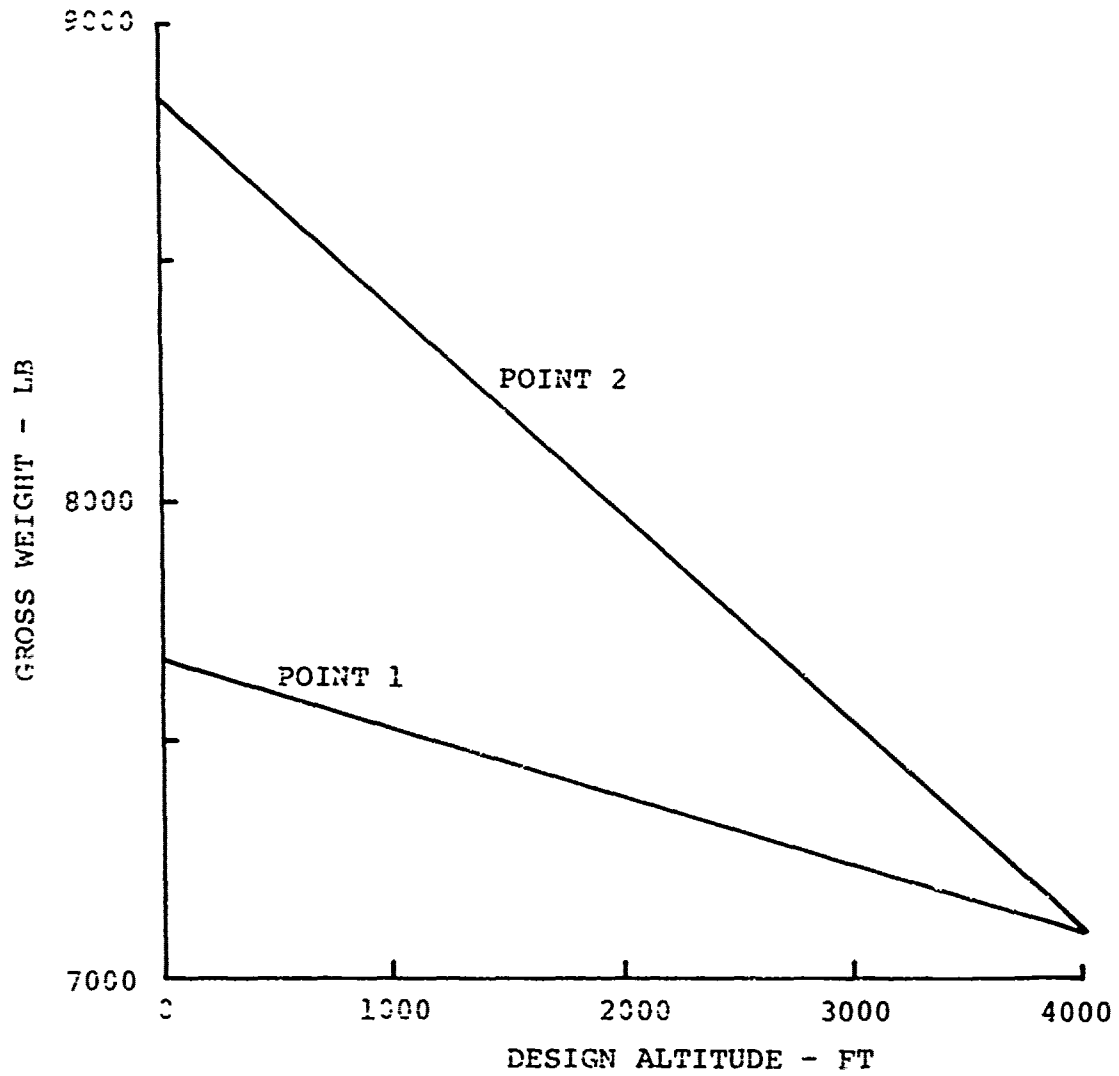


Figure 30 . Gross Weights for Gunship Mission for 35°C.

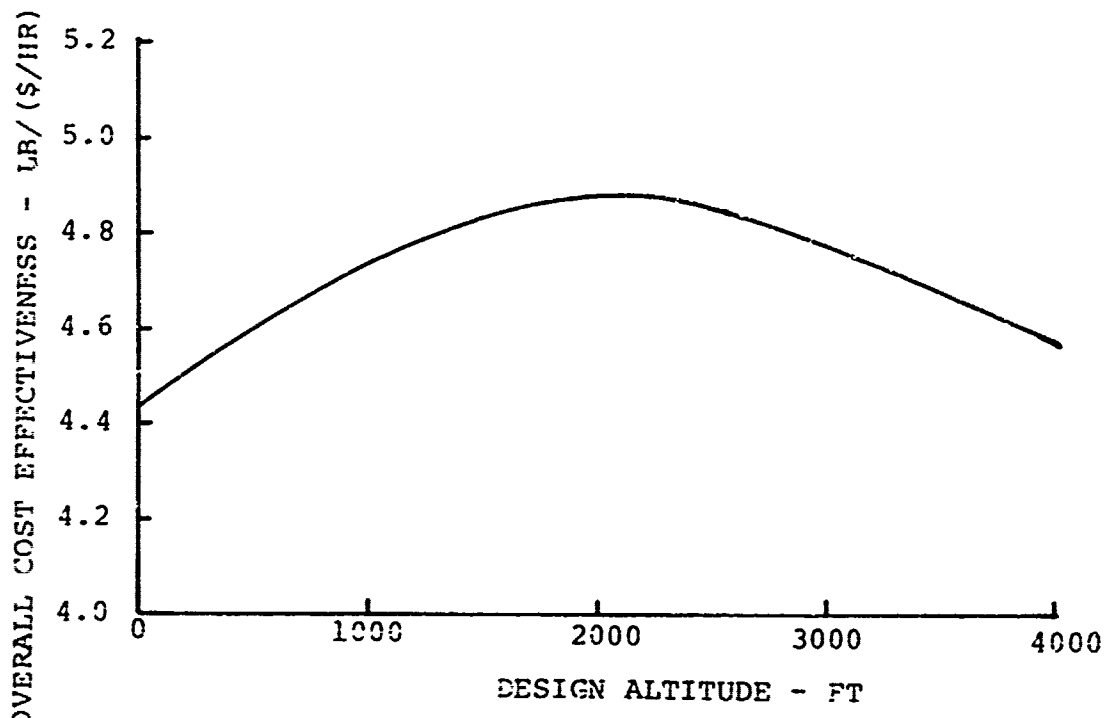


Figure 31 Overall Cost Effectiveness for Gunship Mission for 35°C.

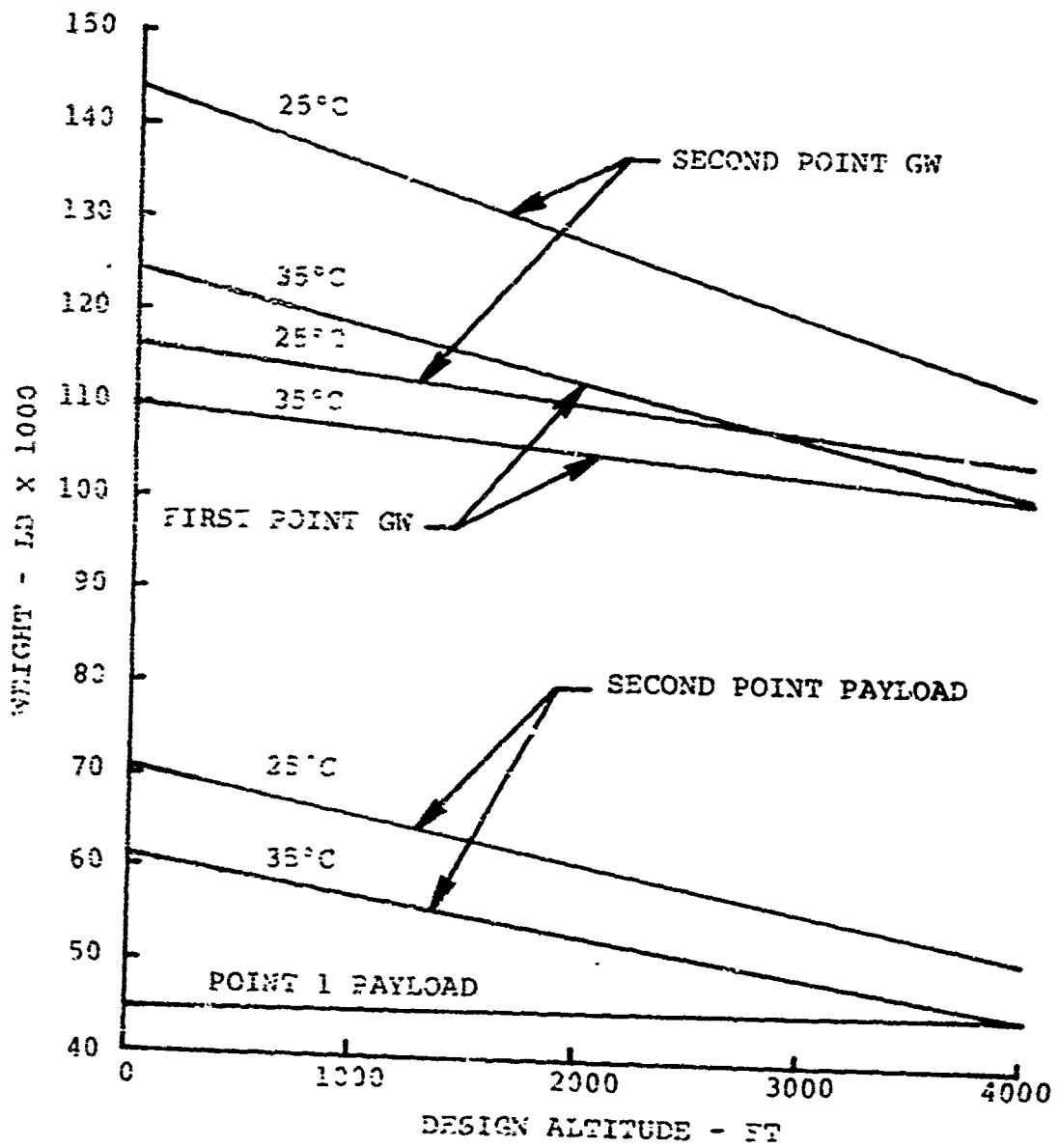


Figure 32 Payloads and Gross Weights for the Crane.

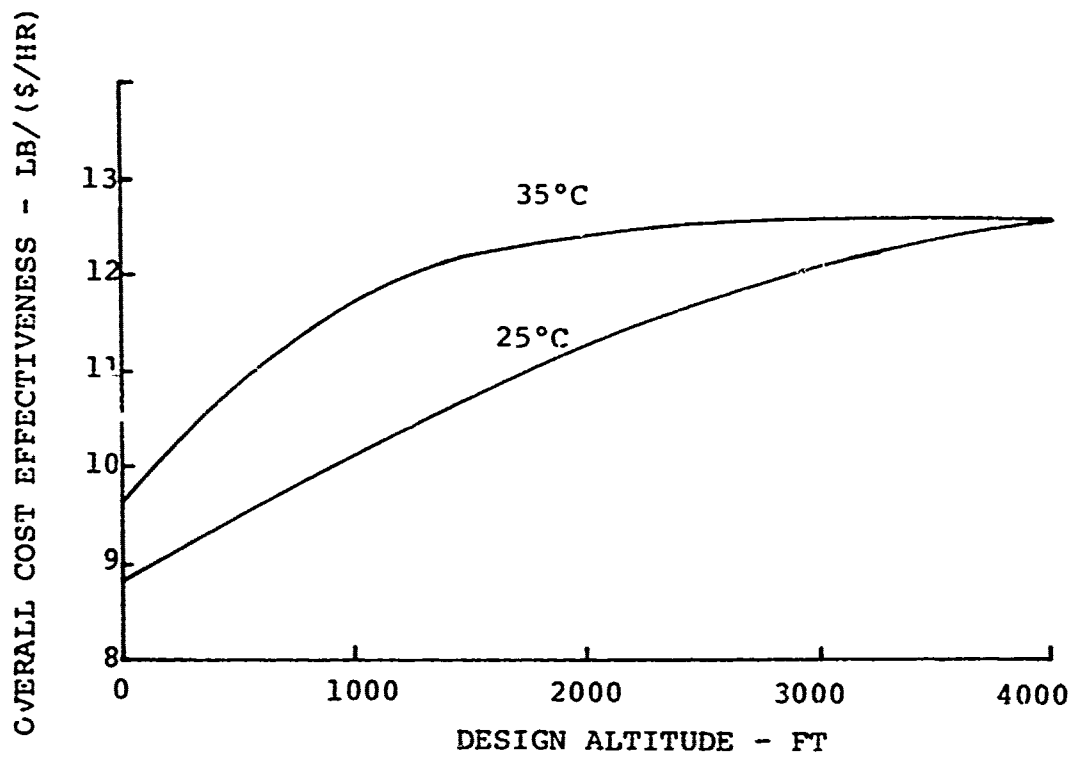


Figure 33. Overall Cost Effectiveness for Crane Mission.

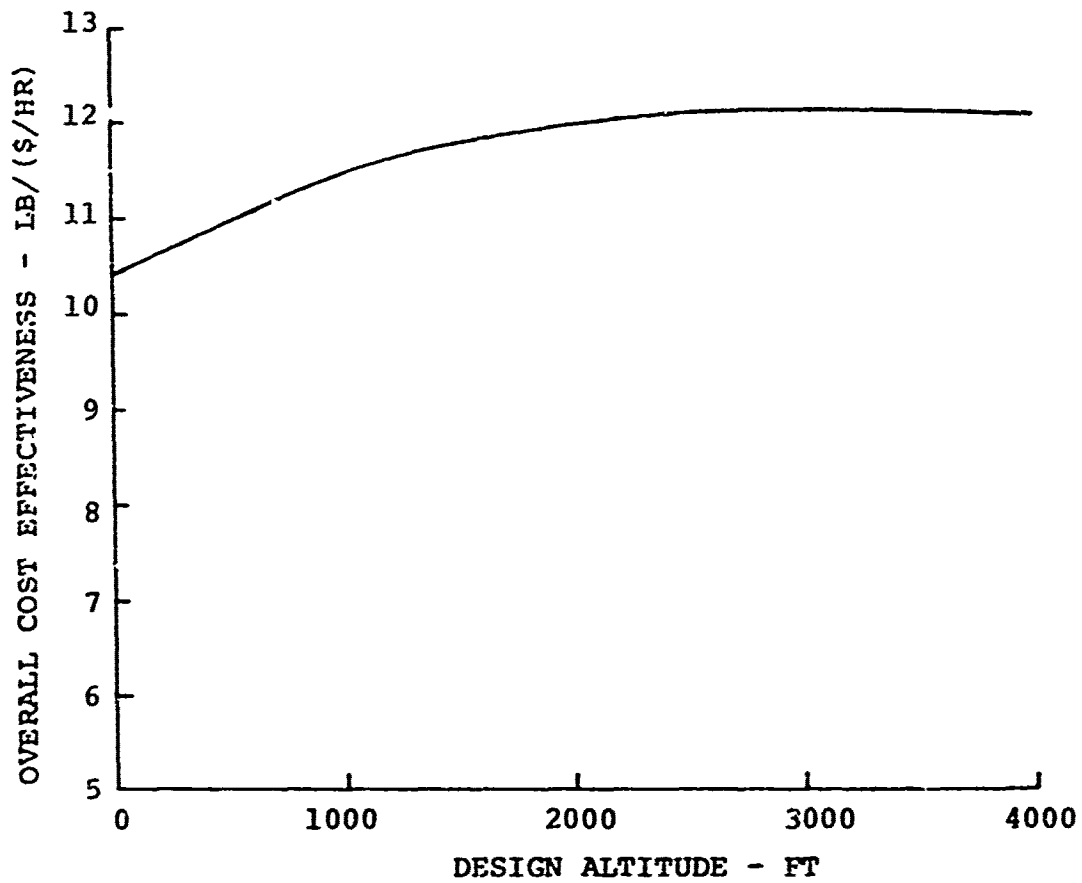


Figure 34. Overall Cost Effectiveness for Transport Model.

DL (disc loading) = 9 lb/ft²
NMR (no. of blades) = 5
NEN (no. of engines) = 4
TAF = 9 (See Table III)
TPY = 45 (See Table III)
KLG = .0247 (See Table III)
= 2 (See Table III)
iAC = 2.26 (See Table III)
PU = 1 (See Table III)

OBSERVATION

The Observation Model differs from Utility in a very basic manner. Instead of increasing the payload at the second design point, the loiter time was increased. The cost effectiveness portion of the model is simplified considerably since there are no probability of hover or payload distribution considerations. For cost effectiveness loiter time is used instead of payload. The mission for the Observation ship is contained in Tables I and II. Other data which differs from the Utility Model is as follows:

DL (disc loading) = 4 lb/ft²
TS (tip speed) = 650 ft/sec
BF = 0 (See Table III)
ITR = 0 (See Table III)
BRK = 0 (See Table III)
TAF = 10 (See Table III)
TPY = 25 (See Table III)
KLG = .0157 (See Table III)
AG = 0 (See Table III)
KNAL = 1.19 (See Table III)

The cost effectiveness results of a run of the Observation model are shown in Figure 35.

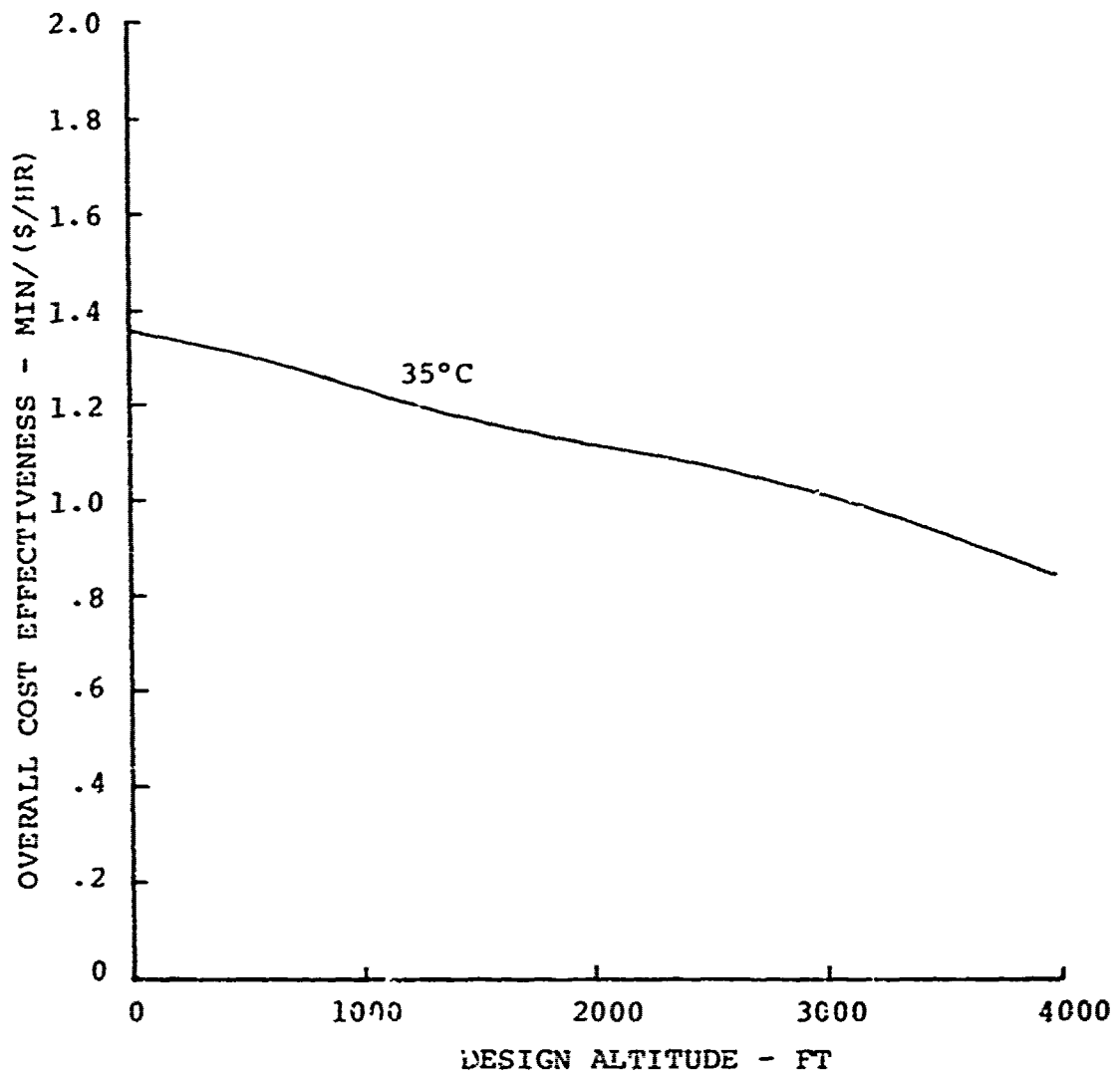


Figure 35. Overall Cost Effectiveness for Observation Model.

CONCLUSIONS

1. An analytical model has been assembled capable of evaluating the effects of a second design point for helicopters.
2. A computer program has been developed which is capable of implementing the solution of these analytical models.
3. It has been shown that optimization points may be obtained that are quite sensitive to several factors. Two of the most important are the assumed payload utilization statistics and the assumed operating environment.
4. The analytical models developed appear to generally give rational results. There are areas, however, where improvements may be made. One of the most worthwhile areas for improvement is the cost model.
5. The objective of this project has been achieved: development of a method which can be used to provide an insight into two-point design criteria and which is capable of selecting criteria which will improve helicopter productivity and cost effectiveness.

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APPENDIX I
ZODIAC II PROGRAM LISTING

| | | |
|---|-----|----|
| IMPLICIT INTEGER(A-U),REAL(V-Z) | Z02 | 1 |
| DEFINE FILE 4(1000,102,U,F14) | Z02 | 2 |
| DEFINE FILE 5(101,20,U,F15) | Z02 | 3 |
| DEFINE FILE 6(20,905,L,F16) | Z02 | 4 |
| INTEGER*2 EQL(100,10,4),PRTLST(50) | Z02 | 5 |
| COMMON /BUG/ DEBUG | Z02 | 6 |
| COMMON /MOD/ VARARY(620),KAPARY(400),EGU,PRTLST | Z02 | 7 |
| COMMON /COMM/ STPCM,STIREG,STPREG,COM(200) | Z02 | 8 |
| COMMON /GEN/ ALBET(50) | Z02 | 9 |
| DIMENSION MODNAM(5) | Z02 | 10 |
| STPCM = 200 | Z02 | 11 |
| STIREG = 201 | Z02 | 12 |
| STPREG = 400 | Z02 | 13 |
| CALL INIT | Z02 | 14 |
| CALL MAININ | Z02 | 15 |
| CALL CATAIN | Z02 | 16 |
| CALL MANSET | Z02 | 17 |
| IF (DEBUG.EQ. 1) CALL PRNTOT(1) | Z02 | 18 |
| 100 CALL MODIN(A,MODNAM,MODNUM) | Z02 | 19 |
| IF(N.EQ.C) GO TO 110 | Z02 | 20 |
| CALL CATAIN | Z02 | 21 |
| IF (DEBUG.EQ. 1) CALL PRNTOT(1) | Z02 | 22 |
| CALL STMOD(MODNAM,MODNUM) | Z02 | 23 |
| GO TO 100 | Z02 | 24 |
| 110 CALL MAINRN | Z02 | 25 |
| CALL ERROR(0) | Z02 | 26 |
| CALL EXIT | Z02 | 27 |
| END | Z02 | 28 |

| | | |
|---|------|----|
| SUBROUTINE INIT | INT | 1 |
| IMPLICIT INTEGER(A-U),REAL(V-Z) | INT | 2 |
| INTEGER*2 EQU(10C,10,4),PRTLST(50) | INT | 3 |
| COMMON /GEN/ ALBET(50) | INT | 4 |
| COMMON /MOD/ VARARY(62C),NAMARY(400),EQU,PRTLST | INT | 5 |
| COMMON /COMP/ STPCOM,STTREG,STPREG,COM(200) | INT | 6 |
| COMMON /TAB/ TABL(20,2) | INT | 7 |
| DIMENSION LBET(50) | INT | 8 |
| DATA LBET /' = , -] 6 3 6 0 (. 9 | INT | 9 |
| A 8 7 6 5 4 3 2 1 0 2 Y X W V U T | INT | 10 |
| B S R Q P O N M L K J I H G F E D C | INT | 11 |
| C B A , / | INT | 12 |
| CG 10C I = 1.620 | 1INT | 13 |
| 100 VARARY(1) = 0 | 1INT | 14 |
| LBET(2) = 21C1362752 | INT | 15 |
| LBET(4) = 163160C7C4 | INT | 16 |
| CG 110 I = 1.50 | 1INT | 17 |
| 110 ALBET(1) = LBET(1), | 1INT | 18 |
| CALL ITCHK(0,-7) | INT | 19 |
| CG 12C I = 1.100 | 1INT | 20 |
| CG 120 J = 1.10 | 2INT | 21 |
| CG 120 K = 1.4 | 3INT | 22 |
| 120 EQU(I,J,K) = 0 | 2INT | 23 |
| EQU(1,1,1) = -1 | INT | 24 |
| CG 130 I = 1.460 | 1INT | 25 |
| 130 NAMARY(1) = 0 | 1INT | 26 |
| CG 14C I = 1.200 | 1INT | 27 |
| 140 COM(1) = 0 | 1INT | 28 |
| NONE = 0 | INT | 29 |
| CNE = 1 | INT | 30 |
| WRITE (3*1) NONE,ONE | INT | 31 |
| CG 150 I = 1.20 | 1INT | 32 |
| TABL(1,1) = 0 | 1INT | 33 |
| 150 TABL(1,2) = 0 | 1INT | 34 |
| RETURN | INT | 35 |
| END | INT | 36 |

| | | |
|---|-----|----|
| SUBROUTINE ERROR(N) | ERR | 1 |
| INTEGER*2 NER(100) | ERR | 2 |
| CATA 1,NER/101*0/ | ERR | 3 |
| IF(N.EQ.C) GO TO 110 | ERR | 4 |
| WRITE (3,100) N | ERR | 5 |
| 100 FORMAT (2(18(' ERROR ')/), ' ERROR NUMBER ',14,/,2(18(' ERROR ')/)) | ERR | 6 |
| I = I + 1 | ERR | 7 |
| IF (I .LE. 100) NER(I) = N | ERR | 8 |
| RETURN | ERR | 9 |
| 110 WRITE (3,120) (NER(J),J = 1,I) | ERR | 10 |
| 120 FORMAT ('1 SUMMARY OF ERRORS ',/,43I3/43I3/14I3) | ERR | 11 |
| RETURN | ERR | 12 |
| END | ERR | 13 |

