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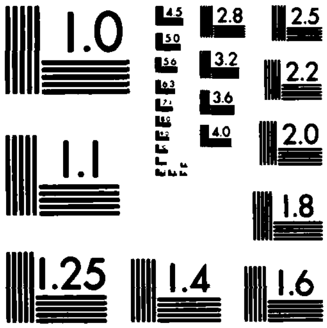

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THESIS

POWERPLANT SELECTION FOR
CONCEPTUAL HELICOPTER DESIGN

by

Timothy Joseph Casey

June 1983

Thesis Advisor: Donald M. Layton

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A method of optimizing the selection of a powerplant based upon engine and fuel weight is developed for use in a conceptual helicopter design course. Historical data is analyzed to verify and modify existing formulae used to estimate engine performance and engine installation weight. Computational programs for use on a hand-held computer and the IBM 3033 are developed to predict analytically engine fuel flow characteristics and to optimize engine selection.

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Powerplant Selection for Conceptual Helicopter Design

by

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Submitted in partial fulfillment of the
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June 1983

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ABSTRACT

A method of optimizing the selection of a powerplant based upon engine and fuel weight is developed for use in a conceptual helicopter design course. Historical data is analyzed to verify and modify existing formulae used to estimate engine performance and engine installation weight. Computational programs for use on a hand-held computer and the IBM 3033 are developed to predict analytically engine fuel flow characteristics and to optimize engine selection.

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I. INTRODUCTION

A. BACKGROUND

The selection of a powerplant in the design process of a helicopter has become an extremely complex task. Mission profile performance, weight, life cycle costs, maintainability, and noise have all become important considerations. Early helicopter designers were concerned only about weight and power available. In fact, until 1876 when N. A. Otto invented the four stroke internal combustion engine, there were no engines with power to weight ratios high enough to enable practical powered flight. It was not until 1907 that a 24 horsepower Antoinette engine provided the power for the first free flight in a helicopter.

Internal combustion engine technology remained well ahead of stability and control design in helicopters through the first half of the 20th century. But in 1954, the H-39 was built by Sikorsky as a test bed for the gas turbine engine (a Turbomeca Artouse II engine), and in 1956 the first version of the UH-1 was flown powered by an American built Lycoming T53-L-11 gas turbine. This design was a major breakthrough in aircraft engines because it significantly reduced the weight while increasing payload and speed over similar utility helicopters driven by reciprocating engines (despite a somewhat lower specific fuel consumption

rate). Continued advancements in turboshaft engine technology over the past 25 years have resulted in a proliferation of engines available for consideration by the helicopter designer--to the extent that even for preliminary design some specific guidance is needed toward making a suitable selection.

The purpose of this study is to develop a process for selecting a powerplant which would best meet preliminary design specifications for a helicopter [Ref. 1]. This process has to be straight-forward enough to be used in an initial design course by graduate students who are not helicopter experts. From an engineering standpoint, initial design of a helicopter to meet given mission and physical specifications focuses upon performance, fuel economy, and weight as primary selection criteria. Those criteria are, therefore, emphasized here.

B. OBJECTIVES

In order to accomplish the overall goal of providing a basic guide for the selection of a powerplant in the preliminary design of a helicopter, the following objectives were to be attained:

1. Presentation of an outline of powerplant selection criteria with references for more detailed explanation of those major considerations which would not be dealt with in this study.
2. A "paring down" of selection criteria to those applicable to an engineering preliminary design course.

3. Collection and tabular presentation of accurate data on 6 turboshaft engines which represent current technology performance.

4. Development of programs to optimize engine selection using either a hand-held calculator (HP-41C) or the IBM 3033 computer (FORTRAN).

5. Verification of data and calculations by comparison with flight manual information for an operational helicopter.

II. APPROACH TO THE PROBLEM

A. OVERVIEW

The selection of a powerplant for a modern helicopter has become so complex that in recent military helicopter programs competing manufacturers designed their aircraft around a particular engine (UH-60A, AH-64, and Lamps III all using versions of the GE T700 engine). In general, research and development costs and time usually limit airframe designers to consideration of existing engines. This approach seemed most realistic and was used in this study (as opposed to developing a "rubber" engine which could have been optimized for use under the design specifications of the particular aircraft being built). The following approach was taken to develop a viable method of evaluating and then selecting the most suitable powerplant available during preliminary design:

1. Broad selection criteria were established.
2. Performance was reasoned to be the essential criteria for initial design.
3. Performance parameters were established.
4. External factors affecting engine performance were evaluated.
5. Methods of obtaining and extracting engine data were explored.
6. Data essential for performance evaluation was determined.

7. Weight calculations were researched.

8. A selection and optimization process was developed.

B. BROAD EVALUATION CRITERIA

[Ref. 2] describes four criteria by which to rate the overall mission effectiveness of any major component in military helicopter design. These criteria include three considerations which are operational in nature and a fourth which is economic. They are:

1. Mission Readiness. This includes:

    a) Mission Capability (specifically, can the component do what it was designed to do).

    b) Availability (which is a function of reliability and maintainability).