| | | |
|--|------|----|
| SUBROUTINE MODIN(INCARD,MODNA,MODNUM) | EIN | 1 |
| IMPLICIT INTEGER (A-U),REAL(V-Z) | EIN | 2 |
| COMMON /GEN/ ALBET(50) | EIN | 3 |
| COMMON /ALL/ VLST(50),MODNAM(30,5) | EIN | 4 |
| INTEGER*2 EQU(100,10,4),PRTLST(50) | EIN | 5 |
| COMMON /MOD/ VARARY(620),NAMARY(400),EQU,PRTLST | EIN | 6 |
| COMMON /COMN/ STPCOM,STTREG,STPREG,COM(200) | EIN | 7 |
| DIMENSION STAT(80), NAME(4), TEM(80),NVAR(16) | EIN | 8 |
| DIMENSION ARG(40),MODNA(5) | EIN | 9 |
| NCARD = 0 | EIN | 10 |
| NOEQ = 100 | EIN | 11 |
| CO 100 I = 1,100 | 1EIN | 12 |
| DO 100 J = 1,10 | 2EIN | 13 |
| CO 100 K = 1,4 | 3EIN | 14 |
| 100 EQU(I,J,K) = 0 | 3EIN | 15 |
| EQU(1,1,1) = -1 | EIN | 16 |
| EQU(2,1,1) = -1 | EIN | 17 |
| EQU(1,1,4) = 2 | EIN | 18 |
| CO 110 I = 1,400 | 1EIN | 19 |
| 110 NAMARY(I) = 0 | 1EIN | 20 |
| DO 120 I = STTREG,600 | 1EIN | 21 |
| 120 VARARY(I) = 0 | 1EIN | 22 |
| CO 130 I = 1,50 | 1EIN | 23 |
| 130 PRTLST(I) = 0 | 1EIN | 24 |
| C | EIN | 25 |
| C READ STATEMENTS IN | EIN | 26 |
| C | EIN | 27 |
| END=0 | EIN | 28 |
| 140 READ(1,150,END=440) STAT | EIN | 29 |
| 150 FORMAT(80A1) | EIN | 30 |
| NCARC = NCARD + 1 | EIN | 31 |
| IF (INCARD .EQ. 1) WRITE (3,160) | EIN | 32 |
| 160 FORMAT ('1 EQUATIONS') | EIN | 33 |
| IF (INCARD .EQ. 60) WRITE (3,170) | EIN | 34 |
| 170 FORMAT ('1 EQUATIONS CONT.') | EIN | 35 |
| WRITE(3,180) NCARC,STAT | EIN | 36 |
| 180 FORMAT(14,3X,80A1) | EIN | 37 |
| CO 190 I = 1,80 | 1EIN | 38 |
| 190 TEM(I) = C | 1EIN | 39 |
| C | EIN | 40 |
| C REMOVE BLANKS AND COMMENTS | EIN | 41 |
| C | EIN | 42 |
| NCM = 0 | EIN | 43 |
| CO 200 K = 1,80 | 1EIN | 44 |
| IF (STAT(K) .EQ. ALBET(50)) NCM = 1 | 1EIN | 45 |
| 200 IF (STAT(K) .EQ. ALBET(13) .OR. NCM .EQ. 1) STAT(K) = 0 | 1EIN | 46 |
| CALL RMVZER(STAT,L) | EIN | 47 |
| C CHECK TYPE OF STATEMENT | EIN | 48 |
| 210 CALL COMND(STAT,ITYP,ARG,ERR) | EIN | 49 |
| IF (ERR .NE. 0) GO TO 140 | EIN | 50 |
| IF (ITYP .EQ. 0) GO TO 370 | EIN | 51 |
| IF (ITYP .EQ. 13) GO TO 320 | EIN | 52 |
| IF (ITYP .EQ. 14) GO TO 140 | EIN | 53 |
| GO TO (220,240,250,260,260,140,260,140,260,270,260,290),ITYP | EIN | 54 |
| C | EIN | 55 |

| | | | |
|---|----------------------------------|------|-----|
| C | ITERATE STATEMENT | EIN | 56 |
| C | | EIN | 57 |
| | 220 NIT = EQU(1,1,4) | EIN | 58 |
| | IF (NIT .LE. 5) GO TO 230 | EIN | 59 |
| | CALL ERROR(22) | EIN | 60 |
| | GO TO 140 | EIN | 61 |
| | 230 EQU(1,NIT,1) = ARG(1) | EIN | 62 |
| | EQU(1,NIT,2) = ARG(3) | EIN | 63 |
| | EQU(1,NIT,3) = ARG(4) | EIN | 64 |
| | EQU(1,NIT,4) = ARG(5) | EIN | 65 |
| | EQU(1,1,4) = NIT + 1 | EIN | 66 |
| | GO TO 140 | EIN | 67 |
| C | | EIN | 68 |
| C | INORDER STATEMENT | EIN | 69 |
| C | | EIN | 70 |
| | 240 EQU(1,1,3) = 1 | EIN | 71 |
| | GO TO 140 | EIN | 72 |
| C | | EIN | 73 |
| C | MODULE NAME STATEMENT | EIN | 74 |
| C | | EIN | 75 |
| | 250 CALL MDNAME(K,ARG) | EIN | 76 |
| | EQU(1,1,1) = K | EIN | 77 |
| | MODNLM = K | EIN | 78 |
| | GO TO 140 | EIN | 79 |
| C | | EIN | 80 |
| C | ILLEGAL COMMAND FOR MODULE | EIN | 81 |
| C | | EIN | 82 |
| | 260 CALL ERROR(24) | EIN | 83 |
| | GO TO 140 | EIN | 84 |
| C | | EIN | 85 |
| C | PRINT STATEMENT | EIN | 86 |
| C | | EIN | 87 |
| | 270 CO 280 I = 1,40 | 1EIN | 88 |
| | 280 PRTLST(I) = ARG(I) | 1EIN | 89 |
| | EQU(1,10,1) = 1 | EIN | 90 |
| | CO TO 140 | EIN | 91 |
| C | | EIN | 92 |
| C | IF - EXPRESSION STATEMENT | EIN | 93 |
| C | | EIN | 94 |
| | 290 CO 300 I = 2,NOEQ | 1EIN | 95 |
| | NIF = I | 1EIN | 96 |
| | IF (EQU(I,1,I) .EQ. 0) GO TO 310 | 1EIN | 97 |
| | 300 CONTINUE | 1EIN | 98 |
| | CALL ERROR(2) | EIN | 99 |
| | GO TO 140 | EIN | 100 |
| | 310 EQU(NIF,2,1) = -6 | EIN | 101 |
| | EQU(NIF,2,2) = ARG(1) | EIN | 102 |
| | EQU(NIF,2,3) = ARG(3) | EIN | 103 |
| | EQU(NIF,2,4) = ARG(2) | EIN | 104 |
| | GO TO 370 | EIN | 105 |
| C | | EIN | 106 |
| C | TABLE LOOK UP | EIN | 107 |
| C | | EIN | 108 |
| | 320 CO 330 I = 1,100 | 1EIN | 109 |
| | EQ = I | 1EIN | 110 |

| | | |
|-----|--|----------|
| | IF (EQU(1,1,1) .EQ. 0) GO TO 340 | 1EIN 111 |
| 330 | CONTINUE | 1EIN 112 |
| | CALL ERROR (3) | EIN 113 |
| | GO TO 140 | EIN 114 |
| 340 | CO 350 I = 1,6 | 1EIN 115 |
| | NVAR(I) = C | 1EIN 116 |
| | IF (STAT(I) .EQ. ALBET(I)) GO TO 360 | 1EIN 117 |
| 350 | NVAR(I) = STAT(I) | 1EIN 118 |
| 360 | CALL NAM(NVAR,K) | EIN 119 |
| | EQU(EQ,1,1) = -1 | EIN 120 |
| | EQU(EQ,1,3) = 3 | EIN 121 |
| | EQU(EQ,1,4) = NCARD | EIN 122 |
| | EQU(EQ,2,1) = -9 | EIN 123 |
| | EQU(EQ,2,2) = ARG(3) | EIN 124 |
| | EQU(EQ,2,3) = ARG(4) | EIN 125 |
| | IF (EQU(EQ,2,3) .EQ. 0) EQU(EQ,2,3) = 401 | EIN 126 |
| | EQU(EQ,2,4) = K | EIN 127 |
| | NVAR(1) = ALBET(23-ARG(2)) | EIN 128 |
| | NVAR(2) = C | EIN 129 |
| | CALL NAM(NVAR,K) | EIN 130 |
| | EQU(EQ,3,1) = -8 | EIN 131 |
| | EQU(EQ,3,2) = ARG(5) | EIN 132 |
| | IF (ARG(5) .EQ. 0) EQU(EQ,3,2) = 401 | EIN 133 |
| | EQU(EQ,3,3) = K | EIN 134 |
| | EQU(EQ,3,4) = ARG(1) | EIN 135 |
| | CO TO 14C | EIN 136 |
| C | | EIN 137 |
| C | SEARCH OUT SYMBOLS AND NAMES | EIN 138 |
| C | SYMBOLS ARE REPLACED BY THE FOLLOWING NUMBERS | EIN 139 |
| C | *=-1,=-2,*=-3,/=-4,**=-5,[=-6,]==-7,x=-8 | EIN 140 |
| C | | EIN 141 |
| 370 | NP = 1 | EIN 142 |
| | I = C | EIN 143 |
| 38C | I = I + 1 | EIN 144 |
| 390 | IF (I .GT. L) GO TO 430 | EIN 145 |
| | IF (STAT(I) .EQ. ALBET(8)) GO TO 400 | EIN 146 |
| | IF (STAT(I) .LT. 0 .OR. STAT(I) .EQ. ALBET (12)) GO TO 400 | EIN 147 |
| | NARG = STAT(I) | EIN 148 |
| | CALL SYMBOL(NARG) | EIN 149 |
| | IF (NARG .EQ. -3 .AND. STAT(I+1) .EQ. ALBET(7)) NARG = -5 | EIN 150 |
| | IF (NARG .EQ. -5 .AND. STAT(I+2) .EQ. ALBET(5)) NARG = -9 | EIN 151 |
| | TEM(NP) = NARG | EIN 152 |
| | NP = NP+1 | EIN 153 |
| | IF (NARG .EQ. -5) I=I+1 | EIN 154 |
| | IF (NARG .EQ. -9) I = I + 2 | EIN 155 |
| | GO TO 38C | EIN 156 |
| 400 | DO 410 K = 1,16 | 1EIN 157 |
| 410 | NVAR(K) = 0 | 1EIN 158 |
| | K = C | EIN 159 |
| | NMB = 0 | EIN 160 |
| | IF (STAT(I) .GT. ALBET(24) .AND. STAT(I) .LT. ALBET(11)) NMB = 1 | EIN 161 |
| 420 | K = K + 1 | EIN 162 |
| | NVAR(K)=STAT(I) | EIN 163 |
| | I=I+1 | EIN 164 |
| | IF(STAT(I) .EQ. ALBET(8)) GO TO 420 | EIN 165 |

| | |
|---|---------|
| IF (STAT(I). LT. 0 .OR. STAT(I) .EQ. ALBET(12)) GO TO 420 | EIN 166 |
| IF (INVAR(K) .EQ. ALBET(45) .AND. NMB .EQ. 1) GO TO 420 | EIN 167 |
| CALL NAM(INVAR,K) | EIN 168 |
| TEM (NP) = K | EIN 169 |
| NP= NP + 1 | EIN 170 |
| GO TO 390 | EIN 171 |
| 430 CONTINUE | EIN 172 |
| CALL SETUP(TEM,NCARD) | EIN 173 |
| C | EIN 174 |
| C PREPARE FOR NEXT STATEMENT OR RETURN | EIN 175 |
| GO TO 140 | EIN 176 |
| 440 RETURN | EIN 177 |
| END | EIN 178 |

| | | | |
|---|------------------------------|------|----|
| | SUBROUTINE SYMBOL (N) | SMB | 1 |
| | INTEGER SYM(8) | SMB | 2 |
| | CATA SYM / * - + / () = ' / | SMB | 3 |
| C | | SMB | 4 |
| C | | SMB | 5 |
| | DO 100 I = 1,8 | 1SMB | 6 |
| | IF (N .NE. SYM(I)) GO TO 100 | 1SMB | 7 |
| | N = -I | 1SMB | 8 |
| | RETURN | 1SMB | 9 |
| | 100 CONTINUE | 1SMB | 10 |
| | END | SMB | 11 |

| | | | |
|-----|---|------|----|
| | SUBROUTINE NAM(N,K) | NAM | 1 |
| | IMPLICIT INTEGER(A-U),REAL(V-Z) | NAM | 2 |
| | INTEGER*2 EQU(100,10,4),PRTLST(50) | NAM | 3 |
| | COMMON /MOC/ VARARY(600),NAMARY(400),EQU,PRTLST | NAM | 4 |
| | COMMON /COMPH/ STPCOM,STTREG,STPREG,COM(200) | NAM | 5 |
| | COMMON /GEN/ ALBET(50) | NAM | 6 |
| | DIMENSION N(16) | NAM | 7 |
| C | | NAM | 8 |
| C | CHECK TO SEE IF N IS A NAME OR A CONSTANT. | NAM | 9 |
| C | | NAM | 10 |
| | IF(N(1).GE. ALBET(23) .AND. N(1) .NE. ALBET(8)) GO TO 180 | NAM | 11 |
| C | | NAM | 12 |
| C | N IS A VARIABLE NAME | NAM | 13 |
| C | | NAM | 14 |
| | CALL NAMCMP(N,NAME,NC) | NAM | 15 |
| | IF (NC .EQ. 0) GO TO 120 | NAM | 16 |
| | CO 100 I = 1,STPCOM | INAM | 17 |
| | L = I | INAM | 18 |
| | IF (COM(I) .EQ. NAME .OR. COM(I) .EQ. 0) GO TO 110 | INAM | 19 |
| 100 | CONTINUE | INAM | 20 |
| | CALL ERROR(1) | NAM | 21 |
| 110 | IF (COM(I) .EQ. 0) VARARY(L) = 123.459E-15 | NAM | 22 |
| | COM(L) = NAME | NAM | 23 |
| | NAMARY(L) = NAME | NAM | 24 |
| | GO TO 170 | NAM | 25 |
| 120 | CO 130 I = 1,STPCOM | INAM | 26 |
| | L = I | INAM | 27 |
| | IF (NAMARY(I) .EQ. NAME) GOTO 170 | INAM | 28 |
| | IF (COM(I) .EQ. 0) GO TO 140 | INAM | 29 |
| 130 | CONTINUE | INAM | 30 |
| 140 | CO 150 I = STTREG,400 | INAM | 31 |
| | L = I | INAM | 32 |
| | IF (NAMARY(I) .EQ. NAME) GO TO 170 | INAM | 33 |
| | IF (NAMARY(I) .EQ. 0) GO TO 160 | INAM | 34 |
| 150 | CONTINUE | INAM | 35 |
| | CALL ERROR(2) | NAM | 36 |
| 160 | NAMARY(L) = NAME | NAM | 37 |
| | VARARY(L) = 123.459E-15 | NAM | 38 |
| 170 | K = L | NAM | 39 |
| | RETURN | NAM | 40 |
| C | | NAM | 41 |
| C | N IS A CONSTANT. | NAM | 42 |
| C | | NAM | 43 |
| 180 | CALL NUMCMP(N,V) | NAM | 44 |
| | L = 401 | NAM | 45 |
| | IF (V .EQ. 0) GO TO 200 | NAM | 46 |
| | CO 190 I = 402,600 | INAM | 47 |
| | L = I | INAM | 48 |
| | IF (VARARY(I) .EQ. V) GO TO 210 | INAM | 49 |
| | IF (VARARY(I) .EQ. 0) GO TO 200 | INAM | 50 |
| 190 | CONTINUE | INAM | 51 |
| | CALL ERROR(2) | NAM | 52 |
| 200 | VARARY(L) = V | NAM | 53 |
| 210 | K = L | NAM | 54 |
| | RETURN | NAM | 55 |
| | END | NAM | 56 |

| | | | |
|-----|---|------|----|
| | SUBROUTINE SETUP(S,NCARD) | SET | 1 |
| | IMPLICIT INTEGER (A-U),REAL(V-Z) | SET | 2 |
| | INTEGER*2 EQU(100,10,4),PRTLST(50) | SET | 3 |
| | INTEGER*2 TEM(40,4) | SET | 4 |
| | COMMON /MCD/ VARARY(620),NAPARY(400),EQU,PRTLST | SET | 5 |
| | COMMON /GEN/ ALBET(50) | SET | 6 |
| | DIMENSION S(80),TEM1(80),TEM2(80) | SET | 7 |
| 100 | NS = 1 | SET | 8 |
| | TVAR = 603 | SET | 9 |
| | CO 110 I = 1,80 | 1SET | 10 |
| 110 | TEM2(I) = 0 | 1SET | 11 |
| | CO 120 I = 1,40 | 1SET | 12 |
| | CO 120 J = 1,4 | 2SET | 13 |
| 120 | TEM(I,J) = 0 | 2SET | 14 |
| C | | SET | 15 |
| C | FIND LOCATION FOR NEXT EQUATION | SET | 16 |
| C | | SET | 17 |
| | CO 130 I = 1,100 | 1SET | 18 |
| | NE = I | 1SET | 19 |
| | IF (EQL(I,1,1) .EQ. 0) GO TO 140 | 1SET | 20 |
| 130 | CONTINUE | 1SET | 21 |
| | CALL ERROR(3) | SET | 22 |
| C | | SET | 23 |
| C | FIND INNERMOST SET OF PARENTHESES | SET | 24 |
| C | | SET | 25 |
| 140 | NPAR = 0 | SET | 26 |
| | HNPARG = 0 | SET | 27 |
| | CO 150 J = 1,80 | 1SET | 28 |
| | IF (S(J) .EQ. -6) NPAR = NPAR + 1 | 1SET | 29 |
| | IF (S(J) .EQ. -7) HNPARG = HNPARG + 1 | 1SET | 30 |
| | IF (HNPARG .LT. 0) CALL ERROR(4) | 1SET | 31 |
| 150 | IF (HNPARG .LT. NPAR) HNPARG = NPAR | 1SET | 32 |
| | IF (HNPARG .EQ. 0) GO TO 310 | SET | 33 |
| | CO 160 I = 1,80 | 1SET | 34 |
| 160 | TEM1(I) = C | 1SET | 35 |
| | NPAR = C | SET | 36 |
| | CO 170 J = 1,80 | 1SET | 37 |
| | K = J | 1SET | 38 |
| | IF (S(J) .EQ. -6) NPAR = NPAR + 1 | 1SET | 39 |
| | IF (S(J) .EQ. -7) NPAR = NPAR - 1 | 1SET | 40 |
| | IF (NPAR .EQ. HNPARG) GO TO 180 | 1SET | 41 |
| 170 | CONTINUE | 1SET | 42 |
| 180 | S(K) = TVAR | SET | 43 |
| | K = K + 1 | SET | 44 |
| | THISVR = TVAR | SET | 45 |
| | TVAR = TVAR + 1 | SET | 46 |
| | CO 190 J = 1,80 | 1SET | 47 |
| | IF (S(K) .EQ. -7) GO TO 200 | 1SET | 48 |
| | TEM1(J) = S(K) | 1SET | 49 |
| | S(K) = 0 | 1SET | 50 |
| 190 | K = K + 1 | 1SET | 51 |
| 200 | S(K) = 0 | SET | 52 |
| | CALL RMVZER(S,N) | SET | 53 |
| | K = K + 1 | SET | 54 |
| 210 | CO 220 I = 1,K | 1SET | 55 |

| | | |
|---|------|-----|
| IF (TEM1(I)) .NE. -5 .AND. TEM1(I) .NE. -9) GO TO 220 | 1SET | 56 |
| TEM(NS,1) = TEM1(I) | 1SET | 57 |
| TEM(NS,2) = TEM1(I-1) | 1SET | 58 |
| TEM(NS,3) = TEM1(I+1) | 1SET | 59 |
| TEM(NS,4) = TVAR | 1SET | 60 |
| TEM1(I-1) = TVAR | 1SET | 61 |
| TEM1(I) = 0 | 1SET | 62 |
| TEM1(I+1) = 0 | 1SET | 63 |
| TVAR = TVAR + 1 | 1SET | 64 |
| NS = NS + 1 | 1SET | 65 |
| 220 CONTINUE | 1SET | 66 |
| CALL RMVZER(TEM1,K) | SET | 67 |
| K = K + 1 | SET | 68 |
| LEN = 0 | SET | 69 |
| KS = 1 | SET | 70 |
| NTERM = 0 | SET | 71 |
| IF (TEM1(I) .LT. C) KS = 2 | SET | 72 |
| DO 270 I = KS,K | 1SET | 73 |
| IF (TEM1(I) .LE. 0 .AND. TEM1(I) .GE. -2) GO TO 230 | 1SET | 74 |
| LEN = LEN + 1 | 1SET | 75 |
| TEM2(LEN) = TEM1(I) | 1SET | 76 |
| IF (LEN .EQ. 1) ST = 1 | 1SET | 77 |
| GO TO 270 | 1SET | 78 |
| 230 NTERM = NTERM + 1 | 1SET | 79 |
| IF (LEN .LE. 1) GO TO 260 | 1SET | 80 |
| KJ = I-1 | 1SET | 81 |
| DO 240 JK = ST,KJ | 2SET | 82 |
| 240 TEM1(JK) = 0 | 2SET | 83 |
| TEM1(I-1) = TVAR | 1SET | 84 |
| CALL TERM(TEM,TEM2,NS,LEN,TVAR) | 1SET | 85 |
| DO 250 IZ = 1,80 | 2SET | 86 |
| 250 TEM2(IZ) = C | 2SET | 87 |
| 260 LEN = 0 | 1SET | 88 |
| 270 CONTINUE | 1SET | 89 |
| CALL RMVZER(TEM1,K) | SET | 90 |
| CALL GATHER(TEM,TEM1,NTERM,THISVR,NS) | SET | 91 |
| IF (NPAR .GT. 0) GO TO 140 | SET | 92 |
| 280 EQU(NE,1,1) = -1 | SET | 93 |
| EQU(NE,1,4) = NCARD | SET | 94 |
| K = 1 | SET | 95 |
| IF (EQU(NE,2,1) .EQ. -6) K = K + 1 | SET | 96 |
| NS = NS - 1 | SET | 97 |
| DO 300 I = 1,NS | 1SET | 98 |
| K = K + 1 | 1SET | 99 |
| DO 290 J = 1,4 | 2SET | 100 |
| 290 EQU(NE,K,J) = TEM1(J) | 2SET | 101 |
| IF (I .EQ. NS) GO TO 300 | 1SET | 102 |
| IF (K .LT. 10) GO TO 300 | 1SET | 103 |
| K = 1 | 1SET | 104 |
| EQU(NE,1,3) = 10 | 1SET | 105 |
| NE = NE + 1 | 1SET | 106 |
| EQU(NE,1,1) = -2 | 1SET | 107 |
| EQU(NE,1,4) = NCARD | 1SET | 108 |
| 300 CONTINUE | 1SET | 109 |
| EQU(NE,1,3) = K | SET | 110 |

| | |
|-------------------------------------|----------|
| RETURN | SET 111 |
| 310 IF (S(2) .NE. -8) CALL ERROR(5) | SET 112 |
| THISVR = S(1) | SET 113 |
| CO 320 I = 3,80 | 1SET 114 |
| 320 TEM1(I-2) = S(I) | 1SET 115 |
| TEM1(79) = 0 | SET 116 |
| TEM1(80) = 0 | SET 117 |
| CALL RMVZER(TEM1,K) | SET 118 |
| CO TO 210 | SET 119 |
| END | SET 120 |

| | | |
|-----------------------------|------|----|
| SUBROUTINE RMVZER (N1,N) | RMV | 1 |
| DIMENSION N1(80) | RMV | 2 |
| K = 0 | RMV | 3 |
| CO ICC I = 1.80 | IRMV | 4 |
| IF (N1(I) .EQ. 0) GO TO 100 | IRMV | 5 |
| K = K + I | IRMV | 6 |
| N1(K) = N1(I) | IRMV | 7 |
| IF (K .LT. I) N1(I) = 0 | IRMV | 8 |
| 100 CONTINUE | IRMV | 9 |
| N = K | RMV | 10 |
| RETURN | RMV | 11 |
| END | RMV | 12 |

| | | |
|-----------------------------|-----|----|
| SUBROUTINE TRM(T,T1,N,L,NV) | TRM | 1 |
| INTEGER*2 T(40,4) | TRM | 2 |
| INTEGER T1(80) | TRM | 3 |
| NS = NV | TRM | 4 |
| NV = NV + 1 | TRM | 5 |
| T(N,1) = T1(2) | TRM | 6 |
| T(N,2) = T1(1) | TRM | 7 |
| T(N,3) = T1(3) | TRM | 8 |
| T(N,4) = NS | TRM | 9 |
| I = 4 | TRM | 10 |
| 100 A = N + 1 | TRM | 11 |
| IF (I .GT. L) RETURN | TRM | 12 |
| T(N,1) = T1(I) | TRM | 13 |
| T(N,2) = NS | TRM | 14 |
| T(N,3) = T1(I+1) | TRM | 15 |
| T(N,4) = NS | TRM | 16 |
| I = I + 2 | TRM | 17 |
| GO TO 100 | TRM | 18 |
| END | TRM | 19 |

| | |
|--|--------|
| SUBROUTINE GATHER (T,T1,NT,NV,N) | GTR 1 |
| INTEGER*2 T(40,4) | GTR 2 |
| INTEGER T1(20) | GTR 3 |
| IF (INT .EQ. 1 .AND. N .GT. 1) GO TO 130 | GTR 4 |
| I = 1 | GTR 5 |
| T(N,1) = -10 | GTR 6 |
| T(N,2) = 1 | GTR 7 |
| IF (T1(1) .GT. 0) GO TO 100 | GTR 8 |
| IF (T1(1) .EQ. -2) T(N,2) = -1 | GTR 9 |
| I = I + 1 | GTR 10 |
| 100 T(N,3) = T1(1) | GTR 11 |
| I = I + 1 | GTR 12 |
| T(N,4) = 6C1 | GTR 13 |
| 110 N = N + 1 | GTR 14 |
| IF (T1(1) .NE. 0) GO TO 120 | GTR 15 |
| T(N-1,4) = NV | GTR 16 |
| RETURN | GTR 17 |
| 120 T(N,1) = T1(1) | GTR 18 |
| T(N,2) = 6C1 | GTR 19 |
| T(N,3) = T1(1) + 1 | GTR 20 |
| T(N,4) = 6C1 | GTR 21 |
| I = I + 2 | GTR 22 |
| GO TO 110 | GTR 23 |
| 130 T(N-1,4) = NV | GTR 24 |
| RETURN | GTR 25 |
| END | GTR 26 |

| | | | |
|---|---|-----|----|
| | SUBROUTINE DATAIN | DIN | 1 |
| | IMPLICIT INTEGER (A-U), REAL (V-Z) | DIN | 2 |
| | INTEGER*2 EQUI(100,10,4),PRT(50) | DIN | 3 |
| | COMMON /MOD/ VARARY(620),NAMARY(460),ECU,PRTLST | CIN | 4 |
| | COMMON /GEN/ ALBET(50) | DIN | 5 |
| | DIMENSION CARD(80),NAM(16),NUM(16) | DIN | 6 |
| | NCDS = 0 | DIN | 7 |
| C | | DIN | 8 |
| C | READ DATA CARD | DIN | 9 |
| C | | DIN | 10 |
| | 100 READ(1,110,END=240)CARD | DIN | 11 |
| | 110 FORMAT (ECA1) | DIN | 12 |
| | NCDS = NCDS + 1 | DIN | 13 |
| | IF (NCDS .EQ. 1) WRITE (3,120) | DIN | 14 |
| | 120 FORMAT('1 DATA') | CIN | 15 |
| C | | DIN | 16 |
| C | REMOVE COMMENTS AND BLANKS | DIN | 17 |
| C | | DIN | 18 |
| | CO 130 I = 1,80 | CIN | 19 |
| | IF (CARD(I) .EQ. ALBET (50)) GO TO 140 | DIN | 20 |
| | IF (CARD(I) .EQ. ALBET (13)) CARD(I) = 0 | DIN | 21 |
| | 130 NS = I+1 | DIN | 22 |
| | GO TO 160 | CIN | 23 |
| | 140 CO 150 I = NS,80 | DIN | 24 |
| | 150 CARD(I) = C | DIN | 25 |
| | 160 CALL RMYZER(CARD,NS) | DIN | 26 |
| C | | DIN | 27 |
| C | CHECK FOR TABLE | DIN | 28 |
| C | | DIN | 29 |
| | IF (CARD(1).NE.ALBET(30).OR.CARD(2).NE.ALBET(49)) GO TO 170 | CIN | 30 |
| | IF (CARD(3).NE.ALBET(48).OR.CARD(4).NE.ALBET(38)) GO TO 170 | DIN | 31 |
| | IF (CARD(5).NE.ALBET(45)) GO TO 170 | DIN | 32 |
| | CALL TABLNI(CARD) | DIN | 33 |
| | GO TO 100 | CIN | 34 |
| | 170 CONTINUE | DIN | 35 |
| C | | DIN | 36 |
| C | CHECK FOR COMMA IN LAST POSITION | DIN | 37 |
| C | | DIN | 38 |
| | IF (CARD(NS) .EQ. ALBET(37)) NS = NS-1 | DIN | 39 |
| | IF (NS .EQ. 0) GO TO 240 | DIN | 40 |
| | IF (NS.LT.20) CARD(NS+1) = 0 | CIN | 41 |
| C | | DIN | 42 |
| C | FIND THE NUMBER OF DATA ITEMS | DIN | 43 |
| C | | DIN | 44 |
| | ND = 1 | CIN | 45 |
| | CO 180 I = 1,NS | DIN | 46 |
| | 180 IF (CARD(I) .EQ. ALBET(3)) ND = ND + 1 | DIN | 47 |
| C | | DIN | 48 |
| C | FIND VARIABLE NAME AND DATA THEN STORE | CIN | 49 |
| C | | DIN | 50 |
| | CO 230 JK = 1,ND | DIN | 51 |
| | CO 190 I = 1,5 | DIN | 52 |
| | NAM(I) = 0 | DIN | 53 |
| | K = I + 1 | DIN | 54 |
| | IF (CARD(I) .EQ. ALBET(1)) GO TO 200 | DIN | 55 |

| | | | |
|-----|--|------|----|
| | NAM(I) = CARD(I) | 2DIN | 56 |
| 190 | CARD(I) = 0 | 2DIN | 57 |
| | NAM(6) = 0 | 1DIN | 58 |
| | IF (CARD(6) .NE. ALBET(1))CALL ERROR (6) | 1CIN | 59 |
| 200 | KS = K + 15 | 1DIN | 60 |
| | CARD(K-1) = 0 | 1DIN | 61 |
| | J = 0 | 1DIN | 62 |
| | DO 210 I= K,KS | 2DIN | 63 |
| | J = J + 1 | 2DIN | 64 |
| | NUM(J) = 0 | 2DIN | 65 |
| | KE = I | 2CIN | 66 |
| | IF (CARD(I) .EQ. 0 .OR. CARD(I) .EQ. ALBET(3)) GO TO 220 | 2DIN | 67 |
| | NUM(J) = CARD(I) | 2DIN | 68 |
| 210 | CARD(I) = 0 | 2DIN | 69 |
| | CALL ERROR(7) | 1CIN | 70 |
| 220 | CARD(KE) = 0 | 1DIN | 71 |
| | CALL NAMCMP(NAM,NAME,NC) | 1DIN | 72 |
| | CALL NUMCMP(NUM,X) | 1DIN | 73 |
| | CALL STORE(NAME,X,NC) | 1CIN | 74 |
| 230 | CALL RMVZER(CARD,NS) | 1DIN | 75 |
| | GO TO 100 | DIN | 76 |
| 240 | RETURN | DIN | 77 |
| | END | DIN | 78 |

| | | |
|--|------|----|
| SUBROUTINE NUMCMP(NUM,X) | NUC | 1 |
| IMPLICIT INTEGER(A-U),REAL(V-Z) | NUC | 2 |
| INTEGER*2 EQU(100,10,4),PRTLST(50) | NUC | 3 |
| COMMON /MOD/ VARARY(620),NAMARY(600),EQU,PRTLST | NUC | 4 |
| COMMON /GEN/ ALBET(50) | NUC | 5 |
| DIMENSION NUM(16) | NUC | 6 |
| C | NUC | 7 |
| C FIND OUT IF FIRST CHARACTER IS A -. | NUC | 8 |
| C | NUC | 9 |
| SGN = 1 | NUC | 10 |
| I' (NUM(1) .NE. ALBET(5)) GO TO 100 | NUC | 11 |
| SGN = -1 | NUC | 12 |
| NUM(1) = -264224704 | NUC | 13 |
| C | NUC | 14 |
| C FIND DECIMAL POINT, EXPONENT, AND CONVERT CHARACTERS TO INTEGERS | NUC | 15 |
| C | NUC | 16 |
| 100 NC=-1 | NUC | 17 |
| NE=0 | NUC | 18 |
| DO 120 I = 1,16 | INUC | 19 |
| IF (NUM(I) .EQ. C) GO TO 130 | NUC | 20 |
| IF (NUM(I) .GT. C .OR. NUM(I) .EQ. ALBET(45)) GO TO 110 | INUC | 21 |
| NUM(I)=(NUM(I) + 264224704)/16777216 | INUC | 22 |
| GO TO 120 | INUC | 23 |
| 110 IF (NUM(I) .EQ. ALBET(12)) NC=I | INUC | 24 |
| IF (NUM(I) .EQ. ALBET(45)) NE = I | INUC | 25 |
| 120 N=1 | INUC | 26 |
| 130 IF (ND .EQ. -1 .AND. NE .EQ. 0) ND = N + 1 | NUC | 27 |
| IF (NC .EQ. -1 .AND. NE .GT. 0) ND = NE | NUC | 28 |
| NP = ND - 1 | NUC | 29 |
| IF (NE .EQ. 0) GO TO 140 | NUC | 30 |
| IF (NE .EQ. N) NP = NE-1 | NUC | 31 |
| NUM(NE) = C | NUC | 32 |
| IF (NUM(NE+1) .GT. 10) NE = NE+1 | NUC | 33 |
| NEX = NUM(NE+1) | NUC | 34 |
| IF (N .EQ. NE+2) NEX = NEX*10 + NUM(NE+2) | NUC | 35 |
| IF (NUM(NE) .EQ. ALBET(5)) NEX = -NEX | NUC | 36 |
| NP = NP + NEX | NUC | 37 |
| N = NE - 1 | NUC | 38 |
| 140 X=0 | NUC | 39 |
| DO 150 I = 1,N | INUC | 40 |
| IF (I .EQ. ND) GO TO 150 | INUC | 41 |
| NP = NP-1 | INUC | 42 |
| Y = NUM(I) | INUC | 43 |
| XNP = NP | INUC | 44 |
| X = X + Y*(10.0**XNP) | INUC | 45 |
| IF (NP .EQ. 0) X = AINT(X+.1) | INUC | 46 |
| 150 CONTINUE | INUC | 47 |
| X = X*SGN | NUC | 48 |
| DO 160 I = 1,16 | INUC | 49 |
| 160 NUM(I) = C | INUC | 50 |
| RETLRN | NUC | 51 |
| END | NUC | 52 |

| | | |
|---|------|----|
| SUBROUTINE NAMCMP(NAM,NAPE,NC) | NAC | 1 |
| IMPLICIT INTEGER(A-U),REAL(V-Z) | NAC | 2 |
| INTEGER*2 EQU(100,10,4),PRTLST(50) | NAC | 3 |
| COMMON /MOD/ VARARY(620),NAMARY(400),EQU,PRTLST | NAC | 4 |
| COMMON /GEN/ ALBET(50) | NAC | 5 |
| DIMENSION NAM(16) | NAC | 6 |
| PI6 = 16**6 | NAC | 7 |
| C | NAC | 8 |
| C FIND NAME LENGTH | NAC | 9 |
| C | NAC | 10 |
| CO 100 I=1,5 | INAC | 11 |
| IF (NAM(I) .EQ. C) GO TO 110 | INAC | 12 |
| 100 NN=I | INAC | 13 |
| C | NAC | 14 |
| C CHECK FOR S | NAC | 15 |
| C | NAC | 16 |
| 110 NC=0 | NAC | 17 |
| IF (NAM(I) .EQ. ALBET(8)) NC=1 | NAC | 18 |
| IF (NN-NC .LE. 4) GO TO 120 | NAC | 19 |
| CALL ERROR(23) | NAC | 20 |
| NN = NC + 4 | NAC | 21 |
| 120 NN = NN - NC | NAC | 22 |
| C | NAC | 23 |
| C PUT BLANKS IN NAME | NAC | 24 |
| C | NAC | 25 |
| IF (NN .EQ. 4) NAME = NAM(1+NC) - 4210752 | NAC | 26 |
| IF (NN .LE. 3) NAME = I073741624 | NAC | 27 |
| IF (NN .LE. 2) NAME = NAME + 4194304 | NAC | 28 |
| IF (NN .GT. 1) GO TO 130 | NAC | 29 |
| NAME = NAME + 16384 + NAM(1+NC)/PI6 + 255 | NAC | 30 |
| CO TO 150 | NAC | 31 |
| C | NAC | 32 |
| C FILE IN CHARACTERS | NAC | 33 |
| C | NAC | 34 |
| 130 NS=1+NC | NAC | 35 |
| NT=NN+NC | NAC | 36 |
| IF (NN .EQ. 4) NS=NS+1 | NAC | 37 |
| CO 140 I= NS, NT | INAC | 38 |
| NAM(I) = NAM(I)*PI6 + 255 | INAC | 39 |
| 140 NAME = NAME + NAM(I)*16**(2*(NT-I)) | INAC | 40 |
| 150 CO 160 I = 1,16 | INAC | 41 |
| 160 NAM(I) = C | INAC | 42 |
| RETURN | NAC | 43 |
| END | NAC | 44 |

| | | | |
|---|--|------|----|
| | SUBROUTINE STORE(N,X,NC) | STR | 1 |
| | IMPLICIT INTEGER(A-U),REAL(V-Z) | STR | 2 |
| | INTEGER*2 EQU(100,10,4),PRT(50) | STR | 3 |
| | COMMON /MOD/ VARARY(620),NAMARY(400),EQU,PRT,ST | STR | 4 |
| | COMMON /COMM/ STPCOM,STTREG,STPREG,COM(200) | STR | 5 |
| C | | STR | 6 |
| C | PRINT VARIABLE AND VALUE | STR | 7 |
| C | | STR | 8 |
| | WRITE (3,100) N,X | STR | 9 |
| | 100 FORMAT (5X,A4,' = ',1PE13.6) | STR | 10 |
| | IF (NC .EQ. 1) WRITE (3,110) | STR | 11 |
| | 110 FORMAT ('+',5') | STR | 12 |
| C | | STR | 13 |
| C | CHECK TO SEE IF NAME IS IN COMMON AREA | STR | 14 |
| C | | STR | 15 |
| | DO 120 I = 1,STPCOM | 1STR | 16 |
| | K = I | 1STR | 17 |
| | IF (N .EQ. NAMARY(I)) GO TO 190 | 1STR | 18 |
| | 120 CONTINUE | 1STR | 19 |
| | 130 IF (NC .NE. 1) GO TO 150 | STR | 20 |
| | WRITE (3,140) | STR | 21 |
| | 140 FORMAT ('+',20X,'THIS VARIABLE IS NOT IN COMMON. DATA IGNORED.') | STR | 22 |
| | RETRN | STR | 23 |
| | 150 DO 160 I = STTREG,400 | 1STR | 24 |
| | K = I | 1STR | 25 |
| | IF (N .EQ. NAMARY(I)) GO TO 190 | 1STR | 26 |
| | IF (NAMARY(I) .EQ. 0) GO TO 170 | 1STR | 27 |
| | 160 CONTINUE | 1STR | 28 |
| | 170 WRITE (3,180) | STR | 29 |
| | 180 FORMAT ('+',20X,'THIS VARIABLE IS NOT USED. DATA IGNORED.') | STR | 30 |
| | RETURN | STR | 31 |
| | 190 IF (VARARY(K) .EQ. 123.459E-15) GO TO 210 | STR | 32 |
| | WRITE (3,200) VARARY(K) | STR | 33 |
| | 200 FORMAT ('+',20X,'THIS VARIABLE WAS DEFINED AS ',1PE13.6) | STR | 34 |
| | 210 VARARY(K) = X | STR | 35 |
| | RETRN | STR | 36 |
| | END | STR | 37 |

| | | | |
|-----|--|------|----|
| | SUBROUTINE ORDER(IN) | ORD | 1 |
| | IMPLICIT INTEGER*2(A-E), LOGICAL*1(F), INTEGER(G-U), REAL(V-Z) | ORD | 2 |
| | INTEGER*2 EQU(100,10,4), PRTLST(50) | ORD | 3 |
| | COMMON /MOC/ VARARY(620), NAMARY(430), EQU, PRTLST | ORD | 4 |
| | INTEGER*2 UNDEF(200) | ORD | 5 |
| | COMMON /COMM/ STPCOM, STTREG, STPREG, CCM(200) | ORD | 6 |
| | COMMON /GEN/ GBET(50) | ORD | 7 |
| | C DIMENSION F(620) | ORD | 8 |
| | CO 100 I = 1,620 | 10RC | 9 |
| 100 | F(I) = .TRUE. | 10RD | 10 |
| | IN = EQU(1,1,3) | ORD | 11 |
| C | | ORD | 12 |
| C | SET LP LOGICAL ARRAY. | ORD | 13 |
| C | | ORD | 14 |
| | CO 110 I = 1,400 | 10RD | 15 |
| 110 | IF (VARARY(I) .EQ. 123.459E-15 .OR. NAMARY(I) .EQ. 0) F(I) = .FALSE. | 10RD | 16 |
| | CO 120 I = 402,600 | 10RD | 17 |
| 120 | IF (VARARY(I) .EQ. 0) F(I) = .FALSE. | 10RD | 18 |
| | CO 130 I = 601,620 | 10RD | 19 |
| 130 | F(I) = .FALSE. | 10RD | 20 |
| C | | ORD | 21 |
| C | DETERMINE ORDER OF EVALUATION. | ORD | 22 |
| C | | ORD | 23 |
| | CO 140 I = 2,10 | 10RC | 24 |
| | CO 140 J = 1,3,2 | 20RD | 25 |
| | IF (EQU(2,1,J) .LE. 0) GO TO 150 | 20RD | 26 |
| 140 | F(EQU(2,1,J)) = .TRUE. | 20RD | 27 |
| 150 | ALPOS = 1 | ORD | 28 |
| | GLPOS = 1 | ORD | 29 |
| 160 | NCHG = 0 | ORD | 30 |
| | NEED = 0 | ORD | 31 |
| | CO 260 I = 3,100 | 10RC | 32 |
| | IF (EQU(1,1,1) .EQ. -2) GO TO 230 | 10RD | 33 |
| | IF (EQU(1,1,1)) 170,270,260 | 10RC | 34 |
| 170 | I1 = I | 10RD | 35 |
| | I2 = I | 10RD | 36 |
| | IF (EQU(I1,2,1) .NE. -8) GO TO 180 | 10RD | 37 |
| | IF (.NOT. (F(EQU(I1,2,2)) .AND. F(EQU(I1,2,3)) .AND. F(EQU(I1,3,2)))) GO | 10RD | 38 |
| | A TO 145 | 10RC | 39 |
| | F(EQU(I1,2,4)) = .TRUE. | 10RD | 40 |
| | GO TO 220 | 10RD | 41 |
| 180 | CO 200 K = 2,10 | 20RD | 42 |
| | IF (EQU(I1,K,1) .EQ. 0) GO TO 210 | 20RC | 43 |
| | IF (.NOT. F(EQU(I1,K,3))) GO TO 230 | 20RD | 44 |
| | IF (EQU(I1,K,1) .EQ. -10) GO TO 190 | 20RD | 45 |
| | IF (.NOT. F(EQU(I1,K,2))) GO TO 230 | 20RD | 46 |
| | IF (EQU(I1,K,1) .EQ. -6) GO TO 200 | 20RD | 47 |
| 190 | F(EQU(I1,K,4)) = .TRUE. | 20RD | 48 |
| 200 | CONTINUE | 20RD | 49 |
| | K = K + 1 | 10RC | 50 |
| 210 | IF (EQU(I1+1,1,1) .NE. -2) GO TO 220 | 10RD | 51 |
| | I1 = I1 + 1 | 10RD | 52 |
| | GO TO 180 | 10RD | 53 |
| 220 | EQU(GLPOS,1,2) = I2 | 10RC | 54 |
| | EQU(I2,1,1) = ALPOS | 10RD | 55 |

| | | |
|--|------|-----|
| ALPOS = 12 | 10RD | 56 |
| GLPOS = 12 | 10RD | 57 |
| I2 = 12 + 1 | 10RD | 58 |
| NCHG = NCHG + 1 | 10RD | 59 |
| IF (I2 .LE. 11) GO TO 220 | 10RC | 60 |
| CO TO 24C | 10RD | 61 |
| 230 NEED = NEED + 1 | 10RD | 62 |
| 240 CO 250 ! = 601,620 | 20RD | 63 |
| 250 F(L) = .FALSE. | 20RC | 64 |
| 26C CONTINUE | 10RD | 65 |
| C | CRD | 66 |
| C CHECK TO SEE IF ALL EQUATIONS HAVE BEEN USED. | ORD | 67 |
| C | ORC | 68 |
| 270 IF (NEED .EQ. 0) GO TO 290 | ORD | 69 |
| C | ORD | 70 |
| C CHECK TO SEE IF ANY ADDITIONS WERE MADE ON THE LAST PASS. | ORD | 71 |
| C | ORD | 72 |
| IF (NCHG .GT. 0) GO TO 160 | ORD | 73 |
| CALL ERROR(9) | ORD | 74 |
| GO TO 320 | ORC | 75 |
| 280 RETURN | ORD | 76 |
| C | ORD | 77 |
| C IF INCRDER WAS REQUESTED CHECK ORDER. | ORD | 78 |
| C | ORC | 79 |
| 29C IF (IN .EQ. 1) RETURN | ORD | 80 |
| CO 30C I = 3,100 | 1CRD | 81 |
| IF (EQU(I,1,2) .EQ. 0) RETURN | 10RD | 82 |
| IF (EQU(I,1,2) .NE. I+1) GO TO 310 | 10RC | 83 |
| 30C CONTINUE | 10RD | 84 |
| RETURN | ORC | 85 |
| 310 CALL ERROR(10) | ORC | 86 |
| RETURN | ORD | 87 |
| 320 K = 1 | ORD | 88 |
| CO 33C I = 1,STPCOM | 10RD | 89 |
| IF (NAMARY(I) .EQ. 0 .OR. F(I)) GO TO 330 | 10RC | 90 |
| UNDEF(K) = I | 10RD | 91 |
| K = K + 1 | 10RD | 92 |
| 330 CONTINUE | 10RC | 93 |
| CO 34C I = STTREG,400 | 10RD | 94 |
| IF (NAMARY(I) .EQ. 0) GO TO 350 | 10RD | 95 |
| IF (F(I)) GO TO 340 | 10RD | 96 |
| UNDEF(K) = I | 10RC | 97 |
| K = K + 1 | 10RD | 98 |
| 340 CONTINUE | 10RD | 99 |
| 350 K = K - 1 | ORD | 100 |
| WRITE (3,360) (NAMARY(UNDEF(I)), I = 1,K) | ORC | 101 |
| 360 FORMAT ('1 UNDEFINED VARIABLES ',/ ,10(5X,20(2X,A4),/)) | ORD | 102 |
| CO TO 280 | ORD | 103 |
| END | ORD | 104 |

| | | |
|---|------|----|
| SUBROUTINE RUNMOD | RNE | 1 |
| IMPLICIT INTEGER(A-D),INTEGER*2(E),INTEGER(F-U),REAL(V-Z) | RNE | 2 |
| INTEGER*2 EQU(100,10,4),PRTLST(50) | RNE | 3 |
| COMMON /MOD/ V(620),NAMARY(400),EQU,PRTLST | RNE | 4 |
| COMMON /GEN/ ALBET(50) | RNE | 5 |
| DIMENSION ITRY(4,5),VIT(4) | RNE | 6 |
| DIMENSION VTAB(3) | RNE | 7 |
| COMMON /ALL/ VLST(50),MCONAM(30,5) | RNE | 8 |
| CO 100 I = 2,10 | 1RNE | 9 |
| CO 100 J = 1,3,2 | 2RNE | 10 |
| IF (EQU(2,1,J) .EQ. 0) GO TO 110 | 2RNE | 11 |
| 100 V(EQU(2,1,J)) = V(EQU(2,1,J+1)) | 2RNE | 12 |
| 110 ITR = 0 | RNE | 13 |
| IF (EQU(1,1,4) .LE. 0) GO TO 130 | RNE | 14 |
| NT = EQU(1,1,4) - 2 | RNE | 15 |
| ITR = NT | RNE | 16 |
| CO 120 I = 1,NT | 1RNE | 17 |
| ITRY(I,1) = 0 | 1RNE | 18 |
| VIT(I) = 0 | 1RNE | 19 |
| CO 120 K = 2,5 | 2RNE | 20 |
| 120 ITRY(I,K) = EQU(I,I+1,K-1) | 2RNE | 21 |
| 130 NEX = EQU(1,1,2) | RNE | 22 |
| CO 320 I = 1,100 | 1RNE | 23 |
| A = NEX | 1RNE | 24 |
| NEX = EQU(N,1,2) | 1RNE | 25 |
| CO 300 J = 2,10 | 2RNE | 26 |
| CP = -EQU(N,J,1) | 2RNE | 27 |
| IF (OP .EQ. 0) GO TO 310 | 2RNE | 28 |
| N1 = EQU(N,J,2) | 2RNE | 29 |
| N2 = EQU(N,J,3) | 2RNE | 30 |
| N3 = EQU(N,J,4) | 2RNE | 31 |
| GO TO (140,150,160,170,210,250,300,240,230,290),OP | 2RNE | 32 |
| 140 V(N3) = V(N1) + V(N2) | 2RNE | 33 |
| GO TO 300 | 2RNE | 34 |
| 150 V(N3) = V(N1) - V(N2) | 2RNE | 35 |
| GO TO 300 | 2RNE | 36 |
| 160 V(N3) = V(N1) * V(N2) | 2RNE | 37 |
| GO TO 300 | 2RNE | 38 |
| 170 IF (V(N2) .NE. 0) GO TO 200 | 2RNE | 39 |
| WRITE(3,100) N | 2RNE | 40 |
| 180 FORMAT(' **WARNING DIVISION BY ZERO IN EQUATION ',I3) | 2RNE | 41 |
| IF(N2 .LE. 200) WRITE(3,190) NAMARY(N2) | 2RNE | 42 |
| 190 FORMAT(' ** ,50X, 'DIVISOR WAS ',A4) | 2RNE | 43 |
| V(N3) = 1.CE60 | 2RNE | 44 |
| GO TO 300 | 2RNE | 45 |
| 200 V(N3) = V(N1)/V(N2) | 2RNE | 46 |
| GO TO 300 | 2RNE | 47 |
| 210 IF (V(N1) .LE. 0) WRITE(3,220) N | 2RNE | 48 |
| 220 FORMAT(' ** WARNING A NEGATIVE NUMBER WAS RAISED TO A POWER IN EQUATION ',I3) | 2RNE | 49 |
| V(N3) = ABS(V(N1))**V(N2) | 2RNE | 50 |
| GO TO 300 | 2RNE | 51 |
| 230 IF (V(N1) .LE. 0) WRITE(3,220) N | 2RNE | 52 |
| V(N3) = ABS(V(N1))**(-V(N2)) | 2RNE | 53 |
| GO TO 300 | 2RNE | 54 |
| | 2RNE | 55 |

| | | | |
|-----|---|------|----|
| 240 | VTAB(1) = V(N1) | 2RNE | 56 |
| | VTAB(2) = V(N2) | 2RNE | 57 |
| | VTAB(3) = V(U(K,3,2)) | 2RNE | 58 |
| | INT1 = V(EQL,3,3) | 2RNE | 59 |
| | INT2 = EQU(N,3,4) | 2RNE | 60 |
| | CALL TABLOK(VTAB,INT1,INT2,VRET) | 2RNE | 61 |
| | V(N3) = VRET | 2RNE | 62 |
| | GO TO 310 | 2RNE | 63 |
| 250 | GO TO (260,270,280),N3 | 2RNE | 64 |
| 260 | IF(V(N1) .LT. V(N2)) GO TO 300 | 2RNE | 65 |
| | GO TO 310 | 2RNE | 66 |
| 270 | IF(V(N1) .EQ. V(N2)) GO TO 350 | 2RNE | 67 |
| | GO TO 310 | 2RNE | 68 |
| 280 | IF(V(N1) .GT. V(N2)) GO TO 300 | 2RNE | 69 |
| | GO TO 310 | 2RNE | 70 |
| 290 | V(N3) = N1 * V(N2) | 2RNE | 71 |
| 300 | CONTINUE | 2RNE | 72 |
| 310 | IF (NEXT .LE. 0) GO TO 330 | 1RNE | 73 |
| 320 | CONTINUE | 1RNE | 74 |
| 330 | IF (ITR .GT. 0) GO TO 350 | RNE | 75 |
| 340 | IF (ECU(I,10,I) .NE. 0) CALL PRNTOT(O) | RNE | 76 |
| | RETURN | RNE | 77 |
| 350 | CO 350 I = 1,NT | 1RNE | 78 |
| | K = I | 1RNE | 79 |
| | ITERY(I,1) = ITERY(I,1) + 1 | 1RNE | 80 |
| | IF (ITERY(I,2) .NE. 0) GO TO 360 | 1RNE | 81 |
| | IF (ITERY(I,1) .LE. ITERY(I,3)) GO TO 130 | 1RNE | 82 |
| | GO TO 350 | 1RNE | 83 |
| 360 | VR = V(ITERY(I,2)) | 1RNE | 84 |
| | IF (ITERY(I,1) .GT. 1) GO TO 370 | 1RNE | 85 |
| | VIT(I) = VR | 1RNE | 86 |
| | GO TO 130 | 1RNE | 87 |
| 370 | VRT = ABS(VIT(I)-VR) | 1RNE | 88 |
| | VIT(I) = VR | 1RNE | 89 |
| | IF (VRT .LT. V(ITERY(I,5))) GO TO 380 | 1RNE | 90 |
| | IF (ABS(VRT/VR) .GT. V(ITERY(I,4))) GO TO 400 | 1RNE | 91 |
| 380 | ITERY(I,1) = 0 | 1RNE | 92 |
| 390 | CONTINUE | 1RNE | 93 |
| | GO TO 340 | RNE | 94 |
| 400 | IF (ITERY(K,1) .LT. ITERY(K,3)) GO TO 130 | RNE | 95 |
| | CALL ERROR(25) | RNE | 96 |
| | GO TO 340 | RNE | 97 |
| | END | RNE | 98 |