2. Survivability

3. Performance. This is based upon predetermined mission profiles which result in specifications (e.g. hover out of ground effect at maximum gross weight at 4000 feet pressure altitude and 95 degrees ambient temperature).

4. Cost Factors

    a) Life Cycle Costs

        i) Research and development.

        ii) Initial investment.

        iii) Operational costs (e.g. fuel, personnel and training).

        iv) Maintenance.

    or:

    b) Incremental Costs. Only those costs which differ between competing components.

Each of the above factors must be weighed according to its importance to the procuring agency.

C. THE ESSENTIAL CRITERIA--PERFORMANCE

It was realized, after some thought, that the single most important factor in the selection of an existing engine is mission capability. Without this factor, the others have little meaning. The engine must first be able to provide sufficient power to enable the aircraft to do its designed mission. Mission capability is predominantly a function of performance characteristics. For the purposes of preliminary engineering design, then, it seemed most logical and useful to focus upon capability, and thus performance, as the criteria for powerplant selection.

D. PERFORMANCE PARAMETERS

Performance of a turboshaft engine designed for use in rotary wing aircraft has been traditionally measured in the following ways:

1. Output shaft horsepower.
2. Specific fuel consumption.
3. Power to weight ratio.

These parameters are used in this study as the essential criteria upon which the final selection of an engine is made for use in preliminary design.

E. EXTERNAL FACTORS AFFECTING ENGINE PERFORMANCE

It was found that engine specification manuals prepared by engine manufacturers contained a myriad of technical specifications and performance data. These manuals quite naturally presented the performance characteristics of their engines in the best possible forms. However, numerous qualifications (e.g. altitude, temperature, bleed air, distortion) were placed on the specifications. Extreme care had to be taken in interpreting the data.

[Ref. 3] outlines an array of considerations which should be accounted for before evaluating raw engine performance data extracted from specification manuals. Included are the following:

1. Basic airframe design (as it applies to installation and removal of the engine and to the location of the output shaft).
2. Air induction system (perhaps most importantly the particle separator).
3. The starting system.
4. The lubrication system.
5. The cooling system.
6. The exhaust system.
7. The fuel system.
8. The fire protection system.
9. Accessories (such as anti-ice and environmental control).

One primary reason for consideration of the above areas is to ascertain the power losses associated with their

operation which may not have been accounted for in the engine specifications.

During the preliminary design phase, the details about the systems noted above may not be known and are very probably determined by the final engine selection. Therefore, for the purposes of preliminary design, a conservative estimate of 1-2 percent bleed air and inlet losses were made [Ref. 4]. A reduction by 10 hp. of the published usable shaft horsepower from the engine manuals is included in the analytical solutions used in this study to account for such losses.

Standard practice in the preliminary design of military helicopters requires that fuel flow rates based upon engine specifications be increased by 5 percent in all calculations [Ref. 5]. This conservative procedure allows for handling characteristics and system degradation over time. This 5 percent increase is incorporated in the programs developed in this study.

F. EXTRACTING DATA AND PREDICTING PERFORMANCE

With the above initial considerations made, the next step was extracting relevent performance data from the manufacturer's manuals. Two things were immediately noted:

1. Technical performance terminology was difficult to understand but was critical to accurate interpretation of the data. Some particularly important definitions were compiled and are in Appendix A.

2. Performance data at standard sea level conditions was always given whereas data at a particular design condition may not have been tabulated.

Since determination of performance characteristics at design specifications is critical, research was conducted on methods by which nonstandard performance data could be obtained. At least three ways of obtaining performance data at specific operating conditions were found:

1. Computer programs developed by the manufacturer: (e.g. [Ref. 6] for the T700-GE-401 engine).

2. Interpolation of charts sometimes included in the manufacturer's specification manual ([Ref. 7] for the T53 Lycoming series engines).

3. Flight data charts from operators manual if the engine was already being used in an operational aircraft ([Ref. 8] for the T400 Pratt Whitney engine).

Computer programs were found to be consistently available on the engines developed within the last 10 years. However these programs were not easily obtained, were complex to use, and often did not interface with available hardware. As a result, each of the above listed methods was used for at least one of the six engines in Appendix B to verify the performance approximations used in this study.

Another method found of predicting engine performance is to digitize published data, then utilize a regression program which results in a formula which predicts engine performance at any desired airspeed or density altitude. Such an approach was taken in [Ref. 9]. This method was found to be very time consuming and was much less accurate than those mentioned above.

G. ESSENTIAL DATA

Minimum essential data for engine performance evaluation was determined to be the following:

1. Output shaft horsepower available and specific fuel consumption at three power settings at sea level standard conditions. This data provided a basic idea of the power available from the engine as well as sufficient information to calculate fuel flow rate at other pressure altitudes and temperatures (using known shaft horsepower required).

2. Maximum static power available at the design conditions and at 25,000 feet. This data allowed engine power evaluation at design (e.g. 4000 ft. and 95 degrees) and hover ceiling specifications (normally below 25,000 ft.).

3. Alternately, since the data in 2. above is not consistently available, an approximation of engine power available at nonstandard conditions may be made ([Ref. 10]) using the formula:

$$SHP = [\delta/\sqrt{\theta}](SHP) \qquad (2.1)$$

A comparison of the performance predicted by this formula versus actual data for a sample engine is made in Table I. It can be seen that this approximation becomes quite conservative at altitudes near normal hover ceilings. However, the results are very reasonable at the design conditions.

Raw engine data may also be correlated with total rotor power required (RSHP) calculations using the following formula [Ref. 1]:

$$ESHP = 1.03 \cdot RSHP + .1 \cdot (n-1) \cdot RSHP + 10 \qquad (2.2)$$

Where n is the number of engines used.

TABLE I

Analytical vs. Actual Engine Performance

20000 ft. -12 F

Engine	SHP Actual	SHP Analytical	% Difference
A	214	208	3
B	369	350	5
C	914	772	15
D	1000	891	11
E	1378	1237	10
F	2070	1682	19

4000 ft. 95 F

Engine	SHP Actual	SHP Analytical	% Difference
A	325	356	9
B	583	601	3
C	1170	1325	13
D	1404	1529	9
E	2055	2123	3
F	3086	2888	6

Engines

A: T63-A720
B: LTS101-750A
C: T700-GE700
D: T400-CP-400
E: T55-L-7
F: T55-L-712

H. WEIGHT

Engine dry weight is normally provided with performance data. However, an installed weight of the engine offers much more accurate weight estimation for power calculations. The installed weight is defined here to include:

a. Lubricant weight.

b. Cooling system.

c. Engine controls.

d. Engine supports.

e. Exhaust ducting.

f. Starting system.

Methods to accurately estimate an engine's installed weight were investigated. Analysis of data collected on current helicopter installed weights revealed that the "rule of thumb" formulae in use in [Ref. 1] correctly predict weight trends. However, the installed weights calculated using those formulae are somewhat low for engine dry weights up to about 700 pounds. Since this range of engines includes approximately 70 percent ([Ref. 11]) of the helicopters in production in the West, an attempt to update the weight estimating relationship is made here.

A search of the literature revealed at least two additional methods of engine weight estimation:

1. Powerplant weight estimation based upon maximum horsepower of the engine [Ref. 12] using the following equation:

$$W_{EI} = 130.243 + .369Hp$$

2. Installation weight as a function of engine dry weight [Ref. 13]; with the percentage of installation weight increasing with engine dry weight according to the formula:

$$W_{EI} = .0974(W_{ED})^{1.2}$$

It was found that method 1 was based upon data taken from early model helicopters which does not reflect current technology. Additionally, the components included in the total installed engine weight were inconsistent between different aircraft manufacturers. This problem arose in the collection of data for this study as well. As an example, Bell Helicopter Textron (BHT) includes only residual fuel and oil in the published values of installed engine weight. Individual component installation weight and balance information had to be obtained from Bell to get data which would be consistent for comparison and analysis.

Method 2 above does not coincide with the design trends reflected by the U.S. helicopters analyzed in this study.

In order to determine an accurate method of estimating engine installed weight, a data base of 20 helicopters was collected. Table II depicts the aircraft, engines, engine weights and engine horsepowers used for the data base. The helicopters in this table include many of the U.S. military rotary wing aircraft currently operational [Ref. 14], [Ref. 15], [Ref. 16].

TABLE II

Turboshaft Engine Data Base

Engine	A/C	Dry Weight lbs.	Installed Weight lbs.	Military SHP @ SS1
T63-A-5A	OH-6A	136.0	175.2	317
All-250-C18	Th-57A	136.0	194.0	317
T63-A-720	OH-58C	158.0	218.0	420
T58-GE-8F	UH-2D	305.0	403.0	1350
T58-GE-5	S-67	335.0	471.0	1500
T58-GE-10	CH-47D	340.0	454.0	1400
T700-GE-700	YAH-63	423.0	547.0	1560
T700-GE-701	AH-64	427.0	587.0	1690
T58-GE-16	CH-46E	430.0	621.0	1870
T53-L-703	AH-1S	495.0	607.0	1485
T53-L13	UH-1H	540.0	683.0	1400
T55-L-7	CH-47A	580.0	671.0	2650
T64-GE-16	AH-56	700.0	969.0	3370
T400-CP400	UH-1N	701.0	910.0	1800
T400-CP400	AH-1J	701.0	908.0	1800
T64-GE-6	CH-53A	723.0	881.0	2850
T400-WV-402	AH-1T	733.0	936.0	1970
T55-L-11D	CH-47C	735.0	897.0	3750
T55-L712	CH-47D	760.0	925.0	3400
JTFD12A-4A	CH-54A	920.0	1093.0	4500