| | | |
|---|------|----|
| SUBROUTINE PRNTO(NAR) | PRT | 1 |
| IMPLICIT INTEGER(A-U),REAL(V-Z) | PRT | 2 |
| INTEGER*2 EQU(100,10,4),PT(50) | PRT | 3 |
| COMMON /MOD/ VARARY(620),NAMARY(400),EQU,PT | PRT | 4 |
| COMMON /COMN/ STPCOM,STTREG,STPREG,COM(200) | PRT | 5 |
| IF (NAR .EQ. 0) GO TO 250 | PRT | 6 |
| WRITE (3,100) | PRT | 7 |
| 100 FORMAT (///,' EQUATIONS'//) | PRT | 8 |
| I = 1 | PRT | 9 |
| WRITE(3,120) I,((EQU(I,J,K),K=1,4),J=1,10) | PRT | 10 |
| CO 110 I = 2,100 | 1PRT | 11 |
| IF (EQU(I,1,1) .EQ. 0) GO TO 130 | 1PRT | 12 |
| NST = EQU(I,1,3) | 1PRT | 13 |
| 110 WRITE(3,120) I,((EQU(I,J,K),K=1,4),J=1,NST) | 1PRT | 14 |
| 120 FORMAT (/,13,1X,4I4,5(4X,4I4)/,4(4X,4I4)) | PRT | 15 |
| 130 WRITE (3,140) | PRT | 16 |
| 140 FORMAT (/////,' CONSTANTS'//) | PRT | 17 |
| CO 150 I = 402,600 | 1PRT | 18 |
| K = I - 1 | 1PRT | 19 |
| IF (VARARY(I) .EQ. 0) GO TO 160 | 1PRT | 20 |
| 150 CONTINUE | 1PRT | 21 |
| 160 WRITE (3,170) (I,VARARY(I),I=401,K | PRT | 22 |
| 170 FORMAT (5(5X,14,' = ',1PE13.6)) | PRT | 23 |
| WRITE(3,180) | PRT | 24 |
| 180 FORMAT(/////,' VARIABLES'//) | PRT | 25 |
| STT = 1 | PRT | 26 |
| STP = STPCOM | PRT | 27 |
| K = C | PRT | 28 |
| CO 190 I = 1,STPCOM | 1PRT | 29 |
| IF (COM(I) .EQ. 0) GO TO 220 | 1PRT | 30 |
| 190 K = I | 1PRT | 31 |
| GO TO 220 | PRT | 32 |
| 200 K = 0 | PRT | 33 |
| CO 210 I = STT,STP | 1PRT | 34 |
| IF (NAMARY(I) .EQ. 0) GO TO 220 | 1PRT | 35 |
| 210 K = I | 1PRT | 36 |
| 220 IF (K .EQ. 0) GO TO 240 | PRT | 37 |
| WRITE (3,230) (I,NAMARY(I),I = STT,K) | PRT | 38 |
| 230 FORMAT (2C(10(3X,13,' = ',A4))) | PRT | 39 |
| 240 IF (STT .EQ. STTREG) RETURN | PRT | 40 |
| STT = STTREG | PRT | 41 |
| STP = 400 | PRT | 42 |
| GO TO 200 | PRT | 43 |
| 250 WRITE (3,260) | PRT | 44 |
| 260 FORMAT (//) | PRT | 45 |
| CO 270 I = 1,50 | 1PRT | 46 |
| K = I-1 | 1PRT | 47 |
| IF (PT(I) .EQ. 0) GO TO 280 | 1PRT | 48 |
| 270 CONTINUE | 1PRT | 49 |
| 280 WRITE (3,250) (NAMARY(PT(I)),VARARY(PT(I)),I=1,K) | PRT | 50 |
| 290 FORMAT (10(5(5X,14,' = ',1PE13.6))) | PRT | 51 |
| RETURN | PRT | 52 |
| END | PRT | 53 |

| | | |
|---|-----|---|
| SUBROUTINE TABLOK(VI,N1,N2,VRET) | TAB | 1 |
| IMPLICIT INTEGER(A-U),REAL(V-Z) | TAB | 2 |
| DIMENSION VI(3),VT(600),VX(100),VY(100),VZ(100) | TAB | 3 |
| READ (6,N2) NT,NX,NY,NZ,(VT(I),I=1,NT),(VX(I),I=1,NX),(VY(I),I=1, | TAB | 4 |
| A NY),(VZ(I),I=1,NZ) | TAB | 5 |
| CALL INTERP(VI,NX,NY,NZ,VT,VX,VY,VZ,VRET,H2) | TAB | 6 |
| RETLRN | TAB | 7 |
| END | TAB | 8 |

| | | |
|--|------|----|
| SUBROUTINE COMND(S,T,R,ER) | CMD | 1 |
| IMPLICIT INTEGER (A-U),REAL(V-Z) | CMD | 2 |
| INTEGER*2 EQU(100,10,4),PRTLST(50) | CMD | 3 |
| COMMON /MOD/ VARARY(620),NAMARY(400),EQU,PRTLST | CMD | 4 |
| COMMON /GEN/ ALBET(50) | CMD | 5 |
| COMMON /TAB/ TABL(20,2) | CMD | 6 |
| EQUIVALENCE (A(1),ALBET(1)) | CMD | 7 |
| DIMENSION S(80),R(40),C(10),NA(16), SAV(80),A(50),COAT(10) | CMD | 8 |
| C THIS ROUTINE CHECKS FOR COMMAS AND RETURNS THEIR ARGUMENTS | CMD | 9 |
| C ER = 1 IF STATEMENT IS IN ERROR | CMD | 10 |
| C ER = C IF STATEMENT IS CORRECT | CMD | 11 |
| C T INDICATES TYPE | CMD | 12 |
| C T = C EQUATION | CMD | 13 |
| C 1 ITERATE | CMD | 14 |
| C 2 INORDER | CMD | 15 |
| C 3 MODULE NAME | CMD | 16 |
| C 4 RUN MOD | CMD | 17 |
| C 5 GET | CMD | 18 |
| C 6 GIVE | CMD | 19 |
| C 7 POINT | CMD | 20 |
| C 8 COMMON | CMD | 21 |
| C 9 REAC | CMD | 22 |
| C 10 PRINT | CMD | 23 |
| C 11 IF - GO TO | CMD | 24 |
| C 12 IF - EXPRESSION | CMD | 25 |
| C 13 TABLE LOOK UP | CMD | 26 |
| C | CMD | 27 |
| C R IS THE ARGUMENT LIST RETURNED | CMD | 28 |
| C | CMD | 29 |
| C DATA COAT/'ITERNCOMMODURUNPGE; GIVEPCINCCPREADPKIN'/ | CMD | 30 |
| C DATA GTO /'GGTO'/ | CMD | 31 |
| C DO 100 I = 1,10 | ICMD | 32 |
| 100 C(I) = COAT(I) | ICMD | 33 |
| T = C | CMD | 34 |
| ER = 1 | CMD | 35 |
| CO 110 I = 1,40 | ICMD | 36 |
| IF (I .LT. 17) NA(I) = 0 | ICMD | 37 |
| SAV(I) = 0 | ICMD | 38 |
| SAV(I+40) = 0 | ICMD | 39 |
| 110 R(I) = 0 | ICMD | 40 |
| C | CMD | 41 |
| C CHECK FOR INITIALIZE | CMD | 42 |
| C | CMD | 43 |
| IF (S(1) .NE. A(41) .OR. S(2) .NE. A(36)) GO TO 120 | CMD | 44 |
| IF (S(3) .NE. A(41) .OR. S(4) .NE. A(30)) GO TO 120 | CMD | 45 |
| IF (S(5) .NE. A(41) .OR. S(6) .NE. A(49)) GO TO 120 | CMD | 46 |
| IF (S(7) .NE. A(38) .OR. S(8) .NE. A(41)) GO TO 120 | CMD | 47 |
| IF (S(9) .NE. A(24) .OR. S(10) .NE. A(45)) GO TO 120 | CMD | 48 |
| GO TO 61C | CMD | 49 |
| C | CMD | 50 |
| C CHECK FOR TABLE LOOK UP | CMD | 51 |
| C | CMD | 52 |
| 120 DO 130 I = 1,20 | ICMD | 53 |
| IF (S(I) .EQ. A(1)) GO TO 140 | ICMD | 54 |
| 130 K = I | ICMD | 55 |

| | | |
|--|------|-----|
| GO TO 150 | CMD | 56 |
| 140 K = K + 2 | CMD | 57 |
| IF (S(K).NE.A(30).OR.S(K+1).NE.A(40).OR.S(K+2).NE.A(40)) GO TO 150 | CMD | 58 |
| K = K + 3 | CMD | 59 |
| IF (S(K).EQ. A(30).AND.S(K+1).EQ.A(45)) GO TO 530 | CMD | 60 |
| C | CMD | 61 |
| C COMPRESS FIRST FOUR CHARACTERS | CMD | 62 |
| C | CMD | 63 |
| 150 DO 160 I = 1,4 | 1CMD | 64 |
| 160 NA(I) = S(I) | 1CMD | 65 |
| CALL NAMCMP(HA,NAME,NC) | CMD | 66 |
| IF (NAME.EQ. GTC) GO TO 690 | CMD | 67 |
| DO 170 I = 1,10 | 1CMD | 68 |
| IF(C(I).EQ.NAME)GO TO (190,210,220,280,290,340,350,360,370,380) | 1CMD | 69 |
| A1 | 1CMD | 70 |
| 170 CONTINUE | 1CMD | 71 |
| IF(S(I).EQ.A(43).AND.S(2).EQ.A(45).AND.S(3).EQ.A(30)) GOTO 390 | CMD | 72 |
| IF(S(I).EQ.A(41).AND.S(2).EQ.A(44)) GO TO 390 | CMD | 73 |
| ER = 0 | CMD | 74 |
| DO 180 I = 1,80 | 1CMD | 75 |
| IF (S(I).EQ.A(1)) RETURN | 1CMD | 76 |
| 180 CONTINUE | 1CMD | 77 |
| ER = 1 | CMD | 78 |
| RETURN | CMD | 79 |
| C | CMD | 80 |
| C ITERATE STATEMENT | CMD | 81 |
| C R(1) = ON DEFAULT = 0 | CMD | 82 |
| C R(2) = FROM DEFAULT = 1 | CMD | 83 |
| C R(3) = TIMES DEFAULT = 50 | CMD | 84 |
| C R(4) = P7OL DEFAULT = 51 | CMD | 85 |
| C R(5) = ATOL DEFAULT = 0 | CMD | 86 |
| C | CMD | 87 |
| 190 IF(S(5).NE.A(45).OR.S(6).NE.A(30).OR.S(7).NE.A(45)) RETURN | CMD | 88 |
| T = 1 | CMD | 89 |
| DO 200 I = 1,6 | 1CMD | 90 |
| 200 S(I) = C | 1CMD | 91 |
| S(7) = A(2) | CMD | 92 |
| C(1) = A(3) | CMD | 93 |
| CALL RMVZER(S,K) | CMD | 94 |
| C | CMD | 95 |
| C FIND FROM | CMD | 96 |
| C | CMD | 97 |
| C(2) = A(44) | CMD | 98 |
| C(3) = A(32) | CMD | 99 |
| C(4) = A(35) | CMD | 100 |
| C(5) = A(37) | CMD | 101 |
| CALL CONFND(C,S,S,NN,PS,1) | CMD | 102 |
| R(2) = VARARY(NM) | CMD | 103 |
| C | CMD | 104 |
| C FIND TIMES | CMD | 105 |
| C | CMD | 106 |
| C(2) = A(30) | CMD | 107 |
| C(3) = A(41) | CMD | 108 |
| C(4) = A(37) | CMD | 109 |
| C(5) = A(45) | CMD | 110 |

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|---|----------|
| C(6) = A(31) | CMD 111 |
| C(7) = A(1) | CMC 112 |
| CALL COMPND(C,S,7,NM,PS,5C) | CPD 113 |
| R(3) = VARARY(NM) | CPD 114 |
| C | CPD 115 |
| C | CMC 116 |
| C | CPD 117 |
| C(2) = A(49) | CPD 118 |
| C(3) = A(3C) | CPD 119 |
| C(4) = A(35) | CPD 120 |
| C(5) = A(38) | CPD 121 |
| C(6) = A(1) | CPD 122 |
| CALL COMPND(C,S,6,NM,PS,0) | CMC 123 |
| R(5) = NM | CPD 124 |
| C | CPD 125 |
| C | CPD 126 |
| C | CPD 127 |
| C(2) = A(34) | CPD 128 |
| AV = C | CPD 129 |
| IF (NM .EQ. 0) NV = 5 | CMC 130 |
| CALL COMPND(C,S,6,NM,PS,NV) | CPD 131 |
| R(4) = NM | CMC 132 |
| C | CPD 133 |
| C | CMC 134 |
| C | CPD 135 |
| C(2) = A(35) | CPD 136 |
| C(3) = A(3E) | CPD 137 |
| CALL COMPND(C,S,3,NM,PS,0) | CMC 138 |
| R(1) = NM | CPD 139 |
| IF (NM .EQ. 40) R(1) = 0 | CPD 140 |
| ER = C | CPD 141 |
| RETURN | CMC 142 |
| C | CPD 143 |
| C | CPD 144 |
| C | CPD 145 |
| 210 IF (S(5) .NE. A(46) .OR. S(6) .NE. A(45) .OR. S(7) .NE. A(32)) RETURN | CPD 146 |
| T = 2 | CPD 147 |
| ER = C | CPD 148 |
| RETURN | CMC 149 |
| C | CPD 150 |
| C | CPD 151 |
| C | CPD 152 |
| R(1) - R(5) WILL CONTAIN THE MODULE NAME IN COMPRESSED FORM | CMC 153 |
| C | CPD 154 |
| 220 IF (S(5) .NE. A(2E) .OR. S(7) .NE. A(3A)) RETURN | CPD 155 |
| T = 3 | CPD 156 |
| GO 230 I = 1,80 | 1CPD 156 |
| K = 1 | 1CMC 157 |
| IF (S(1) .EQ. A(1)) GO TO 240 | 1CPD 158 |
| 230 CONTINUE | 1CPD 159 |
| CALL ERROR(18) | CPD 160 |
| ER = 1 | CPD 161 |
| RETURN | CPD 162 |
| 240 K = K + 1 | CPD 163 |
| KS = K + 15 | CMC 164 |
| IF (KS .GT. 8C) KS = 77 | CPD 165 |

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|--|----------|
| P = 0 | CMD 166 |
| CO 260 I=K,KS,4 | 1CMD 167 |
| M = M + 1 | 1CMD 168 |
| KT = I+3 | 1CMD 169 |
| IF (KT .GT. 80) KT = 80 | 1CMD 170 |
| L = 1 | 1CMD 171 |
| CO 250 J = I,KT | 2CMD 172 |
| NA(L) = S(J) | 2CMD 173 |
| 250 L = L + 1 | 2CMD 174 |
| CALL NAMCMP(NA,NM,NC) | 1CMD 175 |
| R(M) = NM | 1CMD 176 |
| IF (I+4 .GT. 80) GO TO 270 | 1CMD 177 |
| IF (S(I+4) .EQ. C) GO TO 270 | 1CMD 178 |
| 260 CONTINUE | 1CMD 179 |
| 270 ER = C | CMD 180 |
| RETRN | CMD 181 |
| C | CMD 182 |
| C RLM MSG STATEMENT | CMD 183 |
| C R(1) - R(5) CONTAIN THE NAME OF THE MODULE TO BE RUN | CMD 184 |
| C | CMD 185 |
| 280 IF (S(5) .NE. A(25) .OR. S(6) .NE. A(46)) RETURN | CMD 186 |
| T = 4 | CMD 187 |
| E = 0 | CMD 188 |
| K = 6 | CMD 189 |
| GO TO 240 | CMD 190 |
| C | CMD 191 |
| C GET STATEMENT | CMD 192 |
| C R(1) - R(4) CONTAIN LOCATION OF ARGUMENT | CMD 193 |
| C | CMD 194 |
| 290 IF (S(4) .EQ. A(1) .OR. S(5) .EQ. A(1)) RETURN | CMD 195 |
| I = 5 | CMD 196 |
| K = 3 | CMD 197 |
| CM = 0 | CMD 198 |
| 300 K = K + 1 | CMD 199 |
| CO 310 I = X,80 | 1CMD 200 |
| KL = I-I | 1CMD 201 |
| IF (S(I) .EQ. 0) GO TO 320 | 1CMD 202 |
| 310 CONTINUE | 1CMD 203 |
| 320 A = CM | CMD 204 |
| L = C | CMD 205 |
| CO 330 I = K,KL | 1CMD 206 |
| N = N + 1 | 1CMD 207 |
| NA(N) = S(I) | 1CMD 208 |
| IF (S(I) .NE. A(3)) GO TO 330 | 1CMD 209 |
| NA(N) = 0 | 1CMD 210 |
| L = L + 1 | 1CMD 211 |
| IF (CM .EQ. 1) NA(I) = A(I) | 1CMD 212 |
| CALL NAM(NA,J) | 1CMD 213 |
| R(L) = J | 1CMD 214 |
| A = CF | 1CMD 215 |
| 330 CONTINUE | 1CMD 216 |
| NA(N+1) = 0 | CMD 217 |
| IF (CM .EQ. 1) NA(I) = A(I) | CMD 218 |
| CALL NAM(NA,J) | CMD 219 |
| R(L+1) = . | CMD 220 |

| | | |
|---|--|---------|
| | ER = 0 | CMD 221 |
| | RETURN | CMD 222 |
| C | | CMD 223 |
| C | GIVE STATEMENT | CMD 224 |
| C | R(1) - R(4C) CONTAIN ARGUMENT LIST | CMC 225 |
| C | | CMD 226 |
| | 340 IF (S(5) .EQ. A(1)) RETURN | CMD 227 |
| | T = 6 | CMD 228 |
| | K = 4 | CMD 229 |
| | CM = 0 | CMD 230 |
| | GO TO 300 | CMD 231 |
| C | | CMD 232 |
| C | POINT STATEMENT | CMD 233 |
| C | R(1) CONTAINS NAME LOCATION | CMD 234 |
| C | | CMD 235 |
| | 350 IF (S(5) .NE. A(30)) RETURN | CMC 236 |
| | T = 7 | CMD 237 |
| | NA(1) = S(6) | CMD 238 |
| | NA(2) = S(7) | CMD 239 |
| | NA(3) = S(8) | CMC 240 |
| | NA(4) = S(9) | CMD 241 |
| | NA(5) = 0 | CMD 242 |
| | CALL NAM(NA,J) | CMD 243 |
| | R(1) = J | CMC 244 |
| | ER = C | CMD 245 |
| | RETURN | CMD 246 |
| C | | CMD 247 |
| C | COMMON STATEMENT | CMD 248 |
| C | NO ARGUMENT RETURNED | CMD 249 |
| C | | CMD 250 |
| | 360 IF (S(5) .NE. A(35) .OR. S(6) .NE. A(36)) RETURN | CMC 251 |
| | T = 8 | CMD 252 |
| | K = 6 | CMD 253 |
| | CM = 1 | CMD 254 |
| | GO TO 300 | CMC 255 |
| C | | CMD 256 |
| C | READ STATEMENT | CMD 257 |
| C | NO ARGUMENT RETURNED | CMD 258 |
| C | | CMC 259 |
| | 370 IF (S(5) .EQ. A(1)) RETURN | CMD 260 |
| | T = 9 | CMD 261 |
| | ER = C | CMC 262 |
| | RETRN | CMC 263 |
| C | | CMC 264 |
| C | PRINT STATEMENT | CMD 265 |
| C | R(1) - R(4C) CONTAIN PRINT LIST | CMC 266 |
| C | | CMD 267 |
| | 380 IF (S(5) .NE. A(30)) RETURN | CMD 268 |
| | T = 10 | CMD 269 |
| | CM = 0 | CMD 270 |
| | K = 5 | CMD 271 |
| | GO TO 300 | CMD 272 |
| C | | CMD 273 |
| C | IF STATEMENT | CMD 274 |
| C | R(1) CONTAINS FIRST ARGUMENT | CMD 275 |

| | | |
|---|---|----------|
| C | R(2) CONTAINS LOGICAL OPERATOR | CMD 276 |
| C | R(3) CONTAINS SECOND OPERATOR | CMD 277 |
| C | FOR IF - EXPRESSION STATEMENT 5 CONTAINS EXPRESSION | CMD 278 |
| C | FOR IF - GO TO STATEMENT R(4) CONTAINS POINT VAR LOCATION | CMD 279 |
| C | | CMD 280 |
| C | LOOP FOR , | CMD 281 |
| C | | CMD 282 |
| | 390 GO 430 I = 3,80 | 1CMD 283 |
| | K = I | 1CMD 284 |
| | IF (S(I) .EQ. A(3)) GO TO 410 | 1CMD 285 |
| | 400 CONTINUE | 1CMD 286 |
| | ER = C | CMD 287 |
| | RETURN | CMD 288 |
| C | | CMD 289 |
| C | LOOK FOR = SIGN | CMD 290 |
| C | | CMD 291 |
| | 410 GO 420 I = K,80 | 1CMD 292 |
| | IF (S(I) .EQ. A(I)) GO TO 510 | 1CMD 293 |
| | 420 CONTINUE | 1CMD 294 |
| C | | CMD 295 |
| C | FIND GO TO | CMD 296 |
| C | | CMD 297 |
| | C(1) = A(43) | CMD 298 |
| | C(2) = A(35) | CMD 299 |
| | C(3) = A(30) | CMD 300 |
| | C(4) = A(35) | CMD 301 |
| | CALL COMFND(C,S,4,NM,PS,0) | CMD 302 |
| | IF (PS .GT. 0) GO TO 430 | CMD 303 |
| | CALL ERROR (19) | CMD 304 |
| | ER = I | CMD 305 |
| | RETURN | CMD 306 |
| | 430 R(4) = NM | CMD 307 |
| | T = I1 | CMD 308 |
| C | | CMD 309 |
| C | CHECK FOR ISLT R(2) = 1 | CMD 310 |
| C | | CMD 311 |
| | 440 C(1) = A(41) | CMD 312 |
| | C(2) = A(31) | CMD 313 |
| | C(3) = A(38) | CMD 314 |
| | C(4) = A(30) | CMD 315 |
| | CALL COMFND(C,S,4,NM,PS,0) | CMD 316 |
| | IF (PS .EQ. 0) GO TO 450 | CMD 317 |
| | R(3) = NM | CMD 318 |
| | R(2) = 1 | CMD 319 |
| | GO TO 480 | CMD 320 |
| C | | CMD 321 |
| C | CHECK FOR ISEQ R(2) = 2 | CMD 322 |
| C | | CMD 323 |
| | 450 C(3) = A(45) | CMD 324 |
| | C(4) = A(33) | CMD 325 |
| | CALL COMFND(C,S,5,NM,PS,0) | CMD 326 |
| | IF (PS .EQ. 0) GO TO 465 | CMD 327 |
| | R(3) = NM | CMD 328 |
| | R(2) = 2 | CMD 329 |
| | GO TO 480 | CMD 330 |

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|---|-------------------------------|----------|
| C | | CMD 331 |
| C | CHECK FOR ISGT R(2) = 3 | CMD 332 |
| C | | CMD 333 |
| | 460 C(3) = A(43) | CMD 334 |
| | C(4) = A(3C) | CMD 335 |
| | CALL COMFND(C,S,4,NM,PS,0) | CMD 336 |
| | IF (PS .EQ. 0) GC TO 470 | CMD 337 |
| | R(3) = NM | CMD 338 |
| | R(2) = 3 | CMD 339 |
| | GO TO 480 | CMD 340 |
| | 470 CALL ERROR(20) | CMD 341 |
| | ER = 1 | CMD 342 |
| | RETRN | CMD 343 |
| C | | CMD 344 |
| C | FIND IF | CMD 345 |
| C | | CMD 346 |
| | 480 C(2) = A(44) | CMD 347 |
| | CALL COMFND(C,S,2,NM,PS,0) | CMD 348 |
| | IF (PS .EQ. 1) GC TO 490 | CMD 349 |
| | CALL ERROR(21) | CMD 350 |
| | ER = 1 | CMD 351 |
| | RETURN | CMD 352 |
| | 490 R(1) = NM | CMD 353 |
| | ER = C | CMD 354 |
| | IF (T .EQ. 1) RETURN | CMD 355 |
| C | | CMD 356 |
| C | PUT EXPRESSION IN S | CMD 357 |
| C | | CMD 358 |
| | DO 500 I = 1,80 | ICMD 359 |
| | 500 S(I) = SAV(I) | ICMD 360 |
| | RETRN | CMD 361 |
| C | | CMD 362 |
| C | SAVE EXPRESSION IN SAV | CMD 363 |
| C | | CMD 364 |
| | 510 K = K + 1 | CMD 365 |
| | L = 1 | CMD 366 |
| | DO 520 I = K,80 | ICMD 367 |
| | SAV(L) = S(I) | ICMD 368 |
| | S(I) = C | ICMD 369 |
| | 520 L = L + 1 | ICMD 370 |
| | S(K-1) = 0 | CMD 371 |
| | T = 12 | CMD 372 |
| | GO TO 44C | CMD 373 |
| | 530 I = 13 | CMD 374 |
| | K = K + 2 | CMD 375 |
| | DO 540 I = K,80 | ICMD 376 |
| | IF(S(I) .EQ. A(11)) LP = I | ICMD 377 |
| | 540 IF(S(I) .EQ. A(6)) RP = I | ICMD 378 |
| | S(LP) = 0 | CMD 379 |
| | S(RP) = C | CMD 380 |
| | LP = LP + 1 | CMD 381 |
| | RP = RP - 1 | CMD 382 |
| | NV = 1 | CMD 383 |
| | K1 = 1 | CMD 384 |
| | DO 560 I = LP,RP | ICMD 385 |

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|--|----------|
| IF (S(I) .EQ. A(2)) S(I) = 0 | 1CMD 386 |
| NA(K1) = S(I) | 1CMD 387 |
| IF (S(I) .NE. 0 .AND. I .NE. RP) GO TO 550 | 1CMD 388 |
| NA(K1+1) = 0 | 1CMD 389 |
| CALL NAM(NA,K2) | 1CMD 390 |
| NV = NV + 1 | 1CMD 391 |
| R(NV+1) = K2 | 1CMD 392 |
| R(2) = NV-1 | 1CMD 393 |
| K1 = C | 1CMD 394 |
| 550 K1 = K1 + 1 | 1CMD 395 |
| 560 S(I) = 0 | 1CMD 396 |
| LP = LP - 2 | 1CMD 397 |
| L = 0 | 1CMD 398 |
| DO 570 I = X,LP | 1CMD 399 |
| L = L + 1 | 1CMD 400 |
| 570 NA(L) = S(I) | 1CMD 401 |
| CALL NAMCMP(NA,NAME,NC) | 1CMD 402 |
| DO 580 I = 1,20 | 1CMD 403 |
| K = : | 1CMD 404 |
| IF (TABL(I,1) .EQ. NAME) GO TO 600 | 1CMD 405 |
| IF (TABL(I,1) .EQ. 0) GO TO 590 | 1CMD 406 |
| 580 CONTINUE | 1CMD 407 |
| CALL ERROR(27) | 1CMD 408 |
| RETRN | 1CMD 409 |
| 590 TABL(K,1) = NAME | 1CMD 410 |
| TABL(K,2) = N | 1CMD 411 |
| R(1) = K | 1CMD 412 |
| ER = 0 | 1CMD 413 |
| RETURN | 1CMD 414 |
| 600 R(1) = K | 1CMD 415 |
| ER = C | 1CMD 416 |
| IF (TABL(K,2) .EQ. NV) RETURN | 1CMD 417 |
| CALL ERROR(28) | 1CMD 418 |
| ER = 1 | 1CMD 419 |
| RETRN | 1CMD 420 |
| C | 1CMD 421 |
| C INITIALIZE STATEMENT | 1CMD 422 |
| C | 1CMD 423 |
| 610 DO 620 I = 1,10 | 1CMD 424 |
| 620 S(I) = 0 | 1CMD 425 |
| DO 630 I = 2,10 | 1CMD 426 |
| DO 630 J = 1,3,2 | 2CMD 427 |
| P1 = I | 2CMD 428 |
| P2 = J | 2CMD 429 |
| IF (EQU(2,P1,P2) .EQ. 0) GO TO 640 | 2CMD 430 |
| 630 CONTINUE | 2CMD 431 |
| CALL ERROR(31) | 1CMD 432 |
| 640 CALL RMVZER(S,N6) | 1CMD 433 |
| DO 650 I = 1,16 | 1CMD 434 |
| K = : | 1CMD 435 |
| NA(I) = S(I) | 1CMD 436 |
| S(I) = 0 | 1CMD 437 |
| IF (NA(I) .EQ. A(1)) GO TO 660 | 1CMD 438 |
| 650 NA(I+1) = 0 | 1CMD 439 |
| 660 NA(K) = 0 | 1CMD 440 |

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|--|----------|
| CALL NAM(NA,K) | CMD 441 |
| CALL RMVZER(S,N6) | CMD 442 |
| EQU(2,P1,P2) = K | CMD 443 |
| CO 670 I = 1,16 | 1CMD 444 |
| K = 1 | 1CMD 445 |
| NA(I) = S(I) | 1CMD 446 |
| S(I) = 0 | 1CMD 447 |
| IF(NA(I) .EQ. A(3) .OR. NA(I) .EQ. 0) GO TO 680 | 1CMD 448 |
| 670 NA(I+1) = 0 | 1CMD 449 |
| 680 NA(K) = 0 | CMD 450 |
| CALL NAM(NA,K) | CMD 451 |
| EQU(2,P1,P2+1) = K | CMD 452 |
| P2 = 4-P2 | CMD 453 |
| P1 = P1 + (3-P2)/2 | CMD 454 |
| CALL RMVZER(S,N6) | CMD 455 |
| IF (N6 .GT. C) GO TO 640 | CMD 456 |
| EQU(2,1,3) = P2 | CMD 457 |
| T = 14 | CMD 458 |
| ER = 0 | CMD 459 |
| RETURN | CMD 460 |
| 690 IF (S(5) .LE. A(24)) GO TO 700 | CMD 461 |
| T = C | CMD 462 |
| ER = C | CMD 463 |
| RETURN | CMD 464 |
| 700 CO 710 I = 1,4 | 1CMD 465 |
| 710 S(I) = 0 | 1CMD 466 |
| CALL RMVZER(S,K) | CMD 467 |
| CO 720 I = 1,K | 1CMD 468 |
| 720 NA(I) = S(I) | 1CMD 469 |
| NA(K+1) = C | CMD 470 |
| CALL NAM(NA,K) | CMD 471 |
| T = 15 | CMD 472 |
| R(I) = K | CMD 473 |
| ER = C | CMD 474 |
| RETURN | CMD 475 |
| END | CMD 476 |

| | | |
|--|------|----|
| SUBROUTINE COMFNC(C,S,N,NM,PS,R) | CMF | 1 |
| IMPLICIT INTEGER(A-U), REAL(V-Z) | CMF | 2 |
| INTEGER*2 EQU(100,10,4),PRTLST(50) | CMF | 3 |
| COMMON /MOD/ VARARY(620),NAMARY(400),EQU,PRTLST | CMF | 4 |
| COMMON /GEN/ ALBET(50) | CMF | 5 |
| DIMENSION C(16), S(80), NA(16) | CMF | 6 |
| PS = C | CMF | 7 |
| NM = 401 | CMF | 8 |
| ST = 1 | CMF | 9 |
| 100 DO 110 I = ST,80 | 1CMF | 10 |
| K = I | 1CMF | 11 |
| IF (S(I) .EQ. 0) GO TO 120 | 1CMF | 12 |
| IF (S(I) .EQ. C(I)) GO TO 170 | 1CMF | 13 |
| 110 CONTINUE | 1CMF | 14 |
| 120 IF (R .EQ. C) RETURN | CMF | 15 |
| 130 DO 140 I = 402,600 | 1CMF | 16 |
| K = I | 1CMF | 17 |
| IF (VARARY(I) .EQ. K) GO TO 160 | 1CMF | 18 |
| IF (VARARY(I) .EQ. C) GO TO 150 | 1CMF | 19 |
| 140 CONTINUE | 1CMF | 20 |
| PS = -1 | CMF | 21 |
| CALL ERROR(2) | CMF | 22 |
| NM = 0 | CMF | 23 |
| RETURN | CMF | 24 |
| 150 VARARY(K) = R | CMF | 25 |
| 160 NM = K | CMF | 26 |
| RETURN | CMF | 27 |
| 170 KS = K + N - 1 | CMF | 28 |
| ST = K + 1 | CMF | 29 |
| L = 1 | CMF | 30 |
| DO 180 I = K,KS | 1CMF | 31 |
| IF (S(I) .NE. C(L)) GO TO 100 | 1CMF | 32 |
| 180 L = L + 1 | 1CMF | 33 |
| DO 190 I = K,KS | 1CMF | 34 |
| 190 S(I) = 0 | 1CMF | 35 |
| K = KS + 1 | CMF | 36 |
| L = C | CMF | 37 |
| DO 200 I = K,80 | 1CMF | 38 |
| ST = I | 1CMF | 39 |
| IF (S(I) .EQ. 0 .OR. S(I) .EQ. ALBET(3)) GO TO 210 | 1CMF | 40 |
| L = L + 1 | 1CMF | 41 |
| NA(L) = S(I) | 1CMF | 42 |
| 200 S(I) = 0 | 1CMF | 43 |
| 210 NA(L+1) = C | CMF | 44 |
| CALL NAMT(NA,NM) | CMF | 45 |
| PS = 1 | CMF | 46 |
| CALL RMVZER(S,K) | CMF | 47 |
| RETURN | CMF | 48 |
| END | CMF | 49 |

| | | |
|-----|---|---------|
| | SUBROUTINE MAININ | MIN 1 |
| | IMPLICIT INTEGER(A-U),REAL(V-Z) | MIN 2 |
| | DIMENSION S(80),R(40),NA(16) | MIN 3 |
| | LOGICAL CM | MIN 4 |
| | INTEGER*2 MNP(100,6),PRTLST(100),GETLST(100) | MIN 5 |
| | COMMON /BUG/ DEBUG | MIN 6 |
| | COMMON /MAIN/ VRB(620),NAPS(400),MNP,PRTLST,GETLST,MAINM(200) | MIN 7 |
| | COMMON /ALL/ VLST(50),MODNAM(30,5) | MIN 8 |
| | COMMON /GEN/ ALBET(50) | MIN 9 |
| | INTEGER*2 EQU(100,10,4) | MIN 10 |
| | COMMON /MOD/ VARARY(620),NAMARY(400),EQU | MIN 11 |
| | DO 100 I = 1,100 | IMIN 12 |
| | DO 100 J = 1,6 | 2MIN 13 |
| 100 | MNP(I,J) = 0 | 2MIN 14 |
| | EQ = 2 | MIN 15 |
| | RC = C | MIN 16 |
| | APT = 1 | MIN 17 |
| | AGV = 1 | MIN 18 |
| | CARC = 0 | MIN 19 |
| 110 | REAC(1,120,END=330) S | MIN 20 |
| 120 | FORMAT(80A) | MIN 21 |
| | CARD = CARC + 1 | MIN 22 |
| | IF (CARD .EQ. 1 .OR. CARD .EQ. 60) WRITE (3,130) | MIN 23 |
| 130 | FORMAT ('1') | MIN 24 |
| | CMT = 81 | MIN 25 |
| | NRT = 0 | MIN 26 |
| | NB = C | MIN 27 |
| | DO 140 I = 1,80 | IMIN 28 |
| | K = 81 - I | IMIN 29 |
| | IF(S(K).NE. ALBET(13)) NRT = 1 | IMIN 30 |
| | IF(S(K).EQ. ALBET(13) .AND. NRT.EQ.0) NB = K | IMIN 31 |
| 140 | IF(S(K).EQ. ALBET(50)) CMT = K | IMIN 32 |
| | IF(CMT .EQ.81) GO TO 160 | MIN 33 |
| | NTMS = 114 - NB | MIN 34 |
| | WRITE(3,150) CARC,(S(I),I = 1,CMT),(ALBET(13),I = 1,NTMS),(S(I),I = | MIN 35 |
| | A CMT,NB) | MIN 36 |
| 150 | FORMAT(5X,13,2X,120A1) | MIN 37 |
| | GO TO 170 | MIN 38 |
| 160 | WRITE(3,150) CARD,S | MIN 39 |
| 170 | DO 180 I = 1,80 | IMIN 40 |
| 180 | IF(S(I) .EQ. ALBET(13) .OR. I .GE.CMT) S(I) = 0 | IMIN 41 |
| | CALL RMVZER(S,K) | MIN 42 |
| | IF(K.EQ.0) GO TO 110 | MIN 43 |
| C | | MIN 44 |
| C | CHECK FOR DEBUG | MIN 45 |
| C | | MIN 46 |
| | IF (S(1) .NE. ALBET(46).OR.S(2).NE.ALBET(45).OR.S(3).NE.ALBET(48) | MIN 47 |
| | A .OR.S(4).NE.ALBET(29).OR.S(5).NE.ALBET(43)) GO TO 190 | MIN 48 |
| | MNP(1,1) = 1 | MIN 49 |
| | GO TO 110 | MIN 50 |
| 190 | CONTINUE | MIN 51 |
| | CALL COMND(S,T,R,ER) | MIN 52 |
| | IF (T .EQ. 0) GO TO 340 | MIN 53 |
| | IF (T .EQ. 15) GO TO 440 | MIN 54 |
| | IF (T .NE. 0 .AND. ER.EQ. 0) GO TO 210 | MIN 55 |

| | | | |
|-----|---|-----|-----|
| 200 | CALL ERROR(26) | MIN | 56 |
| | GO TO 110 | MIN | 57 |
| 210 | GO TO (220,200,230,230,240,200,270,110,200,290,320,200),I | MIN | 58 |
| | GO TO 200 | MIN | 59 |
| 220 | MNPG(EQ,1) = 1 | MIN | 60 |
| | MNPG(EQ,2) = R(1) | MIN | 61 |
| | MNPG(EQ,3) = R(2) | MIN | 62 |
| | MNPG(EQ,4) = R(3) | MIN | 63 |
| | MNPG(EQ,5) = R(4) | MIN | 64 |
| | MNPG(EQ,6) = R(5) | MIN | 65 |
| | EQ = EQ + 1 | MIN | 66 |
| | GO TO 11C | MIN | 67 |
| C | | MIN | 68 |
| C | RUN MCD STATEMENT | MIN | 69 |
| C | | MIN | 70 |
| 230 | CALL MDNAME(MND,R) | MIN | 71 |
| | MNPG(EQ,1) = 4 | MIN | 72 |
| | MNPG(EQ,2) = MNU | MIN | 73 |
| | MNPG(EQ,3) = RC | MIN | 74 |
| | EQ = EQ + 1 | MIN | 75 |
| | RC = C | MIN | 76 |
| | GO TO 110 | MIN | 77 |
| C | | MIN | 78 |
| C | GET STATEMENT | MIN | 79 |
| C | | MIN | 80 |
| 240 | AND = NGV + 40 | MIN | 81 |
| | MNPG(EQ,1) = 5 | MIN | 82 |
| | MNPG(EQ,2) = NGV | MIN | 83 |
| | K = 1 | MIN | 84 |
| | GO 25C I = NND,NGV | MIN | 85 |
| | IF(R(K) .EQ. C) GO TO 260 | MIN | 86 |
| | GETLST(I) = R(K) | MIN | 87 |
| 250 | K = K + 1 | MIN | 88 |
| 260 | MNPG(EQ,3) = J | MIN | 89 |
| | NGV = J + 1 | MIN | 90 |
| | EQ = EQ + 1 | MIN | 91 |
| | GO TO 110 | MIN | 92 |
| C | | MIN | 93 |
| C | POINT STATEMENT | MIN | 94 |
| C | | MIN | 95 |
| 270 | VARARY(R(1)) = EQ | MIN | 96 |
| | GO TO 11C | MIN | 97 |
| C | | MIN | 98 |
| C | READ STATEMENT | MIN | 99 |
| C | | MIN | 100 |
| 280 | RD = 1 | MIN | 101 |
| | GO TO 110 | MIN | 102 |
| C | | MIN | 103 |
| C | PRINT STATEMENT | MIN | 104 |
| C | | MIN | 105 |
| 290 | AND = NPT + 40 | MIN | 106 |
| | MNPG(EQ,1) = 10 | MIN | 107 |
| | MNPG(EQ,2) = NPT | MIN | 108 |
| | K = 1 | MIN | 109 |
| | GO 30C I = NPT,NAD | MIN | 110 |

| | |
|---|---------|
| IF (R(K) .EQ. 0) GO TO 310 | MIN 111 |
| J = I | MIN 112 |
| PRYLST(I) = R(K) | MIN 113 |
| 300 K = K + 1 | MIN 114 |
| 310 MNPGEQ,3) = J | MIN 115 |
| EQ = EQ + 1 | MIN 116 |
| NPT = J + 1 | MIN 117 |
| GO TO 11C | MIN 118 |
| C | MIN 119 |
| C IF --- GO TO STATEMENT | MIN 120 |
| C | MIN 121 |
| 320 MNPGEQ,1) = 11 | MIN 122 |
| MNPGEQ,2) = R(1) | MIN 123 |
| MNPGEQ,3) = R(2) | MIN 124 |
| MNPGEQ,4) = R(3) | MIN 125 |
| MNPGEQ,5) = R(4) | MIN 126 |
| EQ = EQ + 1 | MIN 127 |
| GO TO 110 | MIN 128 |
| 330 EBLC = MNPGEQ,1,1) | MIN 129 |
| RETURN | MIN 130 |
| 340 CO 350 I = 1,16 | MIN 131 |
| K = 1 | MIN 132 |
| NA(I) = S(I) | MIN 133 |
| S(I) = 0 | MIN 134 |
| IF (NA(I) .EQ. ALBET(1)) GO TO 360 | MIN 135 |
| 350 NA(I+1) = C | MIN 136 |
| 360 NA(K) = 0 | MIN 137 |
| CALL NAP(NA,K) | MIN 138 |
| MNPGEQ,1) = 3 | MIN 139 |
| MNPGEQ,2) = K | MIN 140 |
| MNPGEQ,3) = 401 | MIN 141 |
| MNPGEQ,4) = 1 | MIN 142 |
| MNPGEQ,5) = 401 | MIN 143 |
| CALL RMVZER(S,K) | MIN 144 |
| NPS = 3 | MIN 145 |
| IF (S(I) .EQ. ALBET(5)) GO TO 400 | MIN 146 |
| 370 IF (S(I) .GE. ALBET(23) .AND. S(I) .NE. ALBET(8)) GO TO 410 | MIN 147 |
| EO 380 I = 1,5 | MIN 148 |
| K = 1 | MIN 149 |
| NA(I) = S(I) | MIN 150 |
| IF (S(I) .EQ. ALBET(5) .OR. S(I) .EQ. ALBET(10)) GO TO 390 | MIN 151 |
| S(I) = C | MIN 152 |
| 390 NA(I+1) = C | MIN 153 |
| 390 NA(K) = 0 | MIN 154 |
| CALL NAP(NA,K) | MIN 155 |
| MNPGEQ,NPS) = K | MIN 156 |
| CALL RMVZER(S,K) | MIN 157 |
| IF (K .GT. 0 .AND. NPS .LT. 5) GO TO 400 | MIN 158 |
| EQ = EQ + 1 | MIN 159 |
| GO TO 110 | MIN 160 |
| 400 SGN = 1 | MIN 161 |
| IF (S(I) .EQ. ALBET(5)) SGN = -1 | MIN 162 |
| S(I) = C | MIN 163 |
| CALL RMVZER(S,K) | MIN 164 |
| MNPGEQ,4) = SGN | MIN 165 |

| | |
|---|---------|
| NPS = 5 | MIN 156 |
| GO TO 370 | MIN 167 |
| 410 NST = 0 | MIN 168 |
| CO 42C I = 1,K | MIN 169 |
| AA(I) = S(I) | MIN 170 |
| NA(I+1) = C | MIN 171 |
| IF (S(I) .EQ. ALBET(45)) NST = 2 | MIN 172 |
| IF (S(I) .GT. ALBET(12) .AND. NST .LE. 0) GO TO 430 | MIN 173 |
| NST = NST - 1 | MIN 174 |
| 420 S(I) = 0 | MIN 175 |
| 430 CALL NAP(MA,K) | MIN 176 |
| PMPG(EQ,NPS) = K | MIN 177 |
| CALL RMVZER(S,K) | MIN 178 |
| IF (K .GT. C .AND. NPS .LT. 5) GO TO 370 | MIN 179 |
| EQ = EQ + 1 | MIN 180 |
| GO TO 110 | MIN 191 |
| 440 PMPG(EQ,1) = 2 | MIN 182 |
| PMPG(EQ,2) = R(I) | MIN 183 |
| EQ = EQ + 1 | MIN 184 |
| GO TO 110 | MIN 185 |
| END | MIN 186 |

| | | |
|---|------|----|
| SUBROUTINE MANSET | MST | 1 |
| IMPLICIT INTEGER(A-U),REAL(V-Z) | MST | 2 |
| INTEGER*2 MNP(100,6),PRTLST(100),GETLST(100) | MST | 3 |
| COMMON /MAIN/ VRB(620),NAMS(400),MNP,PRTLST,GETLST,MAINM(200) | MST | 4 |
| INTEGER*2 EQU(100,10,4) | MST | 5 |
| COMMON /MGC/ VARARY(620),NAMARY(400),EQU | MST | 6 |
| COMMON /BLG/ DEBUG | MST | 7 |
| CO 100 I = 1,400 | 1MST | 8 |
| VRB(I) = VARARY(I) | 1MST | 9 |
| 100 NAMS(I) = NAMARY(I) | 1MST | 10 |
| CO 110 I = 401,620 | 1MST | 11 |
| 110 VRB(I) = VARARY(I) | 1MST | 12 |
| IF ((BLG .NE. 1) GO TO 140 | MST | 13 |
| WRITE (3,130) (MNP(I,J),J = 1,6) | MST | 14 |
| CO 120 I = 2,100 | 1MST | 15 |
| IF (MNP(I,1) .EQ. 0) GO TO 140 | 1MST | 16 |
| 120 WRITE (3,120) (MNP(I,J),J = 1,6) | MST | 17 |
| 130 FORMAT (1,6I4) | MST | 18 |
| 140 RETURN | MST | 19 |
| END | MST | 20 |

| | | |
|---|------|----|
| SUBROUTINE STOPDI(MODNAM,MODNUM) | STM | 1 |
| IMPLICIT INTEGER(A-U),REAL(V-Z) | STM | 2 |
| INTEGER*2 EQU(100,10,4),PRTLST(50) | STM | 3 |
| COMMON /MOD/ VARARY(620),NAMARY(400),EQU,PRTLST | STM | 4 |
| COMMON /GEN/ ALBET(50) | STM | 5 |
| ----- | | |
| DIMENSION ST(20),MODNAM(5) | STM | 6 |
| NS = MODNLM + 1 | STM | 7 |
| IF (MODNAM(1) .NE. 1) GO TO 100 | STM | 8 |
| IF (EQU(1,1,1) .LE. 0) RETURN | STM | 9 |
| NS = EQU(1,1,1) + 1 | STM | 10 |
| READ (5*NS) (ST(I),I=1,20) | STM | 11 |
| AREC = ST(6) | STM | 12 |
| GO TO 110 | STM | 13 |
| 100 READ(5*1) AMOD,NREC | STM | 14 |
| A6 = NREC | STM | 15 |
| ST(6) = NREC | STM | 16 |
| 110 TYP = 1 | STM | 17 |
| DO 120 I=1,100,5 | 1STM | 18 |
| IF (EQU(I,1,1).EQ.0) GO TO 140 | 1STM | 19 |
| S = I + 4 | 1STM | 20 |
| WRITE(4*NREC)MODNLM,TYP,(((EQU(I,K,L),L=1,4),K=1,10),J=1,S) | 1STM | 21 |
| DO 120 J = 1,S | 2STM | 22 |
| DO 120 K = 1,10 | 3STM | 23 |
| DO 120 L = 1,4 | 4STM | 24 |
| EQU(I,K,L) = 0 | 4STM | 25 |
| 120 AREC = NREC + 1 | 1STM | 26 |
| 140 ST(7) = NREC - 1 | STM | 27 |
| TYP = 2 | STM | 28 |
| WRITE(4*NREC)MODNLM,TYP,(VARARY(I),I=201,300) | STM | 29 |
| AREC = NREC + 1 | STM | 30 |
| WRITE(4*NREC)MODNUM,TYP,(VARARY(I),I=301,400) | STM | 31 |
| AREC = NREC + 1 | STM | 32 |
| TYP = 3 | STM | 33 |
| WRITE(4*NREC)MODNUM,TYP,(VARARY(I),I =401,500) | STM | 34 |
| AREC = NREC + 1 | STM | 35 |
| WRITE(4*NREC)MODNLM,TYP,(VARARY(I),I=501,600) | STM | 36 |
| AREC = NREC + 1 | STM | 37 |
| TYP = 4 | STM | 38 |
| WRITE(4*NREC)MODNLM,TYP,(NAMARY(I),I = 1,100) | STM | 39 |
| AREC = NREC + 1 | STM | 40 |
| WRITE(4*NREC)MODNUM,TYP,(NAMARY(I),I = 101,200) | STM | 41 |
| AREC = NREC + 1 | STM | 42 |
| WRITE(4*NREC)MODNLM,TYP,(NAMARY(I),I = 201,300) | STM | 43 |
| AREC = NREC + 1 | STM | 44 |
| WRITE(4*NREC)MODNUM,TYP,(NAMARY(I),I = 301,400) | STM | 45 |
| AREC = NREC + 1 | STM | 46 |
| TYP = 5 | STM | 47 |
| WRITE(4*NREC)MODNLM,TYP,(PRTLST(I),I=1,50) | STM | 48 |
| AREC = NREC + 1 | STM | 49 |
| 150 IF (MODNAM(1) .EC. 1) RETURN | STM | 50 |
| AMOD = NMOD + 1 | STM | 51 |
| DO 100 I = 1,5 | 1STM | 52 |
| 160 ST(I) = MODNAM(I) | 1STM | 53 |
| WRITE(5*NS)(ST(I),I = 1,20) | STM | 54 |
| WRITE(5*1)AMOD,NREC | STM | 55 |
| RETURN | STM | 56 |
| END | STM | 57 |

| | | | |
|-----|---|-----|----|
| | SUBROUTINE MAINRN | MRN | 1 |
| | IMPLICIT INTEGER (A-U), REAL (V-Z) | MRN | 2 |
| | INTEGER*2 MNPG(100,6), PRTLST(100), GETLST(100) | MRN | 3 |
| | COMMON /MAIN/ V (620), NF (400), MNPG, PRTLST, GETLST, MAINM(200) | MRN | 4 |
| | COMMON /ALL/ VLST(50), MODNAM(30,5) | MRN | 5 |
| | COMMON /MOD/ VRB(620), NAMS(400) | MRN | 6 |
| | COMMON /COMMON/ STPCOM, STTREG, STPREG, CCM(200) | MRN | 7 |
| | WRITE (3,100) | MRN | 8 |
| 100 | FORMAT ('1') | MRN | 9 |
| | DO 110 I = 1, STPCOM | MRN | 10 |
| 110 | AM(I) = CCM(I) | MRN | 11 |
| | IP = 2 | MRN | 12 |
| | VLM = 1.23459E-13 | MRN | 13 |
| 120 | IF (MNPG(IP,1) .EQ. 0) GO TO 270 | MRN | 14 |
| | IGO = MNPG(IP,1) | MRN | 15 |
| | GO TO (130,290,280,150,180,140,140,140,140,200,230,140), IGO | MRN | 16 |
| | IP = IP + 1 | MRN | 17 |
| | GO TO 120 | MRN | 18 |
| 130 | CALL ITCHK(IP, CGA) | MRN | 19 |
| | IF (CGA .EQ. 0) IP = MNPG(IP,3) - 1 | MRN | 20 |
| | IP = IP + 1 | MRN | 21 |
| | GO TO 120 | MRN | 22 |
| 140 | IP = IP + 1 | MRN | 23 |
| | GO TO 120 | MRN | 24 |
| 150 | MODNUM = MNPG(IP,2) | MRN | 25 |
| | CALL GETMOD(MODNUM) | MRN | 26 |
| | IF (MNPG(IP,3) .EQ. 1) CALL CATAIN | MRN | 27 |
| | IF (MNPG(1,1) .EQ. 1) WRITE (3,160) (MODNAM(MODNUM, I), I=1,5) | MRN | 28 |
| 160 | FORMAT (' *****', 5A4) | MRN | 29 |
| | CALL RUNMOD | MRN | 30 |
| | IF (MNPG(1,1) .EQ. 1) CALL BUGPRT | MRN | 31 |
| | DO 170 I = 1, STPCOM | MRN | 32 |
| 170 | V(I) = VRB(I) | MRN | 33 |
| | IP = IP + 1 | MRN | 34 |
| | GO TO 120 | MRN | 35 |
| 180 | S = MNPG(IP,2) | MRN | 36 |
| | ST = MNPG(IP,3) | MRN | 37 |
| | K = 1 | MRN | 38 |
| | DO 190 I = 1, ST | MRN | 39 |
| | V(IGETLST(I)) = VLST(K) | MRN | 40 |
| 190 | K = K + 1 | MRN | 41 |
| | IP = IP + 1 | MRN | 42 |
| | GO TO 120 | MRN | 43 |
| 200 | S = MNPG(IP,2) | MRN | 44 |
| | ST = MNPG(IP,3) | MRN | 45 |
| | IF (MNPG(IP-1,1) .NE. 10) WRITE (3,210) | MRN | 46 |
| 210 | FORMAT ('/5X, 'CONTROL MODULE') | MRN | 47 |
| | WRITE(3,220) (M(PRTLST(I)), V(PRTLST(I)), I = 1, ST) | MRN | 48 |
| 220 | FORMAT(5(5), A4, ' = ', 1PE13.6) | MRN | 49 |
| | IP = IP + 1 | MRN | 50 |
| | GO TO 120 | MRN | 51 |
| 230 | IGO = MNPG(IP,3) | MRN | 52 |
| | IF (V(MNPG(IP,2)) .EQ. VLM .OR. V(MNPG(IP,4)) .EQ. VLM .OR. V(MNPG(IP,5)) | MRN | 53 |
| | .EQ. VLM) GO TO 300 | MRN | 54 |
| | GO TO (240,250,260), IGO | MRN | 55 |