Several curve fitting techniques were applied to engine weight criteria based upon three separate comparisons:

1. Engine dry weight vs. installation weight as a percentage of dry weight.

2. Engine military horsepower available vs. total installed weight.

3. Engine dry weight vs. total installed weight.

It was found that the best weight estimating relationship could be obtained using comparison 3 with a linear regression. The weight estimating relation is:

$$W_{EI} = 44.684 + 1.193W_{ED}$$

For consistency with other equations used for helicopter preliminary design, this formula is rounded to two significant figures:

$$W_{EI} = 45 + 1.2W_{ED} \qquad (2.3)$$

This relationship yielded an R^2 value of .9819. Figure 1 is a plot of installed weight estimation based on equation 2.3.

I. SELECTION AND OPTIMIZATION

The engines at Appendix B are considered as those which are available for the purposes of preliminary design selection here. Those engines were selected for inclusion in this study for the following reasons:

1. Currently in use in military helicopters with accurate and tested data available.

2. Representative spectrum of shaft horsepower required in military rotorcraft.

3. Latest developments incorporated (SFC and weight especially).

4. Variety of manufacturers [Ref. 7], [Ref. 17], [Ref. 18], and [Ref. 19].

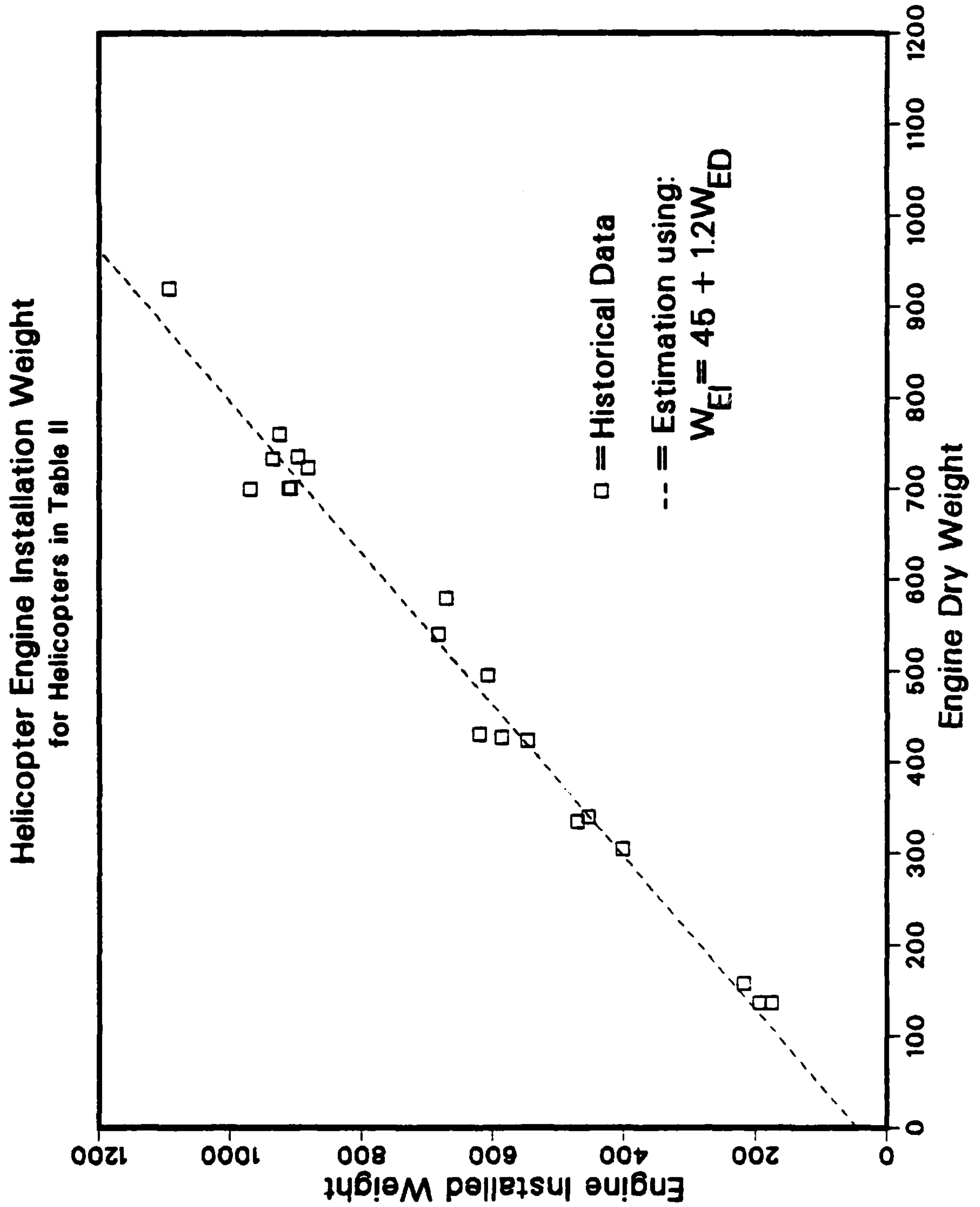

Figure 2.1 Engine Dry Weight vs. Installed Weight

Essentially, an engine(s) which would fulfill a specific mission capability could have been selected by inspection almost at random from this list once power requirements were determined. However, it seemed much more realistic to optimize the selection in some way.