| | | | |
|-----|---|-----|----|
| 240 | IF (V(MNPG(IP,2)).LT. V(MNPG(IP,4)))IP = V(MNPG(IP,5))-1 | MRN | 56 |
| | IP = IP + 1 | MRN | 57 |
| | GO TO 120 | MRN | 58 |
| 250 | IF (V(MNPG(IP,2)).EQ. V(MNPG(IP,4)))IP = V(MNPG(IP,5))-1 | MRN | 59 |
| | IP = IP + 1 | MRN | 60 |
| | GO TO 120 | MRN | 61 |
| 260 | IF (V(MNPG(IP,2)).GT. V(MNPG(IP,4)))IP = V(MNPG(IP,5))-1 | MRN | 62 |
| | IP = IP + 1 | MRN | 63 |
| | GO TO 120 | MRN | 64 |
| 270 | RETURN | MRN | 65 |
| 280 | IF(V(MNPG(IP,3)).EQ.VUN.OR.V(MNPG(IP,5)).EQ.VUN) GO TO 300 | MRN | 66 |
| | V(MNPG(IP,2)) = V(MNPG(IP,3)) + PMPG(IP,4) * V(MNPG(IP,5)) | JRN | 67 |
| | IF (MXPG(IP,2) .LE. STPCOM) VRB(MNPG(IP,2)) = V(MNPG(IP,2)) | MRN | 68 |
| | IP = IP + 1 | MRN | 69 |
| | GO TO 120 | MRN | 70 |
| 290 | IP = V(MNPG(IP,2)) | MRN | 71 |
| | GO TO 120 | MRN | 72 |
| 300 | CALL ERROR(34) | MRN | 73 |
| | CALL PDLMP(V(1),MNP(10,6),0) | MRN | 74 |
| | RETURN | MRN | 75 |
| | END | MRN | 76 |

| | | |
|--|-----|----|
| SUBROUTINE ITCHK(P,CON) | ICK | 1 |
| IMPLICIT INTEGER(A-U),REAL(V-Z) | ICK | 2 |
| INTEGER*2 M (100,6),PRTLST(100),GETLST(100) | ICK | 3 |
| COMMON /MAIN/ V(200),N(400),M,PRTLST,GETLST,MAINM(200) | ICK | 4 |
| DIMENSION IT(2,10),VAL(10) | ICK | 5 |
| IF(CON .NE. -7) GO TO 110 | ICK | 6 |
| CO 100 I = 1,10 | ICK | 7 |
| 100 IT(1,I) = 0 | ICK | 8 |
| RETURN | ICK | 9 |
| 110 CO 120 I = 1,10 | ICK | 10 |
| K = I | ICK | 11 |
| IF (IP.EQ.IT(1,I)) GO TO 150 | ICK | 12 |
| 120 CONTINUE | ICK | 13 |
| CO 130 I = 1,10 | ICK | 14 |
| K = I | ICK | 15 |
| IF (IT(1,I).EQ. 0) GO TO 140 | ICK | 16 |
| 130 CONTINUE | ICK | 17 |
| 140 IT(1,K) = F | ICK | 18 |
| IT(2,K) = 1 | ICK | 19 |
| CON = 0 | ICK | 20 |
| IF (M(P,2) .EQ. C) RET JKN | ICK | 21 |
| VAL(K) = V(M(P,2)) | ICK | 22 |
| RETURN | ICK | 23 |
| 150 IT(2,K) = IT(2,K) + 1 | ICK | 24 |
| CON = 0 | ICK | 25 |
| IF (M(P,2) .EQ. C) GO TO 160 | ICK | 26 |
| V1 = VAL(K) | ICK | 27 |
| V2 = V(M(P,2)) | ICK | 28 |
| VAL(K) = V2 | ICK | 29 |
| IF (ABS(V1-V2) .LE. V(M(P,6))) CON = 1 | ICK | 30 |
| IF (ABS((V1-V2)/V2)*10 .LE. V(M(P,5))) CON = 1 | ICK | 31 |
| 160 IF (IT(2,K) .GE. M(P,4)) CON = 1 | ICK | 32 |
| IF (CON EQ. 0) RETURN | ICK | 33 |
| IT(1,K) = C | ICK | 34 |
| IT(2,K) = C | ICK | 35 |
| RETURN | ICK | 36 |
| END | ICK | 37 |

| | |
|---|---------|
| SUBROUTINE GE(MOD(MN)) | GTM 1 |
| IMPLICIT INTEGER(A-U),REAL(V-Z) | GTM 2 |
| INTEGER*2 EQ(100,10,4),PRTLST(50) | GTM 3 |
| COMMON /MOD/ VARARY(620),NAMARY(400),EQ ,PRTLST | GTM 4 |
| DIMENSION ST(20),MODNAM(5) | GTM 5 |
| MODNAM(1) = 1 | GTM 6 |
| IF (EQ(1,1,1) .EQ. MN) RETURN | GTM 7 |
| NS = MN + 1 | GTM 8 |
| CALL STOMOD(MODNAM,MN) | GTM 9 |
| READ (5*NS) (ST(I),I = 1,20) | GTM 10 |
| NREC = ST(6) | GTM 11 |
| DO 100 I = 1,100,5 | 1GTM 12 |
| IF (NREC .GT. ST(7)) GO TO 110 | 1GTM 13 |
| S = I + 4 | 1GTM 14 |
| READ (4*NREC) NAM,TY,(((EQ(J,K,L),L=1,4,K=1,10),J=1,S) | 1GTM 15 |
| 100 NREC = NREC + 1 | 1GTM 16 |
| 110 READ (4*NREC) NAM,TY,(VARARY(I),I=201,300) | GTM 17 |
| NREC = NREC + 1 | GTM 18 |
| READ (4*NREC) NAM,TY,(VARARY(I),I=301,400) | GTM 19 |
| NREC = NREC + 1 | GTM 20 |
| READ (4*NREC) NAM,TY,(VARARY(I),I=401,500) | GTM 21 |
| NREC = NREC + 1 | GTM 22 |
| READ (4*NREC) NAM,TY,(VARARY(I),I=501,600) | GTM 23 |
| NREC = NREC + 1 | GTM 24 |
| READ (4*NREC) NAM,TY,(NAMARY(I),I=1,100) | GTM 25 |
| NREC = NREC + 1 | GTM 26 |
| READ (4*NREC) NAM,TY,(NAMARY(I),I=101,200) | GTM 27 |
| NREC = NREC + 1 | GTM 28 |
| READ (4*NREC) NAM,TY,(NAMARY(I),I=201,300) | GTM 29 |
| NREC = NREC + 1 | GTM 30 |
| READ (4*NREC) NAM,TY,(NAMARY(I),I=301,400) | GTM 31 |
| NREC = NREC + 1 | GTM 32 |
| READ (4*NREC) NAM,TY,(PRTLST(I),I=1,50) | GTM 33 |
| EQ(1,1,1) = MN | GTM 34 |
| IF (EQ(2,1,1) .EQ. 1) GO TO 120 | GTM 35 |
| CALL ORDER(INO) | GTM 36 |
| EQ(2,1,1) = 1 | GTM 37 |
| 120 RETURN | GTM 38 |
| END | GTM 39 |

| | | |
|--|------|----|
| SUBROUTINE MDNAME(NUM,NAM) | MDN | 1 |
| IMPLICIT INTEGER(A-U),REAL(V-Z) | MDN | 2 |
| COMMON /ALL/ VLST(50),MODNAM(30,5) | MDN | 3 |
| DIMENSION NAM(5) | MDN | 4 |
| DO 110 I = 1,30 | MDN | 5 |
| ALM = I | MDN | 6 |
| IF (MODNAM(I,1) .EQ. 0) GO TO 120 | MDN | 7 |
| IF (NAM(I) .NE. MODNAM(I,1)) GO TO 110 | MDN | 8 |
| DO 100 J = 1,5 | 2MKN | 9 |
| IF (NAM(J) .NE. MODNAM(I,J)) GO TO 110 | 2MKN | 10 |
| 100 CONTINUE | 2MDN | 11 |
| RETURN | MDN | 12 |
| 110 CONTINUE | MDN | 13 |
| CALL ERROR(23) | MDN | 14 |
| RETURN | MDN | 15 |
| 120 DO 130 I = 1,5 | 1MKN | 16 |
| 130 MODNAM(NUM,I) = NAM(I) | 1MKN | 17 |
| RETLRN | MDN | 18 |
| END | MDN | 19 |

| | | |
|---|------|----|
| SUBROUTINE TABLIN(S) | TIN | 1 |
| IMPLICIT INTEGER(A-U),REAL(V-Z) | TIN | 2 |
| COMMON /GEN/ A(50) | TIN | 3 |
| COMMON /MOD/ VAR (620),NAM (400) | TIN | 4 |
| COMMON /TAB/ TABL(20,2) | TIN | 5 |
| DIMENSION S(80),C(16),NSZ(3),V(600),X(100),Y(100),Z(100) | TIN | 6 |
| NSZ(1) = 1 | TIN | 7 |
| NSZ(2) = 1 | TIN | 8 |
| NSZ(3) = 1 | TIN | 9 |
| C(1) = A(36) | TIN | 10 |
| C(2) = A(45) | TIN | 11 |
| C(3) = A(37) | TIN | 12 |
| C(4) = A(45) | TIN | 13 |
| C(5) = A(1) | TIN | 14 |
| CALL COMFNC(C,S,5,NM,PS,0) | TIN | 15 |
| DO 100 I = 1,80 | 1TIN | 16 |
| IF (S(I) .EQ. 0) GO TO 110 | 1TIN | 17 |
| IF (S(I) .EQ. A(11)) LP = I + 1 | 1TIN | 18 |
| 100 IF (S(I) .EQ. A(6)) RP = I - 1 | 1TIN | 19 |
| 110 NV = 1 | TIN | 20 |
| L = C | TIN | 21 |
| DO 120 I = LP,RP | 1TIN | 22 |
| L = L + 1 | 1TIN | 23 |
| IF (S(L) .EQ. A(3)) S(L) = 0 | 1TIN | 24 |
| C(L) = S(I) | 1TIN | 25 |
| IF (C(L) .NE. 0 .AND. .P .NE. 1) GO TO 120 | 1TIN | 26 |
| C(L+1) = 0 | 1TIN | 27 |
| CALL NUMCMP(C,VR) | 1TIN | 28 |
| NSZ(NV) = VR | 1TIN | 29 |
| L = C | 1TIN | 30 |
| NV = NV + 1 | 1TIN | 31 |
| 120 S(I) = 0 | 1TIN | 32 |
| NT = NV-1 | TIN | 33 |
| WRITE (3,130) NAM(NM),(NSZ(I),I = 1,NT) | TIN | 34 |
| 130 FORMAT (//,5X,'TABLE ',A4,3X,'SIZE = ',T26,I3,T30,I3,T29,'.',T34, | TIN | 35 |
| A T3,T23,'.',') | TIN | 36 |
| WRITE (3,250) | TIN | 37 |
| GO TO (18C,160,14C),NT | TIN | 38 |
| 140 WRITE (3,150) | TIN | 39 |
| 150 FORMAT ('+',6X,'Z') | TIN | 40 |
| 160 WRITE (3,170) | TIN | 41 |
| 170 FORMAT ('+',19X,'Y') | TIN | 42 |
| 180 WRITE (3,180) | TIN | 43 |
| 190 FORMAT ('+',32X,'X') | TIN | 44 |
| NT = NSZ(1)*NSZ(2)*NSZ(3) | TIN | 45 |
| NXT = NSZ(1) | TIN | 46 |
| NYT = NSZ(2) | TIN | 47 |
| KZT = NSZ(3) | TIN | 48 |
| READ (1,200,END=300) (X(I),I=1,NXT) | TIN | 49 |
| 200 FORMAT (3E10.5) | TIN | 50 |
| WRITE (3,250) | TIN | 51 |
| WRITE (3,210) (X(I),I=1,NXT) | TIN | 52 |
| 210 FORMAT ('+',27X,E(2X,1PE11.4),12(/,26X,8(2X,1PE11.4)) | TIN | 53 |
| IF (NYT .EQ. 1) GO TO 220 | TIN | 54 |
| READ (1,200,END=300) (Y(I),I=1,NYT) | TIN | 55 |

| | | | |
|-----|---|------|----|
| | IF (NXT .EQ. 1) GO TO 220 | TIN | 56 |
| | READ (1,200,END=300) (Z(I),I=1,NXT) | TIN | 57 |
| 220 | NS = 1 | TIN | 58 |
| | NST = NXT | TIN | 59 |
| | WRITE (3,250) | TIN | 60 |
| | CO 260 I = 1,NXT | 1TIN | 61 |
| | IF (NV .GT. 3) WRITE (3,240) Z(I) | 1TIN | 62 |
| | IF (NV .LE. 3) WRITE (3,250) | 1TIN | 63 |
| | CO 260 J = 1,NXT | 2TIN | 64 |
| | IF (NV .GT. 2) WRITE (3,230) Y(J) | 2TIN | 65 |
| | REAC(1,200) (V(K),K=NS,NST) | 2TIN | 66 |
| | WRITE (3,210) (V(K),K=NS,NST) | 2TIN | 67 |
| | NS = NST + 1 | 2TIN | 69 |
| 230 | FORMAT ('+',14X,1PE11.4) | 2TIN | 69 |
| 240 | FORMAT (/,2X,1PE11.4) | 2TIN | 70 |
| | IF (NXT .NE. 8) WRITE (3,250) | 2TIN | 71 |
| 250 | FORMAT (' ') | 2TIN | 72 |
| 260 | NST = NS + NXT - 1 | 2TIN | 73 |
| | K = 1 | TIN | 74 |
| | CO 270 I = 1,20 | 1TIN | 75 |
| | IF (TABL(I,1) .EQ. 0) GO TO 280 | 1TIN | 76 |
| | IF (TABL(I,1) .EQ. NAM(NM)) GO TO 290 | 1TIN | 77 |
| 270 | K = I + 1 | 1TIN | 78 |
| | CALL ERROR(27) | TIN | 79 |
| 280 | TABL(K,1) = NAM(NM) | TIN | 80 |
| | TABL(K,2) = NV | TIN | 81 |
| 290 | IF (TABL(K,2) .NE. NV) CALL ERROR(28) | TIN | 82 |
| | WRITE (6,K) NT,NXT,NYT,NZT,(V(I),I=1,NT),(X(I),I=1,NXT),(Y(I),I=1 | TIN | 83 |
| | A ,NYT),(Z(I),I=1,NZT) | TIN | 84 |
| | RETURN | TIN | 85 |
| 300 | CALL ERROR(30) | TIN | 86 |
| | RETURN | TIN | 87 |
| | END | TIN | 88 |

| | | |
|--|-----|----|
| SUBROUTINE INTERP(VI,NX,NY,NZ,V7,VX,VY,VZ,VRET,N2) | INT | 1 |
| DIMENSION VI(3),VT(NX,NY,NZ),VX(NX),VY(NY),VZ(NZ) | INT | 2 |
| CALL GETIND(VI(1),VX,NX,NX1,VXD,K2,1) | INT | 3 |
| CALL GETIND(VI(2),VY,NY,NY1,VYD,N2,2) | INT | 4 |
| CALL GETIND(VI(3),VZ,NZ,NZ1,VZD,N2,3) | INT | 5 |
| NTM = 0 | INT | 6 |
| 100 VRET = VT(NX1,NY1,NZ1) + VXD*(VT(NX1+1,NY1,NZ1)-VT(NX1,NY1,NZ1)) | INT | 7 |
| IF (NY .LE. 1) RETURN | INT | 8 |
| VPT1 = VRET | INT | 9 |
| NY1 = NY1 + 1 | INT | 10 |
| VRET = VT(NX1,NY1,NZ1) + VXD*(VT(NX1+1,NY1,NZ1)-VT(NX1,NY1,NZ1)) | INT | 11 |
| NY1 = NY1 - 1 | INT | 12 |
| VPT2 = VRET | INT | 13 |
| VRET = VPT1 + VYD*(VPT2-VPT1) | INT | 14 |
| IF (NZ .EQ. 1) RETURN | INT | 15 |
| IF (NTM .EQ. 1) GO TO 110 | INT | 16 |
| VPT3 = VRET | INT | 17 |
| NTM = 1 | INT | 18 |
| NZ1 = NZ1 + 1 | INT | 19 |
| GO TO 100 | INT | 20 |
| 110 VRET = VPT2 + VZD*(VRET-VPT3) | INT | 21 |
| RETURN | INT | 22 |
| END | INT | 23 |

| | | |
|---|------|----|
| SUBROUTINE GETIND(VD,VA,NT,N,VI,NTAB,NVAR) | G10 | 1 |
| DIMENSION VA(NT) | G10 | 2 |
| COMMON /TAB/ TABL(20,2) | G10 | 3 |
| IF (NT .GT. 1) GO TO 100 | G10 | 4 |
| K = 1 | G10 | 5 |
| VI = 0 | G10 | 6 |
| RETURN | G10 | 7 |
| 100 IF (VD .LT. VA(1) OR. VD .GT. VA(NT)) GO TO 130 | G10 | 8 |
| CO IIC I = 2,NT | IG10 | 9 |
| A = [-1 | IG10 | 10 |
| IF (VC .LE. VA(1)) GO TO 120 | IG10 | 11 |
| 110 CONTINUE | IG10 | 12 |
| 120 VI = (VD-VA(N))/(VA(N+1)-VA(N)) | G10 | 13 |
| RETURN | G10 | 14 |
| 130 CALL ERROR(29) | G10 | 15 |
| WRITE (3,140) TABL(NTAB,1),NVAR,VD | G10 | 16 |
| 140 FORMAT (7 TABLE NAME = ',A4,' VARIABLE NO = ',I2,' VALUE WAS ', | G10 | 17 |
| A'PE13.6) | G10 | 18 |
| N = NT-1 | G10 | 19 |
| IF(VC .LT. VA(1)) N = 1 | G10 | 20 |
| GO TO 120 | G10 | 21 |
| END | G10 | 22 |

| | | |
|--|------|----|
| SUBROUTINE BUGPRT | BUG | 1 |
| IMPLICIT INTEGER (A-U), REAL (V-Z) | BUG | 2 |
| COMMON /MOE/ VARARY(820), NAMARY(400) | BUG | 3 |
| COMMON /COMMON/ STPCOM, STTREG, STPREG, COM(200) | BUG | 4 |
| J = C | BUG | 5 |
| DO 100 I = 1, STPCOM | 1BUG | 6 |
| IF (COM(I) .EQ. C) GO TO 110 | 1BUG | 7 |
| 100 J = I | 1BUG | 8 |
| 110 IF (J .EQ. 0) GO TO 130 | 8LC | 9 |
| WRITE (3,120) (COM(I),VARARY(I),I = 1,J) | BUG | 10 |
| 120 FORMAT (' COMMON VARIABLES',/,10(5(5X,A4,' = ',1PE13.6)/)) | BUG | 11 |
| 130 J = 5 | BUG | 12 |
| DO 140 I = STTREG,400 | 1BUG | 13 |
| IF (NAMARY(I) .EQ. 0) GO TO 150 | 1BUG | 14 |
| 140 J = I | 1BUG | 15 |
| 150 IF (J .EQ. 0) RETURN | BUG | 16 |
| WRITE (3,160) (NAMARY(I),VARARY(I),I = STTREG,J) | BUG | 17 |
| 160 FORMAT (' NON COMMON VARIABLES',/,10(5(5X,A4,' = ',1PE13.6)/)) | 8LC | 18 |
| RETURN | BUG | 19 |
| END | BUG | 20 |

APPENDIX II
MODEL LISTINGS

UTILITY MODEL

```

COMMON Gm,mFL,mFL1,WEL2,ERR
COMMON Gm1,um2,mPLO,mPL1
COMMON PTO,PRA,SFC
COMMON um,umEM
COMMON m,mA,mP,TAS,REN,YAR,SL,N,DPL,mCR,mFL,CPH,PK3,umh,MFM
COMMON K,PTU,SFO,F
COMMON INDX,LISC,ALI,GAT
COMMON IXA,IXD
COMMON WPLZ
PRINT ONE
RUN MOD SIZE
GM = Gm
RUN MOD T U ALLOWANCE AND CRUISE
RUN MOD MAX RANGE
RUN MOD TOTAL FUEL
GM = umh
RUN MOD STAT WEIGHT
RUN MOD GROSS WEIGHT
ITERATE UN um, FROM ONE, ATOL = 20
mFL1 = mFL
RUN MOD STORE OLD DATA
PRINT ALI,GAT
PRINT um,umEM,mFL,mPLO,PTC,PRA,SFC
PRINT PUAT
PRINT PAIT
RUN MOD NEW SIZE DATA
ITR = 0
PRINT TWO
RUN MOD SIZE
GM = Gm
RUN MOD T U ALLOWANCE AND CRUISE
RUN MOD MAX RANGE
RUN MOD TOTAL FUEL
GM = umh
mFL2 = mFL
RUN MOD ANAL WEIGHT
GM2 = Gm
RUN MOD GROSS WEIGHT TWO
GM1 = Gm
GMH = GM
RUN MOD T U ALLOWANCE AND CRUISE
RUN MOD MAX RANGE
RUN MOD TOTAL FUEL
GM = umh
mFL1 = mFL
RUN MOD PAYLOAD
GM = GM2
RUN MOD ERAGR
ITR = ITR + 1
IF ITR IS GT MXTR, GO TO THRE
IF ERR IS GT 20, GO TO TNC
PRINT THRE
PRINT ALI,umT,ITR
PRINT Gm1,umEM2,mFL1,mPL1,PTC,PRA,SFC
PRINT um2,mFL2,mPL2

```

```

DGW = GW2
MEM = MEM2
DPL = MPL2
RUN MJD PARG COSTS
RUN MJD JMAX      FINE MAXIMUM VALUE FOR J = JMAX = U/UPH
SI = 0
SDCE = 0
PRINT FOUR
SI = SI + 1
RUN MJD PAYLOADS
ITAT = 0
POINT FIVE
RUN MJD CUMS
GMH = GM
RUN MJD T O ALLOWANCE AND CRUISE
RUN MJD MAX RANGE
RUN MJD TOTAL FUEL
Gh = GMH
ITAT = ITAT + 1
ITERATE ON DML,PTOL=1,FCR FIVE
RUN MJD MAINT COSTS
RUN MJD HOVER PROS
RUN MJD MEI
PRINT SDCE, MEI, SCFM, PUF, SPMCV, SPL, SGW, SCLF
IF AN ISUT $1.00 TO FOUR
IDXA = IDXA + 1
ITERATE FROM PALT, TIMES = 5
IDXA = 1
IDXB = IDXB + 1
ITERATE FROM PORT, TIMES = 2

```

```

IOXJ = 1
IOXA = 1
MXTX = 25
NP = 1000
IAS = 15.0
YAR = 40
SI = 10
N = 5
MCR = 400
JPM = .1
MEM = 100
TABLE NAME = EUP, SIZE = (2)
0 1.5
1.0 1.0
TABLE NAME = USET, SIZE = (19)
12.2 E+03 60.0 E+03 10.0 E+04 25.5 E+04 54.0 E+04 10.0 E+05 20.0 E+05 44.0 E+05
12.5 E+04
1.5 E-03 1.35 E-03 1.2 E-03 1.5 E-03 1.75 E-03 1.5 E-03 1.75 E-03 1.5 E-03
1.6 E-06
TABLE NAME = MLAG, SIZE = (7)
1000. 47007.5 373320. 783597. 3.5887 E+5 1.1104E+7 1.0 E+8
1.2 E-2 6.542 E-3 2.904 E-3 2.237 E-3 1.819 E-3 1.274 E-3 0.0
TABLE NAME = PUE, SIZE = (2)
0 1.5
.33333 .33333
TABLE NAME = TMAX, SIZE = (14)
0 500. 1000. 2000. 3000. 4000. 5000. 6000.
7000. 8000. 9000. 10000. 11000. 12000.
42.22 45.25 46.64 43.85 42.5 40.50 39.64 37.78
35.53 35.25 25.67 21.11 12.75 12.5
TABLE NAME = MPRD, SIZE = (14)
0 .1995 .3205 .5108 .6208 .7749 .8442 .89.1
.0336 .49035 .9792 .9915 .9998 1.0
0 500. 1000. 2000. 3000. 4000. 5000. 6000.
7000. 8000. 9000. 10000. 11000. 12000.
TABLE NAME = MYLD, SIZE = (11)
1.0 2.0 3.0 4.0 5.0 6.0 7.0 8.0
9.0 10.0 11.0
40.0 50.0 60.0 100.0 110.0
TABLE NAME = PUE, SIZE = (11)
1.0 2.0 3.0 4.0 5.0 6.0 7.0 8.0
9.0 10.0 11.0
15.0 25.0 30.0 25.0 5.0
TABLE NAME = TPRD, SIZE = (24,14)
-23.23 -17.79 -12.22 -6.67 -3.86 -1.11 1.07 4.44
7.22 10.0 12.78 15.56 19.33 21.11 23.90 26.67
29.44 32.22 35.0 37.78 40.56 43.33 46.11 48.89
0 500. 1000. 2000. 3000. 4000. 5000. 6000.
7000. 8000. 9000. 10000. 11000. 12000.
0 0 0 0 0 0 0 0
.0096 .0213 .0373 .0566 .0755 .1000 .1444 .2147
.3242 .5143 .7236 .9697 .0216 .0210 .0571 1.0
0 0 0 0 0 0 0 .0062

```

| | | | | | | | |
|-------|-------|-------|-------|-------|-------|-------|-------|
| .0139 | .0271 | .0405 | .0665 | .0925 | .1251 | .1642 | .2817 |
| .4117 | .5767 | .7307 | .8535 | .9340 | .9814 | 1.0 | 1.0 |
| 0 | 0 | 0 | C | 0 | 0 | 0 | .0053 |
| .0115 | .0222 | .0342 | .0557 | .0930 | .1280 | .2043 | .3158 |
| .4555 | .6125 | .7524 | .8514 | .9130 | .9511 | 1.0 | 1.0 |
| 0 | 0 | 0 | C | 0 | 0 | 0 | .0080 |
| .0100 | .0297 | .0480 | .0726 | .1076 | .1690 | .2441 | .4295 |
| .4794 | .6264 | .7373 | .8290 | .8743 | .9000 | 1.0 | 1.0 |
| 0 | 0 | 0 | 0 | 0 | 0 | .0053 | .112 |
| .0233 | .0414 | .0634 | .1055 | .1497 | .2522 | .3730 | .3280 |
| .4571 | .6068 | .7530 | .8475 | .9057 | 1.0 | 1.0 | 1.0 |
| 0 | 0 | 0 | 0 | 0 | 0 | .0050 | .0149 |
| .0335 | .0535 | .0844 | .1382 | .2140 | .3270 | .4092 | .6252 |
| .7554 | .8568 | .9268 | .9712 | 1.0 | 1.0 | 1.0 | 1.0 |
| 0 | 0 | 0 | C | 0 | 0 | .0093 | .0200 |
| .0430 | .0670 | .1183 | .1896 | .2907 | .4190 | .5557 | .6746 |
| .8043 | .8837 | .9417 | .9803 | 1.0 | 1.0 | 1.0 | 1.0 |
| 0 | 0 | 0 | C | 0 | .0030 | .0120 | .0262 |
| .0443 | .0522 | .1473 | .2410 | .3687 | .5206 | .6060 | .7833 |
| .8674 | .9278 | .9548 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 |
| 0 | 0 | 0 | C | 0 | .0054 | .0159 | .0264 |
| .0596 | .1241 | .2141 | .3555 | .5224 | .6852 | .7970 | .9063 |
| .9327 | .9830 | .9915 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 |
| 0 | 0 | 0 | 0 | 0 | .0055 | .0102 | .0561 |
| .1296 | .2151 | .3267 | .5046 | .6751 | .8007 | .9763 | .9355 |
| .9639 | .9837 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 |
| 0 | 0 | 0 | C | .0050 | .0030 | .1322 | .2663 |
| .4235 | .6050 | .7603 | .9244 | .9704 | .9906 | .9983 | 1.0 |
| 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 |
| 0 | 0 | .001E | .0144 | .0640 | .2051 | .3702 | .5185 |
| .6777 | .8551 | .9542 | .9948 | .9976 | 1.0 | 1.0 | 1.0 |
| 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 |
| 0 | 0 | .008E | .1420 | .2892 | .4377 | .6232 | .7095 |
| .9281 | .9790 | .9990 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 |
| 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 |
| 0 | .07 | .078 | .2900 | .5000 | .700 | .7900 | .8600 |
| .9500 | .9500 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 |
| 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 |

TABLE NAME = MAP, SIZE = (6,4)

| | | | | | | |
|-------|----------|----------|----------|----------|----------|-----|
| 4.0 | 1.0 | E-32.0 | E-3 3.0 | E-3 5.0 | E-3 7.0 | E-3 |
| 6.0 | 6.0 | 9.0 | 10.0 | | | |
| 42E.J | E-4053.0 | E-4670.0 | E-4690.0 | E-4694.0 | E-4700.0 | E-4 |
| 51A.J | E-4555.0 | E-4585.0 | E-4611.0 | E-4642.0 | E-4603.0 | E-4 |
| 475.J | E-4520.0 | E-4570.0 | E-4500.0 | E-4545.0 | E-4600.0 | E-4 |
| 459.J | E-4537.0 | E-4530.0 | E-4627.0 | E-4590.0 | E-4710.0 | E-4 |

TABLE NAME = MAP, SIZE = (6,4)

| | | | | | | |
|-------|------|---------|---------|---------|---------|-----|
| 4.0 | 1.0 | E-3 2.0 | E-3 3.0 | E-3 5.0 | E-3 7.0 | E-3 |
| 6.0 | 6.0 | 9.0 | 10.0 | | | |
| 46.J | 58.0 | 52.0 | 47.0 | 41.0 | 35.0 | |
| 84.J | 65.0 | 52.0 | 57.0 | 50.0 | 45.0 | |
| 93.J | 79.0 | 65.0 | 64.0 | 56.0 | 51.0 | |
| 118.J | 88.0 | 76.0 | 69.0 | 59.0 | 53.0 | |

TABLE NAME = IAS, SIZE = (8,4,12)

| | | | | | | | | |
|-----|-----|--------|--------|--------|--------|--------|--------|-----|
| 4.0 | 1.0 | E-32.0 | E-33.0 | E-34.0 | E-35.0 | E-36.0 | E-37.0 | E-3 |
| 6.0 | 6.0 | 9.0 | 10.0 | | | | | |

| .06 | .065 | .07 | .075 | .08 | .09 | .10 | .12 |
|-------|-------|-------|-------|-------|-------|-------|-------|
| .14 | .16 | .18 | .20 | | | | |
| 126.0 | 92.0 | 73.5 | | | | | |
| 154.1 | 107.0 | 83.5 | 68.5 | | | | |
| 142.3 | 111.2 | 81.5 | | | | | |
| 43.1 | 56.4 | | | | | | |
| 137.4 | 103.7 | 84.0 | 74.2 | 56.0 | 59.2 | | |
| 142.0 | 112.0 | 93.0 | 81.2 | 72.3 | 62.0 | | |
| 159.0 | 122.0 | 94.0 | 79.8 | | | | |
| 92.0 | 80.5 | 70.5 | 62.5 | 52.5 | 45.0 | | |
| 146.4 | 113.1 | 94.8 | 83.9 | 75.3 | 70.1 | 65.1 | 60.0 |
| 140.0 | 125.6 | 102.5 | 89.0 | 80.3 | 73.6 | 67.6 | 62.4 |
| 172.5 | 125.8 | 105.0 | 89.5 | 79.0 | 70.0 | 58.5 | |
| 110.0 | 90.0 | 80.3 | 73.0 | 57.3 | 62.5 | 57.0 | 53.0 |
| 153.2 | 120.2 | 102.0 | 90.5 | 82.2 | 76.0 | 71.3 | 67.5 |
| 175.0 | 132.1 | 105.5 | 95.5 | 86.5 | 80.0 | 75.0 | 70.2 |
| 175.5 | 136.2 | 111.8 | 95.5 | 86.5 | 78.0 | 72.8 | 67.1 |
| 119.2 | 99.0 | 87.6 | 80.0 | 74.5 | 70.0 | 66.0 | 62.1 |
| 139.3 | 120.5 | 103.0 | 96.2 | 88.1 | 82.1 | 76.5 | 72.8 |
| 179.0 | 135.0 | 116.0 | 101.4 | 91.7 | 85.0 | 80.0 | 75.5 |
| 178.0 | 148.0 | 117.5 | 102.5 | 92.4 | 84.3 | 78.8 | 73.8 |
| 134.5 | 112.0 | 95.5 | 80.7 | 74.4 | 69.0 | 64.0 | 60.5 |
| 149.4 | 136.8 | 118.2 | 105.2 | 97.0 | 90.5 | 84.8 | 81.0 |
| 185.5 | 148.5 | 125.0 | 111.5 | 100.6 | 93.1 | 87.7 | 83.4 |
| 181.5 | 151.5 | 127.0 | 111.5 | 101.5 | 92.7 | 87.2 | 82.5 |
| 145.2 | 120.2 | 109.5 | 99.6 | 92.7 | 87.4 | 82.0 | 79.5 |
| 177.7 | 146.1 | 126.2 | 113.0 | 104.3 | 97.5 | 91.5 | 87.4 |
| 150.0 | 150.1 | 133.2 | 115.2 | 108.2 | 100.0 | 94.2 | 89.4 |
| 183.5 | 157.5 | 134.3 | 116.8 | 109.8 | 100.1 | 93.4 | 88.8 |
| 161.0 | 140.1 | 124.8 | 112.5 | 104.0 | 97.5 | 91.5 | 86.5 |
| 191.0 | 162.0 | 135.8 | 125.8 | 116.8 | 108.4 | 102.1 | 97.8 |
| 199.0 | 169.4 | 146.2 | 130.9 | 119.7 | 111.7 | 104.9 | 99.2 |
| 186.0 | 164.5 | 146.0 | 131.5 | 120.5 | 111.5 | 104.5 | 98.7 |
| 173.2 | 154.5 | 136.2 | 125.7 | 115.4 | 110.0 | 104.1 | 99.2 |
| 202.5 | 170.5 | 151.0 | 130.2 | 120.0 | 110.0 | 111.3 | 106.0 |
| 206.0 | 180.0 | 156.6 | 140.6 | 126.0 | 120.0 | 114.2 | 107.5 |
| 189.0 | 168.5 | 151.5 | 136.5 | 128.5 | 119.0 | 112.7 | 107.0 |
| 184.8 | 161.7 | 146.2 | 134.6 | 125.2 | 116.3 | 110.5 | 107.0 |
| 211.0 | 182.5 | 160.0 | 145.0 | 133.5 | 125.5 | 119.0 | 113.5 |
| 213.4 | 187.3 | 165.5 | 146.5 | 137.0 | 126.0 | 121.3 | 114.7 |
| 192.0 | 171.0 | 156.7 | 144.5 | 135.0 | 126.3 | 119.7 | 114.7 |
| 195.0 | 170.1 | 155.2 | 142.2 | 133.0 | 125.5 | 119.3 | 113.8 |
| 218.0 | 189.0 | 167.5 | 152.5 | 141.0 | 134.7 | 126.0 | 120.7 |
| 218.5 | 188.5 | 171.6 | 156.5 | 143.5 | 134.5 | 127.2 | 120.1 |
| 196.0 | 174.0 | 156.0 | 148.0 | 136.0 | 129.2 | 122.6 | 117.3 |
| 200.0 | 178.2 | 162.4 | 149.0 | 139.5 | 131.5 | 125.1 | 119.6 |
| 225.0 | 196.0 | 174.7 | 156.0 | 147.0 | 136.2 | 131.5 | 126.0 |
| 225.0 | 198.6 | 177.1 | 161.6 | 149.3 | 140.1 | 132.1 | 124.8 |
| 196.0 | 176.0 | 161.5 | 150.5 | 141.0 | 133.0 | 126.0 | 120.5 |

TABLE NAME = PRQ, SIZE = (E, 4, 10)

| 4.0 | 1.0 | E-3 2.0 | E-33.0 | E-34.0 | E-3 5.0 | E-30.0 | E-37.0 | E-3 |
|-------|-------|---------|--------|--------|---------|--------|--------|-----|
| 70.0 | 80.0 | 90.0 | 100.0 | 110.0 | 120.0 | 130.0 | 140.0 | |
| 150.0 | 160.0 | | | | | | | |

| | | | | | | | | |
|-------|-----------|-----------|-----------|------------|------------|------------|------------|-----|
| 228.0 | E-4065.0 | E-4691.0 | E-4731.0 | E-4755.0 | E-4800.0 | E-4835.0 | E-4871.0 | E-4 |
| 229.0 | E-4500.0 | E-4591.0 | E-4630.0 | E-4663.0 | E-4700.0 | E-4735.0 | E-4773.0 | E-4 |
| 230.0 | E-4535.0 | E-4571.0 | E-4601.0 | E-4633.0 | E-4670.0 | E-4710.0 | E-4749.0 | E-4 |
| 231.0 | E-4550.0 | E-4590.0 | E-4626.0 | E-4663.0 | E-4698.0 | E-4735.0 | E-4770.0 | E-4 |
| 232.0 | E-4695.0 | E-4740.0 | E-4800.0 | E-4850.0 | E-4900.0 | E-4950.0 | E-5000.0 | E-4 |
| 233.0 | E-4570.0 | E-4623.0 | E-4675.0 | E-4733.0 | E-4775.0 | E-4800.0 | E-4890.0 | E-4 |
| 234.0 | E-4530.0 | E-4590.0 | E-4643.0 | E-4690.0 | E-4750.0 | E-4800.0 | E-4853.0 | E-4 |
| 235.0 | E-4570.0 | E-4590.0 | E-4651.0 | E-4700.0 | E-4750.0 | E-4800.0 | E-4850.0 | E-4 |
| 236.0 | E-4700.0 | E-4810.0 | E-4803.0 | E-4865.0 | E-4900.0 | E-4915.0 | E-4933.0 | E-4 |
| 237.0 | E-4550.0 | E-4610.0 | E-4745.0 | E-4821.0 | E-4895.0 | E-4970.0 | E-5045.0 | E-4 |
| 238.0 | E-4550.0 | E-4630.0 | E-4700.0 | E-4783.0 | E-4850.0 | E-4920.0 | E-4990.0 | E-4 |
| 239.0 | E-4551.0 | E-4626.0 | E-4704.0 | E-4770.0 | E-4850.0 | E-4920.0 | E-4990.0 | E-4 |
| 240.0 | E-4900.0 | E-4903.0 | E-41004.0 | E-41104.0 | E-41200.0 | E-41310.0 | E-41419.0 | E-4 |
| 241.0 | E-4900.0 | E-4736.0 | E-4837.0 | E-4890.0 | E-4930.0 | E-4943.0 | E-4953.0 | E-4 |
| 242.0 | E-4500.0 | E-4655.0 | E-4775.0 | E-4890.0 | E-4900.0 | E-4900.0 | E-4920.0 | E-4 |
| 243.0 | E-4563.0 | E-4673.0 | E-4778.0 | E-4853.0 | E-4900.0 | E-4915.0 | E-4923.0 | E-4 |
| 244.0 | E-4900.0 | E-41002.0 | E-41125.0 | E-41273.0 | E-41000.0 | E-41150.0 | E-41433.0 | E-4 |
| 245.0 | E-4900.0 | E-4810.0 | E-4950.0 | E-41004.0 | E-4123.0 | E-41377.0 | E-41505.0 | E-4 |
| 246.0 | E-4913.0 | E-4752.0 | E-4823.0 | E-4823.0 | E-4823.0 | E-4823.0 | E-4823.0 | E-4 |
| 247.0 | E-4550.0 | E-4735.0 | E-4890.0 | E-41018.0 | E-41100.0 | E-41333.0 | E-41472.0 | E-4 |
| 248.0 | E-4972.0 | E-41128.0 | E-41225.0 | E-41470.0 | E-41000.0 | E-41100.0 | E-42015.0 | E-4 |
| 249.0 | E-4970.0 | E-4921.0 | E-41105.0 | E-41260.0 | E-41400.0 | E-41620.0 | E-41795.0 | E-4 |
| 250.0 | E-4900.0 | E-4830.0 | E-41013.0 | E-41205.0 | E-41300.0 | E-41362.0 | E-41520.0 | E-4 |
| 251.0 | E-4900.0 | E-4825.0 | E-41019.0 | E-41203.0 | E-41411.0 | E-41600.0 | E-42030.0 | E-4 |
| 252.0 | E-41065.0 | E-41280.0 | E-41497.0 | E-41720.0 | E-4155.0 | E-42100.0 | E-42370.0 | E-4 |
| 253.0 | E-4823.0 | E-41050.0 | E-41273.0 | E-41503.0 | E-41750.0 | E-41900.0 | E-42270.0 | E-4 |
| 254.0 | E-4733.0 | E-4900.0 | E-41130.0 | E-41421.0 | E-41000.0 | E-41100.0 | E-42270.0 | E-4 |
| 255.0 | E-4700.0 | E-4930.0 | E-41170.0 | E-41463.0 | E-41010.0 | E-42270.0 | E-42730.0 | E-4 |
| 256.0 | E-41195.0 | E-41470.0 | E-41753.0 | E-42010.0 | E-42250.0 | E-42500.0 | E-43000.0 | E-4 |
| 257.0 | E-4935.0 | E-41205.0 | E-41510.0 | E-41744.0 | E-41950.0 | E-42220.0 | E-42690.0 | E-4 |
| 258.0 | E-4813.0 | E-41101.0 | E-41335.0 | E-41500.0 | E-41900.0 | E-42300.0 | E-43000.0 | E-4 |
| 259.0 | E-4783.0 | E-41105.0 | E-41515.0 | E-41920.0 | E-42500.0 | E-43100.0 | E-43900.0 | E-4 |
| 260.0 | E-41305.0 | E-41602.0 | E-42040.0 | E-42370.0 | E-42500.0 | E-42571.0 | E-43000.0 | E-4 |
| 261.0 | E-41045.0 | E-41347.0 | E-41762.0 | E-42011.0 | E-42300.0 | E-42022.0 | E-43000.0 | E-4 |
| 262.0 | E-4921.0 | E-41245.0 | E-41440.0 | E-42100.0 | E-42300.0 | E-42700.0 | E-43000.0 | E-4 |
| 263.0 | E-4851.0 | E-41353.0 | E-41960.0 | E-42507.0 | E-4317.0 | E-43000.0 | E-43900.0 | E-4 |
| 264.0 | E-41500.0 | E-41033.0 | E-42343.0 | E-42720.0 | E-43217.0 | E-43000.0 | E-43900.0 | E-4 |
| 265.0 | E-41095.0 | E-41500.0 | E-42040.0 | E-42500.0 | E-43000.0 | E-43000.0 | E-43900.0 | E-4 |
| 266.0 | E-41050.0 | E-41475.0 | E-41730.0 | E-42400.0 | E-42700.0 | E-43000.0 | E-43900.0 | E-4 |
| 267.0 | E-41060.0 | E-41870.0 | E-43000.0 | E-410000.0 | E-410000.0 | E-410000.0 | E-410000.0 | E-4 |

TABLE NAME = JFCP , SIZE = (19)

| | | | | | | | |
|------|------|------|------|------|------|------|------|
| .2 | .25 | .30 | .35 | .40 | .45 | .50 | .55 |
| .6 | .65 | .70 | .75 | .80 | .85 | .90 | .95 |
| 1.0 | 2.0 | | | | | | |
| 2.12 | 1.92 | 1.52 | 1.40 | 1.32 | 1.25 | 1.20 | 1.16 |
| 1.13 | 1.10 | 1.08 | 1.05 | 1.04 | 1.03 | 1.02 | 1.01 |
| 1.0 | 1.0 | | | | | | |

MODULE NAME = SIZE
 COMMON G,PTO,PRA,SEO,C.F.R,NEN,S,CB,NMR,TS,DI
 COMMON VRC,PM
 COMMON ALT,UAT
 COMMON RM,VM,HP2,HP1,EA
 PF = (1-ALT/145300)**5.255 PRESSURE RATIO
 TR = (OAT+273.16)/288.16 TEMPERATURE RATIO
 DR = KR/TR DENSITY RATIO
 PTO = (.051*G*(DL/DR)**.41+2.424E-5*VRC*GM)/(1-PM/100) POWER AT TAKEOFF
 PRA = PTO/(PR*(1-2.0*(TR-1))) TOTAL ENGINE RATED HP
 SEO = 1.13*(PRA/NEN)**-.105 SFC AT RATED HP
 O = 310*PTO*TS**1*G**5*DL**-.5 TORQUE AT ENGINE OUTPUT BUT MR RPM
 F = .035*G**0.657 CURRENT UTILITY HELD W/C EXTERNAL STORES
 R = .5052*G**5*DL**-.5 MR RADIUS
 S = DL/BL SOLIDITY
 CR = 3.1416*R*S/NMR MAIN ROTOR CHORD
 RM = R
 MCW = GM
 VM = TS
 HP2 = PRA
 HP1 = PTO
 EN = NEN

MODULE NAME = T O ALLOWANCE AND CRUISE

COMMON PARAMS: PRA, P, PTO, DLSC, WFL, SEQ

COMMON ITIM

ALT = 0

TIM = 0

WFL = 0

PR = (1-ALT/145300)**.255

PRESS RATIO

FI = 0.15 * PRA * PR * TIM/60

FUEL INCR

WFL = WFL + FI

TOTAL FUEL USED

GW = GW - FL

FINAL GW

TTIM = TIM

ALT = 4000

TAT = 35

SM = 10

KPP = .9174

DIS = 50

TAS = 130

PA = .9

PR = (1-ALT/145300)**.255

PRESS RATIO

TR = (TAT+273.15)/288.15

TEMP. RATIO

DR = PR/TR

DENS. RATIO

DLN = GW/(3.1416**2*DR)

PA = PRA*(PR*(1-2.08*(TR-1)))

MAX. HP. AVAIL.

FOW = F*DR/GW

DRAG-WEIGHT PARAM

P = PA * RA

IF P IS GT PTO, P=PTO

SAS = 7J-SM+15.7*(15-DLN)/((FCW*1000)**.25*8)

STALL KTAS

TAS = SAS

IF TAS IS GT 160, TAS = 160

PCW = TABLE PRW(FOW, DLN, TAS)

PCW = PCW * GW/KPP

IF PCW IS LT P, P = PCW

PCW = P * KPP/GW

TAS = TABLE TAS(FOW, DLN, PCW)

TIM = GW*DIS/TAS

PPF = P/(PR*TR*.5*PRA)

SSF = TABLE SFLP(PPF)

FL = TIM * V * SEQ * SSF/60

WFL = WFL + FL

GW = GW - FL

TTIM = TTIM + TIM

```

MODULE NAME = MAX RANGE
COMMON U, R, PRA, E, PTO, DISC, WFL, SFD, WFL
COMMON TTIM
INITIALIZE SAR=0, TAS=80, DEL=5, FL1 = 0
INITIALIZE TIM1 = 0
ITERATE ON TAS, ATOL=1          A/S FOR MAX RANGE
PR = (1-ALT/1453001)**.259      PRESS RATIO
TP = (OAT-273.15)/288.15      TEMP. RATIO
DR = PR/TK                      DENS. RATIO
DLN = Gw/(3.1416*R**2*DR)
PA = PRA*/R*(1-2.03*(TR-1))    MAX. HP. AVAIL.
FCW = F*DR/Gw                  DRAG-HEIGHT PARAM
P = .9*PA
IF P IS GT PTO, P=PTO
PUW=TABLE PRW(FCW,DLN,TAS)
PRQ=PUW*Gw/KPP
SSF=PRW/(PRA*PR*TP**.5)
SSP=TABLE SFCP(PRF)
SAR1=SAR
SAR = TAS/(SSF*SE(*PRQ))
DSAR = SAR - SAR1
SAS = 70-SM+15.7*(15-DLN)/((FCW*1000)**.2598)  STALL KTAS
IF TAS IS GT SAS, DEL = 0
IF DSAR IS GT 0, TAS = TAS+DEL
TIM = 60 * DIS/TAS
FL = TIM * PRQ * SFD * SSP / 60
WFL = WFL + FL - FL1
FL1 = FL
TTIM = TTIM + TIM - TIM1
TIM1 = TIM

```

ALT = 4000
DAT = 35
SM = 10
KPP = .9174
DIS = 160

MODULE NAME = TOTAL FUEL

COMMON = FL, CAP

FL = (RCP/100)*WFL*(1-(RCP/100)) FUEL INCREMENT

WFL = WFL*FL

CAP = WFL/6.5

RCP = 10

MODULE NAME = STAT WEIGHT
 ORDER
 COMMON RM, MU, VM, MP2, MPI, CAP, EA, S, CR, NMR, BODY, WCR, WEM
 COMMON TAIL, ALGI
 COMMON MASS, ALS
 WENU = 1.350*EN*(MP2/EA)**.733
 WBL = .151E+11*(NG*NULT/100)/(AR**599*VM**331*DMNR**65*NOF**431) BLADE WT
 WGH = 2.145*WBL**893 BLADE WEIGHT SUPPORTING CALCULATIONS
 R = 2 * RM
 AR = 800/2/46 BLADE ASPECT RATIO
 AR = RM*CR/NMR TOTAL BLADE AREA (SQ. FT.)
 DMNR = DMNR DISC LOADING * NUMBER OF ROTORS
 DM = DM/3.141592/R**2 DISC LOADING
 NCF = 14.255*S**400
 WMR = .0104*(WBL*.5*RM*RP**2*1E-6)**1.127*QMR**405*NL**052/IY**059
 RPM = 9.549*VM/RM MAIN ROTOR RPM
 QMR = 5250*MP1/RPM
 IY = .6246E-2*DM**1.635
 FLD = .12*(MDL*WME)*8F
 ITR = KTR*(1-C*(R/CR*V**2))**1.29 TAIL ROTOR
 C = .092*RM**651
 N = 1.062*RT**773
 WMS = .2045*ATF**5*LT**1.7*ID**10**2*ATF**28
 WTF = 1.433*DM**1.53 HORIZONTAL STABILIZER CALCULATIONS
 LTF = .95*RM**1.02
 KLU = (LW*(M*F))
 FUS = KFUS*KLU**030L**05*AG*CM**1.12/((DM*TRD)**.23*ITR**43*IX**38)
 LU = .255*RM**1.474 FUSELAGE LENGTH FUSELAGE WEIGHT CALCULATIONS
 H = 2.53*LA**115 FUSELAGE HEIGHT, MAX
 IY = .221E-3*DM**1.907 ROLL INERTIA
 H = .405*SI*H**1.224 FUSELAGE HEIGHT, MAX
 SINM = .981*H**0.743 = LGIA*SINM USE SINM WHEN LGIA*SINM > 0.981*H**0.743
 WTR = .41*H**1.75 MAIN WHEEL TREAD
 TR = 13392.0*CM*P2/(R*DM*RM)
 AFUS = .183*LI*P**5*ATF**13*FUS**44/(QMR/(ITR*LT))**45
 LTP = 1.57*RT**0.336 TAIL ROTOR PYLON LENGTH
 RT = .067*RM**1.22 TAIL ROTOR RADIUS
 LTR = 36.07/RM**0.273 LENGTH OF TAIL Pylon
 WPY = .063*PA**7*ITR**42*TPY**24 PYLON WEIGHT
 PA = .36*(5*RT*LTR)**4*TPY**74 PYLON PROFILE AREA
 WLG1 = .190*KL*GM*DM**97*(AG*2)**41*TRD**48/IX**46
 FC = .50E-0*NG**1.07*WCF**30*VM**1.66*AL**45/LGIA**69
 LGIA = 1.717*RM**1.005
 WFS = .068*K*ALC*(FUS*AFUS*WPY**1.25*(WENG/ENF)**1.06*VM**1/MP2**55
 ENF = .275*MP2**235
 VM = 26.51*MP2**257*ENF**37 WAGELLE VOLUME
 WPTS = .434E-3*DM**1.82*WCF**1.65*(1.23*DM**3.87/LM**1.56/R**0.14
 QMR1 = 52.50*MP1/RPM MAIN ROTOR TORQUE/100
 R = 2.57/RM**0.174 MAIN TRANSMISSION REDUCTION RATIO
 WENL = .018*EN**08*WENG**1.93/MP2**59 ENGINE ACCESSORY WEIGHT
 ACS = .25*ALS COOLING SYSTEM WEIGHT
 WLS = .0145*H**0.8*WPTS**194*CAP**1.01 LUBRICATION SYSTEM
 WFS = 3.00*CAP**71 FUEL SYSTEM
 WFC = 3.75*ENF**1.3*2*P**0.61
 WSS = 3.10*(3*P/MP2)**1.11*(WENG/ENF)**1.37 STARTING SYSTEM