The most useful method of selecting the "best" engine(s) in a preliminary design process appears to be one in which the minimum total weight is obtained (enabling the biggest payload, most range, or most additional equipment installed). The total weight includes the total fuel weight required by the engine to accomplish a specified mission as well as the installed weight of the powerplant itself. The estimation of engine installed weight is made using equation 2.3. The total fuel required is calculated using the mission criteria stated in [Ref. 1]:

$$\text{Fuel Wt.} = .05W_f<\text{NRP}> + W_f<\text{cruise}>*\text{Range}<\text{max}>/V<\text{cruise}>$$
$$+ .25W_f<V<\text{end}>> + .05W_f<\text{NRP}> \qquad (2.4)$$

The optimum powerplant is then determined by adding the fuel and engine(s) weights and using the smallest value found.

III. SOLUTION

The calculations necessary to make the total weight comparisons were initially done manually using equations and the mission profile from [Ref. 1]. Then programs were developed to aid in the optimization process. Considerations in the development of the computer programs are:

1. Compatibility with previous work using both a hand-held calculator and a main frame computer.

2. Reasonable simplicity so that the feel for the design process is not lost within the computing machine.

3. Flexibility and adaptability (easily modified or expanded).

4. Output of intermediate data required for helicopter design (e.g. fuel flow rates) as well as final comparisons.

5. Weight used as the optimization criteria.

Three basic computer programs were written, two for use on the HP-41C and the third for interactive use on the IBM 3033. All programs assume that calculations for rotor shaft horsepower required (RSHP) can be made. Inputs required are:

1. Engine SHP and SFC at three power settings at sea level standard day conditions.

2. Pressure altitude and temperature.

3. Dry weight of engine.

4. Access to power equations: "Flite" [Ref. 20], "Power" (Appendix E), or the Helicopter Computation Package [Ref. 21].

Program outputs are:

1. Zero shaft horsepower intercept.
2. Slope of fuel flow vs. ESHP line.
3. Phantom SHP [Ref. 22].
4. Fuel flow rate at desired RSHP and density altitude.
5. Total fuel weight for mission profile.
6. Total weight of fuel plus installed powerplant.
7. Recommended selection between two candidate powerplants (FORTRAN program only).

IV. RESULTS

A. COMPUTATIONAL PROGRAMS AND DATA

The research and programming results of this study are presented in Appendices C thru E:

1. Appendix C contains the fuel flow characteristics and the engine and mission fuel weight calculation programs for the hand-held calculator. The fuel and engine weight program requires the user to manually compare total weights calculated for each engine analyzed. This procedure was followed to save calculator register space. Also in Appendix C are program flow charts and sample problems.

2. Appendix D contains the FORTRAN engine optimizer as well as the program algorithm and a sample problem.

3. Appendix E contains three supporting programs for use with the HP-41C calculator:

   a. "Power" which calculates the total power required for a helicopter in level flight. This program was developed to enable rapid calculation of fuel flow characteristics at varying conditions and design parameters. It was found that total power calculations using existing programs for the HP-41C were very cumbersome to use for the purpose of determining fuel flow and fuel weight data.

   b. "VE" which computes the maximum endurance velocity for the preliminary design of a helicopter. This program uses "POWER" iteratively to achieve a solution for maximum endurance velocity.

   c. "VMR" which computes the maximum range velocity for the preliminary design of a helicopter. This program uses "POWER" iteratively to achieve a solution for maximum range velocity.

B. ACCURACY

Appendix F contains a comparison between actual performance for the UH-60A (Blackhawk) helicopter [Ref. 23], and the analytical results obtained by the use of the computational programs in Appendices C thru E. Tables XI-XIII show that the analytical results obtained agree quite well with actual helicopter performance. Although only one helicopter was used to evaluate the program outputs, an encouraging indication of their accuracy is at least provided. However, it can be seen that at higher airspeeds (especially at non-standard conditions) the analytical solutions become increasingly less exact. This is primarily a function of the basic nature of the equations used to predict rotor power required for a preliminary helicopter design. Several real world conditions are not modeled by the equations (e.g. rotor downwash on the fuselage, compressibility effects, and blade stall). Such conditions result in higher actual power requirements than those predicted (especially above about 120 knots).

The basic equations used to predict fuel flow rates, however, appear to model actual conditions extremely well. Table XI shows consistently lower error for fuel flow rate analytical results than for predicted engine shaft horsepower required. Additionally, when the actual engine shaft horsepower required from the operator's manual was used to

calculate fuel flow rate, the result was within 5 percent of chart values in every case compared.