SHP = .0245*HP2**0.837 STARTING MGRSEPCWER
 WXS1 = 0.215*MR5**0.75 MAIN TRANSMISSION
 QMR5 = 5250 *HP2/RPM
 ACPV = .0127*UMR6**0.766 ACCESSORY DRIVE PROVISION
 QMR6 = 5250*MP1/RPM MAIN FOTOP TOPQUE
 WITR = KTR*MK2**0.625*ITR INTERMEDIATE TAIL ROTOR GEARBOX
 QMR2 = .07*WJK
 WTRB = KTR*MK3**0.64 TAIL ROTOR GEARBOX
 QMR3 = .15*UMR
 WTR3 = KTR*1E-2*CM3**0.31*(1.23*RP)**1.64
 WEDS = 19.197*(1040/1000)**0.17*EN**1.25 ENGINE DRIVE SHAFT
 WRP = .214*UMR**0.44*DP**0.10*BRK
 DPM = WBL*MM**2/9273.6 MAIN ROTOR PCLAP INERTIA
 APU = 46.92*ACPV**0.0509*JPL AUXILIARY POWER PLANT GROUP
 WFIX = .170E5*(CP**0.32*(LL*(WPH))**0.14*CM**0.05*EN**2.00/NG**0.62 FIXED WEIGHT
 NG = 2.145*MD**0.893 NORMAL GROSS WEIGHT
 CM = 1.23*MM**0.172 USE LIGHTED VALUES IF KNOWN
 WPTX = WBL + WMUB + FLD
 TAIL = WTR + WTS
 BODY = FUS + AFUS + WPY
 ASE = .15 * FC
 WFC = FC + ASE
 PRCP = WEMH + SDG + WEAC + WCSI + WLS1 + WES + WEC + WSS + WUS
 LPC = WCS2 + WLS2
 WDS = WXS + ACPV + WITR + WTRB + WTRS + LPC + WEDS + WKS + WKB
 WXS = WXS1 - WKS
 WEA = WIND + WEXH
 WFM = WPTX + TAIL + BODY + WLG1 + WFC + WES + PRCP + WFIX + APU + WING
 WCSI = .15 * WLS
 WLS1 = .00 * WLS
 WFS = 3.599 * CAP**0.711
 WPS = .18 * WXS1
 WIND = .53 * WEAC
 WEXH = .47 * WEAC
 WLNW = 4.30 * SW
 WCS2 = .1 * WLS
 WLS2 = .4 * WLS

DF = 1 FLIDING ROTOR
JTR = 1 INTERMEDIATE TR GEARBOX
BPK = 1 ROTOR BRAKE
KFUS = .0528 CONVENTIONAL GEARED
KTR = .183 CONVENTIONAL GEARED
KITR = .2296 STATISTICAL BASELINE CONSTANT FOR INTERMEDIATE T. ROT. GB
KTRB = .2279 TAIL ROTOR GEARBOX CONST-----STAT. BASELINE
KTRS = .058 TAIL ROTOR DRIVE SHAFT CONST.-----STAT. BASELINE
NR = 1
MULT = 4.5
TAF = 13
TPY = 62
KLG = .0329
AG = 1
KNAC = .96
CP = 2
SDG = 0.0
SW = 0
TPU = 0

MODULE NAME = GROSS WEIGHT
COMPLD = EM + FL + CR + PL + Gb
GM = EM + FL + CR + MPL

MPL = 2640

MODULE NAME = NEW SIZE DATA
COMMON ALT, DAT, MSC, PM, DL, T, REM, GR
COMMON ALT, DAT, CU, U, GR, GR, REM2, BEP
COMMON MPL, MPO
COMMON ICKA, ICKQ
MPL = MPO
Q = QO
GR = GRQ
REM = REMO
ALT = ICKA-11*1000
DAT = 43 - 10*1000

MODULE NAME = ANAL WEIGHT

COMMON G, W, WKT, WMSG, WTR, WEM, CO, WEM2

COMMON Gw, GwJ, BODY

COMMON TAIL, WLG1

COMMON WXS, WGS

DEL1 = (J-JJ)*12

CHANGE IN TORQUE IN IN-LB

QILB = Q*12

TORQUE IN IN-LB

DEL1 = TABLE DELT(QILB)

DEL2 = TABLE BLAD(QILB)

DEL3 = Gw/GwJ-1

WEM2 = WEM + (BODY*TAIL+WLG1)*DEL3 + DEL1*DELG*WGS/WXS + DEL2*DELG

MODULE NAME = GROSS WEIGHT TWO
COMMON WCMZ, WFL1, WPL, WCR, GW
GW = WCMZ + WFL1 + WPL + WCR


```
MODULE NAME = ERROR  
COMMON ERR,WPL0,WPL1  
COMMON Gm  
GM = Gm + 1.5*(WPL0-WPL1)  
ERR = ((WPL0-WPL1)*(WPL0-WPL1))*.5
```

MODULE NAME = PAPC COSTS

COMMON = M, P, TAS, PRA, NEN, YAR, SL, WEM, CPIA, CD

WA = 126 + .745 * WEM

CET = 1.21 * WA * (220 / NP + .75 * NP ** -.15)

CL = 1.111 * WEM * .55 * NP ** -.29

CM = 9.31e-11 * WA * TAS * 1.24 * NP ** -.12

CE = PRA * (58 - 6E-3 * PRA / NEN)

IF PRA IS 1 3500, CE = NEN * (1.295E5 + 37 * (PRA / NEN) - 3500)

CG = -37E3 + 4.75 * WA

CP = CET + CL + CM + CE + CG

CI = .1 * CP

CA = YAR * CP * SL / NP

CC = 101 + 3.325E-3 * WEM

CPGL = 0

CPIA = CP + CI + CA

CD = CC + CPGL

MODULE NAME = JMAX
EJMAX = 1.0/SCPH

```
MODULE NAME = PYLOADS  
COMMD, PUF, PL2, PL, I  
PPL = TABLE PYLD(I)  
PL = PPL/100*PL2  
PUF = TABLE PUF(I)  
PUF = PUF / 100
```


MODULE NAME = MAINT COSTS

COMMON GLE,UG,UGM,EM,CFIA,MFL,SL,CFPH,CD

COMMON MFL,TTIM

OLF = Gm/UGM

TN = .077m + 5544/EM

T = .093*TN/(OLF + .0177)/1.151**3

CFM = TN/T*(.07.4 + .05362*EM)

COPL = TN/T*(1E.14 + .00233*EM)

IF EM ISLT 3200, CFM = TN/T*(.00191*EM**1.323)

IF EM ISLT 3200, COPL = TN/T*(1.016*EM**0.4)

CMI = CFM + COPL

CFPH = 6(PIA/(12*MFH*SL) + CD + CMT

CFUL = MFL/6.5**25

CFPH = CPM + CFUL*50/TTIM

PRINT (PIA,CFM,CD,CFUL,TTIM

```

*GOJL = NAME = MOVER PROC
COMMON IMAX, JMAX, DPH, DL, CA, DG, VRC, PFA, PM, AT, PI, A, J, PIU
INITIALIZE J = 0, A = 0, PT = 0, DELT = 1
PM = 1 - JOUPH
H = TABLE HPRD(PM)
TMAX = TABLE TMAX(H)
APR = (1 - H/14*300)**5.255
CCN1 = DL * Gw**3.435/(DG*APR)
CCN2 = 47.51E-5*VRC*Gw
CCN3 = PFA*APR*(1-PM/100)
ATR = J
ATR = 1.491 - .J2452*(CCN1*ATR)**.41*CCN2/CCN3
ATR = 1.401 - .J2452*(CCN1*ATR)**.41*CCN2/CCN3
ATR = 1.401 - .J2452*(CCN1*ATR)**.41*CCN2/CCN3
ATR = 1.451 - .J2452*(CCN1*ATR)**.41*CCN2/CCN3
ATR = 1.401 - .J2452*(CCN1*ATR)**.41*CCN2/CCN3
ATR = 1.401 - .J2452*(CCN1*ATR)**.41*CCN2/CCN3
ATT = ((PT*(1-PM/100)-2.42E-5*Gw*VRC)/(1.051*Gw))**(.1/.4)/(DL*Gw/(DG*APR))
IF ATT IS LT AYR, ATR = ATT
AT = 206.16 * ATR - 273.15
PT1 = PT
AT1 = AT
IF AT1 IS AT -23, AT1 = -23
PT = TABLE TPRD(AT, H)
A = DPH*(1-(PT+PT1)/2) * A
IF J IS EQ 0, A = J
IF AT IS GT TMAX, DELT = 0
IF J IS GT JMAX, J = J - DELT
J = J + DELT
ITERATE ON J, ATCL = .5

```

CONTROL MODULE FOR TRANSPORT MODEL

```

1  COMMON GW,WFL,WFL1,WFL2,ERR
2  COMMON GW1,GW2,WPLO,WPL1
3  COMMON PTO,PRA,SFO
4  COMMON GWO,WMW
5  COMMON WEM,NP,TAS,WEN,YAR,SL,N,DPL,WCR,WFL,DPH,PRA,DGM,WFH
6  COMMON R,PTC,SFO,F
7  COMMON INDX,DISC,ALT,CAT
8  COMMON IDXA,IOXD
9  COMMON MPL2
10 POINT ONE
11 RUN MOD SIZE
12 RUN MOD T O ALLOWANCE
13 RUN MOD CLIMB
14 RUN MOD CRUISE AT MCP
15 RUN MOD FLIGHT IDLE
16 RUN MOD CLIMB
17 RUN MOD MAX RANGE
18 RUN MOD TOTAL FUEL
19 RUN MOD STAT WEIGHT
20 RUN MOD GROSS WEIGHT
21 ITERATE ON GW, FROM ONE, ATOL = 20
22 WFL1 = WFL
23 RUN MOD STORE OLD DATA
24 PRINT ALT,OUT
25 PRINT GW,WEM,WFL,WPLO,PTO,PRA,SFO
26 RUN MOD JMAX
27 POINT POAT
28 POINT PAAT
29 RUN MOD NEW SIZE DATA
30 ITR = 0
31 POINT TWO
32 RUN MOD SIZE
33 RUN MOD T C ALLOWANCE
34 RUN MOD CLIMB
35 RUN MOD CRUISE AT MCP
36 RUN MOD FLIGHT IDLE
37 RUN MOD CLIMB
38 RUN MOD MAX RANGE
39 RUN MOD TOTAL FUEL
40 WFL2 = WFL
41 RUN MOD ANAL WEIGHT
42 GW2 = GW
43 RUN MOD GROSS WEIGHT TWO
44 GW1 = GW
45 RUN MOD T C ALLOWANCE
46 RUN MOD CLIMB
47 RUN MOD CRUISE AT MCP
48 RUN MOD FLIGHT IDLE
49 RUN MOD CLIMB
50 RUN MOD MAX RANGE
51 RUN MOD TOTAL FUEL
52 RUN MOD PAYLOAD
53 RUN MOD ERROR
54 ITR = ITR + 1
55 IF ITR IS GT MXTR, GO TO THRE
56 IF ERR IS GT 20, GOTG TWO
57 POINT THRE
58 PRINT ALT,OUT,ITR
59 PRINT GW1,GW2,WFL1,WPL1,PTC,PRA,SFO

```

~~60 PRINT GW2,WFL2,UPL2~~
~~61 RUN MOD PANC COSTS~~
~~62 SI = 0~~
~~63 SOCS = 0~~
~~64 POINT FOUR~~
~~65 SI = SI + 1~~
~~66 RUN MOD PAYLOADS~~
~~67 ITAT = 0~~
~~68 POINT FIVE~~
~~69 RUN MOD OGMS~~
~~70 RUN MOD F C ALLOWANCE~~
~~71 RUN MOD CLIPB~~
~~72 RUN MOD CRUISE AT MCP~~
~~73 RUN MOD FLIGHT IOLE~~
~~74 RUN MOD CLIPB~~
~~75 RUN MOD MAX RANGE~~
~~76 RUN MOD TOTAL FUEL~~
~~77 ITAT = ITAT + 1~~
~~78 ITERATE ON SWFL,PTOL=1,FRGM-FIVE~~
~~79 RUN MOD MAINT COSTS~~
~~80 RUN MOD MOVER PROB~~
~~81 RUN MOD NET~~
~~82 PRINT SOLE,SMEI,SCPFH,SPLF,SPHOV,SPL,SGN,SCLF~~
~~83 IF SN ISGT SI,GO TO FOUR~~
~~84 IDXA = IDXA + 1~~
~~85 ITERATE FROM PALT,TIMES = 5~~

CONTROL MODULE FOR OBSERVATION MODEL

```
1 COMMON GW,WFL,WFL1,WFL2,ERR
2 COMMON GW1,GW2,WPLC,WPL1
3 COMMON PTO,PRA,SFO
4 COMMON GW0,WEM
5 COMMON WEM,AP,TAS,NEN,YAR,SL,N,CPL,WCR,WFL,DPH,PRA,CGW,MFH
6 COMMON R,PTO,SFO,F
7 COMMON INDX,DISC,ALT,CAT
8 COMMON IOXA,IDXO
9 COMMON-WPL2
10 POINT ONE
11 RUN MOD SIZE
12 RUN-MOD MISSION-FUEL
13 RUN MOD STAT WEIGHT
14 RUN MOD GROSS WEIGHT
15 ITERATE ON GW, FROM ONE, ATCL ← 20
16 WFL1 = WFL
17 RUN MOD STORE OLD DATA
18 PRINT-ALT,OAT
19 PRINT GW,WEM,WFL,WPL0,PTO,PRA,SFO
20 POINT PAAT
21 POINT-PALT
22 RUN MOD NEW SIZE DATA
23 ITR = 0
24 POINT-TWO
25 RUN MOD SIZE
26 RUN MOD ANAL WEIGHT
27 RUN MOD-MISSION-TIME
28 WFL2 = WFL
29 GW2 = GW
30 RUN-MOD GROSS WEIGHT-TWO
31 GW1 = GW
32 RUN MOD MISSION FUEL
33 WFL1 = WFL
34 RUN MOD PAYLOAD
35 GW = GW2
36 RUN MOD-ERROR
37 ITR = ITR + 1
38 IF ITR IS GT MXTR, GC TO THRE
39 IF ERR IS GT 20, GC TO TWO
40 POINT THRE
41 PRINT ALT,OAT,ITR
42 PRINT GW1,$WEM2,WFL1,WPL1,PTO,PRA,SFO
43 PRINT GW2,WFL2,WPL2
44 DGM = GW2
45 WEM = WEM2
46 DPL = WPL2
47 GW = GW2
48 $EUF = 1
49 $OCE = 0
50 RUN MOD P APC COSTS
51 RUN MOD-MAINT COSTS
52 RUN MOD MEI
53 PRINT $OCE,$MEI,$CPFH,$MIST,GW
54 IOXA = IOXA + 1
55 ITERATE FROM PALT,TIMES = 5
```

CONTROL MODULE FOR CRANE MODEL

1 COMMON GW,WFL,WFL1,WFL2,ERR
2 COMMON GW1,GW2,WPLO,WPL1
- 3 COMMON PTO,PRA,SFO
4 COMMON GW0,WMEM
5 COMMON MEM,NP,TAS,P,EN,YAR,SL,N,DPL,WCR,WFL,DPH,PRA,UGW,MFH
- 6 COMMON N,PTO,SFO,F
7 COMMON INDX,DISC,ALT,CAT
8 COMMON IDXA,IDXO
- 9 COMMON WPL2
10 POINT ONE
11 RUN MOD SIZE
- 12 RUN MOD FLIGHT IDLE
13 RUN MOD T O ALLOWANCE
14 RUN MOD HOVER
- 15 RUN MOD MAX RANGE
16 $GW = GW + DPL$
17 $F = F + CF$
- 18 RUN MOD HOVER
19 RUN MOD MAX RANGE
20 RUN MOD TOTAL FUEL
- 21 RUN MOD STAT WEIGHT
22 RUN MOD GROSS WEIGHT
23 ITERATE ON GW, FROM ONE, ATOL = 20
- 24 WFL1 = WFL
25 RUN MOD STORE OLD DATA
26 PRINT ALT, DAT
- 27 PRINT GW, MEM, WFL, WPLO, PTC, PRA, SFO
28 POINT POAT
29 POINT PALT
- 30 RUN MOD RUN SIZE DATA
31 ITR = 0
32 POINT TWO
- 33 RUN MOD SIZE
34 RUN MOD FLIGHT IDLE
35 RUN MOD T O ALLOWANCE
- 36 RUN MOD HOVER
37 RUN MOD MAX RANGE
38 $GW = GW + DPL$
- 39 $F = F + CF$
40 RUN MOD HOVER
41 RUN MOD MAX RANGE
- 42 RUN MOD TOTAL FUEL
43 $WFL2 = WFL$
44 RUN MOD ANAL WEIGHT
- 45 $GW2 = GW$
46 RUN MOD GROSS WEIGHT TWO
47 $GW1 = GW$
- 48 RUN MOD FLIGHT IDLE
49 RUN MOD T O ALLOWANCE
50 RUN MOD HOVER
- 51 RUN MOD MAX RANGE
52 $GW = GW + DPL$
53 $F = F + CF$
- 54 RUN MOD HOVER
55 RUN MOD MAX RANGE
56 RUN MOD TOTAL FUEL
- 57 WFL1 = WFL
58 RUN MOD PAYLOAD
59 $GW = GW2$

```

50 RUN MOD ERROR
51 ITR = ITR + 1
52 IF ITR IS GT MXTR, GC TO THRE
53 IF EKR IS GT 20, GOTC TWO
54 POINT THRE
55 PRINT ALT, OAT, ITR
56 PRINT GW1, WEM2, WFL1, WPL1, PTC, PRA, SFG
57 PRINT GW2, WFL2, WPL2
58 DGM = GW2
59 WEM = WEM2
70 DPL = WPL2
71 RUN MOD P APC COSTS
72 RUN MOD JMAX
73 $I = 0
74 $OCE = 0
75 POINT FOUR
76 $I = $I + 1
77 RUN MOD PAYLOADS
78 ITAT = 0
79 POINT FIVE
80 RUN MOD DGWS
81 RUN MOD FLIGHT IDLE
82 RUN MOD T O ALLOWANCE
83 RUN MOD HOVER
84 RUN MOD MAX RANGE
85 GW = GW + DPL
86 F = F + DF
87 RUN MOD HOVER
88 RUN MOD MAX RANGE
89 RUN MOD TOTAL FUEL
90 ITAT = ITAT + 1
91 ITERATE ON $WFL, PTOL=1, FROM FIVE
92 RUN MOD MAINT COSTS
93 RUN MOD HOVER PROB
94 RUN MOD MEI
95 PRINT $OCE, MEI, $CPFH, $PUF, $PHCV, $PL, $SW, $GLF
96 IF $N ISGT 1, GO TO FOUR
97 IOXA = IOXA + 1
98 ITERATE FROM PALT, TIMES = 5
99 IOXA = 1
100 IOXD = IOXD + 1
101 ITERATE FROM POAT, TIMES = 2

```

CONTROL MODULE FOR GUNSHIP MODEL

```
1 COMMON GW,WFL,WFL1,WFL2,ERR
2 COMMON GW1,GW2,WPLC,WPL1
3 COMMON PTC,PRA,SFO
4 COMMON GWO,WEM
5 COMMON WEM,AP,TAS,NEN,YAR,SL,N,DPL,WCR,WFL,DPH,PRA,CGW,MFM
6 COMMON R,PTO,SFO,F
7 COMMON INDX,DISC,ALT,CAT
8 COMMON IDXA,IDXO
9 COMMON WPLZ
10 POINT ONE
11 RUN MOD SIZE
12 RUN MOD CRUISE HOVER AND VMAX
13 RUN MOD MAX RANGE
14 RUN MOD TOTAL FUEL
15 RUN MOD STAT WEIGHT
16 RUN MOD CROSS WEIGHT
17 ITERATE ON GW, FROM ONE, ATOL = 20
18 WFL1 = WFL
19 RUN MOD STORE OLD DATA
20 PRINT ALT,OAT
21 PRINT GW,WEM,WFL,WPLC,PTO,PRA,SFO
22 POINT POAT
23 POINT PALT
24 RUN MOD NEW SIZE DATA
25 ITR = 0
26 POINT TWO
27 RUN MOD SIZE
28 RUN MOD CRUISE HOVER AND VMAX
29 RUN MOD MAX RANGE
30 RUN MOD TOTAL FUEL
31 WFL2 = WFL
32 RUN MOD ANAL WEIGHT
33 GW2 = GW
34 RUN MOD GROSS WEIGHT TWO
35 GW1 = GW
36 RUN MOD CRUISE HOVER AND VMAX
37 RUN MOD MAX RANGE
38 RUN MOD TOTAL FUEL
39 WFL1 = WFL
40 RUN MOD PAYLOAD
41 GW = GW2
42 RUN MOD ERROR
43 ITR = ITR + 1
44 IF ITR IS GT MXTR, GO TO THRE
45 IF ERR IS GT 20, GO TO TWO
46 POINT THRE
47 PRINT ALT,OAT,ITR
48 PRINT GW1,WEM2,WFL1,WPL1,PTC,PRA,SFO
49 PRINT GW2,WFL2,WPL2
50 DGW = GW?
51 WEM = WEM2
52 DPL = WPL2
53 RUN MOD P APC COSTS
54 RUN MOD JMAX
55 $I = 0
56 $OCE = 0
57 POINT FOUR
58 $I = $I + 1
59 RUN MOD PAYLOADS
```



```
60 ITAT = 0
61 POINT FIVE
62 RUN MGD OGWS
63 RUN MGD CRUISE HOVER AND VMAX
64 RUN MGD MAX RANGE
65 RUN MGD TOTAL FUEL
66 ITAT = ITAT + 1
67 ITERATE ON SWFL, DTOL=1, FROM FIVE
68 RUN MGD MAINT CGSYS
69 RUN MGD HOVER PROC
70 RUN MGD MEI
71 PRINT $OCE, $MEI, $CPFH, $PUF, $PHOV, $PC, $GN, $ODF
72 IF $N ISGT 31, GO TO FCUR
```

MODULE NAME = MEI
\$PHIV = 1 - \$A
\$MEI = *L*PHUV
\$OCE = \$OCE+\$MEI/\$CPFH*\$PUF

LIST OF SYMBOLS

| | |
|------|---|
| A | joint probability plot area |
| ALT | altitude, ft |
| APR | atmospheric pressure ratio |
| AR | aspect ratio |
| AT | atmospheric temperature - °F |
| ATR | atmospheric temperature ratio |
| BL | blade loading - lb/ft ² |
| CA | attrition costs - \$ |
| CB | main rotor blade chord - ft |
| CC | crew costs - \$/flight hr |
| CD | direct costs - \$/flight hr |
| CE | engine cost - \$ |
| CET | cost of engineering and tooling - \$ |
| CFM | field maintenance cost - \$/flight hr |
| CG | cost of GFE - \$ |
| CI | initial spares cost - \$ |
| CL | cost of labor - \$ |
| CM | cost of materials - \$ |
| CMT | total maintenance cost - \$/flight hr |
| COPL | overhaul parts and labor cost - \$/flight hr |
| CP | total aircraft production cost - \$ |
| CPFH | total cost per flight hour - \$/flight hr |
| CPIA | production, initial spares and attrition costs - \$ |
| CPOL | fuel cost - \$/flight hr |

LIST OF SYMBOLS (Continued)

| | |
|-----|---|
| DE | design value of endurance - min |
| DGW | design gross weight - lb |
| DIS | distance - n mi |
| DL | disc loading - lb/ft ² |
| DLN | normalized disc loading - DL/DR |
| DPH | incremental altitude probability width |
| DPL | design payload or change in payload - lb |
| DR | density ratio - ρ/ρ_0 |
| E | endurance - min |
| EN | number of engines |
| EUF | endurance utilization frequency |
| F | equivalent flat plate drag area - ft ² |
| FL | mission segment fuel load - lb |
| FOW | ratio of drag area times DR to GW - (F)(DR)/GW |
| FRC | forward rate of climb - ft/min |
| GW | gross weight - lb |
| GW0 | single-point design gross weight - lb |
| GW1 | first design point gross weight - lb |
| GW2 | second design point gross weight - lb |
| H | altitude - ft |
| HP | horsepower |
| KPP | power reduction - MRHP/SHP |
| MEI | mission effectiveness index |
| MFH | average monthly flight hours - hr |

LIST OF SYMBOLS (Continued)

| | |
|------|--|
| MOW | maximum overload gross weight, lb |
| MRHP | main rotor horsepower |
| N | number of payload increments |
| NEN | number of engines |
| NMR | number of main rotor blades |
| NP | number of ships produced (fleet size) |
| OAT | outside air temperature - °C |
| OCE | overall cost effectiveness index |
| OE | operating endurance - min |
| OLF | overload factor - % |
| OPL | operating payload - lb |
| PA | power available - hp |
| PHOV | hover probability |
| PM | power margin - % |
| POW | power-to-weight ratio - MRHP/GW |
| PR | pressure ratio |
| PRA | intermediate rated power of engine @ SL, 59°F - hp |
| PRF | referred power - hp |
| PRQ | power required for level flight - hp |
| PT | temperature probability |
| PTO | power at transmission torque limit - hp |
| PTI | previous value of PT |
| PUF | payload utilization frequency |
| Q | torque limit of transmission - ft-lb |

LIST OF SYMBOLS (Continued)

| | |
|------|--|
| QMR | main rotor torque - ft-lb |
| R | main rotor radius - ft |
| RA | maximum continuous power rating factor |
| RCP | percent fuel for reserve - % |
| R/C | rate of climb |
| RPL | relative payload (to design) |
| S | solidity = σ |
| SAR | specific air range - n mi/lb |
| SAS | stall limited air speed - kn |
| SFC | specific fuel consumption - lb/hr-hp |
| SFO | specific fuel consumption at PRA - lb/hr-hp |
| SL | system life - years |
| SM | airspeed margin to stall - kn |
| SSF | normalized specific fuel consumption |
| T | actual average MTBF - hr |
| TAS | true airspeed - kn |
| TIM | time - min |
| TMAX | maximum temperature at a given altitude - °F |
| TN | normal average MTBF - hr |
| TR | temperature ratio |
| TS | main rotor tip speed - ft/sec |
| VRC | vertical rate of climb - ft/min |
| WA | AMPP weight - lb |
| WCR | weight of crew - lb |

LIST OF SYMBOLS (Continued)

| | |
|----------|--|
| WEM | empty weight of ship - lb |
| WFL | fuel weight - lb |
| WPL | payload - lb |
| YAR | average yearly attrition rate - no./yr |
| Ω | rotor speed - rad/sec |