C. LIMITATIONS

1. Modeling of required rotor power does not include all aerodynamic effects. These limitations are discussed in [Ref. 24].

2. Accuracy at non-standard conditions and airspeeds greater than 120 knots is only fair; nonlinearities of the fuel flow lines are not considered.

3. Maximum and minimum engine fuel flow rates are not considered.

4. Changes in engine shaft horsepower available with temperature and altitude are not programmed. These changes must be checked manually (see Appendix B).

D. HP-41C MEMORY REQUIREMENTS

The programs listed in Table III use a total of 239 registers of program memory. Size 46 is required to provide sufficient memory storage for all programs.

TABLE III

PROGRAM STORAGE REGISTER REQUIREMENTS

Subject Area	Program		Subroutine	
	Name	Registers	Name	Registers
Engine fuel flow characteristics	FUELFL	56	--	--
Mission fuel and engine weights	WEIGHT	30	FUELFL	56
Total helicopter power required	POWER	106	--	--
Maximum endurance velocity	VE	22	POWER	106
Maximum range velocity	VMR	25	POWER	106

V. CONCLUSIONS AND RECOMMENDATIONS

A. USEFULNESS FOR PRELIMINARY DESIGN

The programs developed in this study and the equations used in their development appear to provide an excellent basis upon which to conduct the preliminary design of a modern helicopter. The use of the programs requires a reasonable understanding of helicopter performance and the user should carefully execute the example problems to insure understanding of the computational process. Since all of the programs developed here build upon existing code, complexity has increased; hopefully however, not at the expense of clarity.

B. RECOMMENDATIONS

1. Comparisons of analytical results with actual performance data for a number of operational helicopters should be conducted. The true applicability of the equations and programs used here can best be determined in this way.

2. UH-60A operational data indicate that analytically predicted power requirements and fuel flow rates could be brought to within 5-10 percent accuracy simply by increasing the loss factor between the engine and the rotor by 15 percent. That is by letting:

   $$ESHP = ((.1*N) + 1.18)*RSHP + 10$$

   Such an increase may better account for power reductions resulting from pressure losses and accessories. The validity of changing the loss factor in this manner needs to be verified by making the additional comparisons recommended in 1 above.

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APPENDIX A

DEFINITIONS

Absolute Altitude: The maximum altitude at which the engine will function properly under specified ram pressure ratios.

Cold Atmospheric Conditions: Cold atmospheric air pressures are given in MIL-STD-210. Cold atmospheric air temperature is -54.3 C from sea level to 25,500 feet altitude.

Cruise Power: Most often defined as 75 percent of normal rated power, but may be a different percentage, especially in older engine manuals.

ESHP: Used in this study to specifically designate Engine Shaft Horsepower. However, this term is also defined as Equivalent Shaft Horsepower by engine manufacturers. Equivalent Shaft Horsepower is a modified power output rating which includes jet thrust:

$$\text{Static ESHP} = \text{SHP} + F_n/2.5$$

$$\text{Flight ESHP} = \text{SHP} + (F_n \times V)/261$$

where: F_n is net jet thrust in pounds.

V is flight speed in knots.

Gross Jet Thrust: The thrust delivered at the exhaust duct exit as determined from the product of exhaust gas mass flow and velocity, plus exhaust duct area times the difference between gas static pressure and ambient exhaust pressure.

Hot Atmospheric Conditions: Hot atmospheric air pressures are given in MIL-STD-210. Hot atmospheric temperature is 55 C at sea level and decreases at a rate of .0025 C per foot of altitude to 38,000 feet altitude.

Inlet Air Distortion: Steady state and dynamic inlet air pressure variations and steady state temperature variations as defined by Distortion Indexes (DI) of the form:

$$DI = \frac{\left(P_{T_{MEAN}} - P_{T_{LOW\ MEAN}} \right)}{P_{T_{MEAN}}}$$

$$DI = \frac{\left(T_{1_{MAX}} - T_{1_{MEAN}} \right)}{T_{1_{MEAN}}}$$

Military Rated Power: The highest power at which the engine may be operated for a 30 minute period without special maintenance, provided such operation is followed by a return to Normal Rated Power or lower power for a specified time.

Net Jet Thrust: Gross Jet Thrust minus the product of engine air mass flow and free stream velocity.

Normal Rated Power (NRP): The highest power at which the engine may be operated continuously without restriction (other than scheduled maintenance); also referred to as maximum continuous power.

Ram Efficiency: The ratio of inlet air total pressure to free stream air total pressure.

Shaft Horsepower (SHP): The horsepower delivered at the output shaft of the engine.

Specific Fuel Consumption (SFC): The weight of fuel consumed by the engine in pounds of fuel per hour per shaft horsepower.

APPENDIX B

ENGINE SELECTION DATA

A. AVAILABLE POWER PLANTS

The power plants in Table IV are those considered available for preliminary design selection.

TABLE IV

Available Power Plants

Engine	Dry Weight (lbs)	Standard Sea Level Performance SHP	SFC
A	158	M: 420	.650
(T63-A-720)		N: 370	.651
		C: 278	.709
B	268	M: 708	.573
(LTS101-750A)		N: 659	.573
		C: 494	.599
C	423	M: 1561	.460
(T700-GE-700)		N: 1318	.470
		C: 989	.510
D	709	M: 1800	.595
(T400-CP-400)		N: 1530	.606
Note: Dual engine with single gear box.		C: 1148	.661
E	580	M: 2500	.615
(T55-L-7)		N: 2200	.622
		C: 1650	.678
F	750	M: 3400	.543
(T55-L-712)		N: 3000	.562
		C: 2250	.610

M: Military Power
N: Normal Power
C: Cruise Power

B. ENGINE PERFORMANCE AT OTHER THAN STANDARD SEA LEVEL CONDITIONS

The effects of altitude and temperature on engine performance may be approximated using the formula:

$$ESHP = (\delta/\sqrt{\theta})\ (ESHP)$$

Where $\delta = P/P_{SSL}$

$\theta = T/T_{SSL}$ (Absolute temperature)

C. ENGINE INSTALLED WEIGHT

Engine installed weight includes the dry engine(s) weight plus an installation fraction which includes: air induction system, exhaust system, cooling, controls, starting system, mounts, and residual fuel and oil. The total installed weight may be computed as:

$$W_{EI} = 45. + 1.2 \cdot W_{ED} \quad \text{(per engine)}$$

APPENDIX C

FUEL FLOW AND WEIGHT COMPUTATION USING THE HP-41C

This appendix contains the programs developed for use with the HP-41C programmable calculator. Two main programs were written:

1. FUELFL

   a. Computes fuel flow characteristics from engine standard sea level performance data (SFC and SHP).

   b. Computes fuel flow rate for an input value of rotor shaft horsepower required.

2. WEIGHT

   a. Computes estimated engine installed weight.

   b. Requires prior execution of "FUELFL" to compute fuel flow rates.

   c. Computes total weight of installed engine and fuel for a design mission profile.

Both programs are designed to accept direct user input of required rotor power or to accept a user specified forward velocity and calculate total rotor power required using the program "POWER" in Appendix E. "POWER" was developed to enable rapid calculation of total power required at any forward velocity (or hover) for use in the above programs as well as for calculation of maximum endurance velocity and maximum range velocity (Appendix E).

FUELFL

1. Purpose

This program computes the fuel flow rate for a specific engine for input values of altitude (up to 36,000 feet), temperature and rotor shaft horsepower required. The user must input engine performance data at military, normal, and cruise power settings at sea level from manufacturer's specifications. The program incorporates an increase by 5 percent of specification fuel consumption in accordance with accepted military design criteria.

"FUELFL" is designed with two subroutines which allow calculation of fuel flow rates at varying operating conditions after one initial entry of engine performance data. They are:

a. "FF" which computes the fuel flow rate for an input value of rotor shaft horsepower required (or velocity if "POWER" is used). This subroutine converts rotor power into engine power by adding power losses in the transmission and drive train as well as power consumed by accessories.

b. "OPCON" which contains "FF" but which also prompts for current environmental operating conditions.

If "POWER" is to be used to calculate rotor shaft horsepower required, it must be run first so that design data for a specific helicopter may be calculated and stored.

The fuel flow characteristics calculated and displayed are as follows:

Display:	Explanation:
BETA =	Average slope of fuel flow line.
ALPHA =	Zero horsepower intercept per engine at standard sea level conditions.
ZHI =	Zero horsepower intercept per engine at operating conditions.
PSHP =	Zero velocity horsepower (Phantom SHP).
WF =	Fuel flow rate (lb/hr).

2. Equations

$SFC_i = (SFC_i + .05 \times SFC_i)$ $i = M, N, C$ (5% increase)

$$W_{f_i} = SFC_i \times SHP_i$$

$$\hat{\beta} = \frac{W_{f_M} - W_{f_N}}{SHP_M - SHP_N} + \frac{W_{f_M} - W_{f_C}}{SHP_M - SHP_C} + \frac{W_{f_N} - W_{f_C}}{SHP_N - SHP_C} \div 3$$

$$\hat{\alpha} = |\hat{\beta}\ (SHP_M + SHP_N + SHP_C) - (W_{f_M} + W_{f_N} + W_{f_C})| \div 3$$

$$\delta = {}^{P}/P_{SSL} = [1 - (h_p \times 6.8754 \times 10^{-6})]^{5.256}$$

$$\sqrt{\theta} = \sqrt{{}^{T}/T_{SSL}} = \sqrt{\frac{T + 459.688}{518.688}}$$

$$ZHI = \hat{\alpha}(\delta\sqrt{\theta})$$

$$PSHP = \frac{n(ZHI)}{\hat{\beta}} \quad \text{AND} \quad ESHP = 1.03(RSHP) + .1(n-1)(RSHP) + 10$$

$$W_f = [PSHP + ESHP]\ \hat{\beta}$$

where:

SFC is specific fuel consumption (lb/hr/shp)

SHP is shaft horsepower of the engine

W_f is fuel flow rate (lb/hr)

$\hat{\beta}$ is the average slope of the fuel flow line

$\hat{\alpha}$ is the zero horsepower increment for one engine at standard sea level conditions

δ is the ratio of pressure to standard sea level pressure

P is atmospheric pressure at operating conditions (psi)

P_{SSL} is standard sea level atmospheric pressure (psi)

h_p is pressure altitude (ft)

θ is the ratio of temperature to standard sea level temperature (absolute)

T is temperature in degrees F

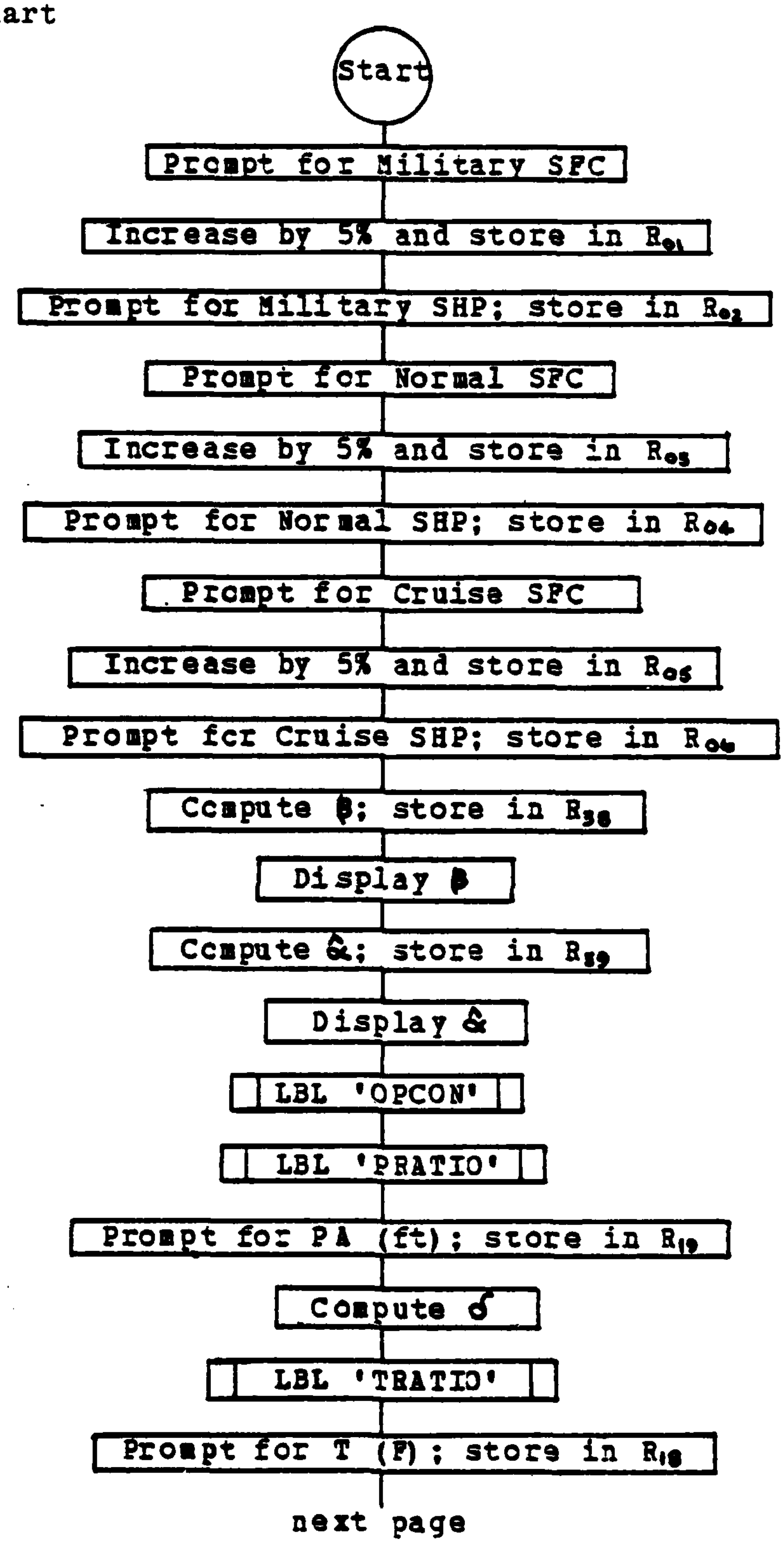
ZHI is the zero horsepower increment at input conditions

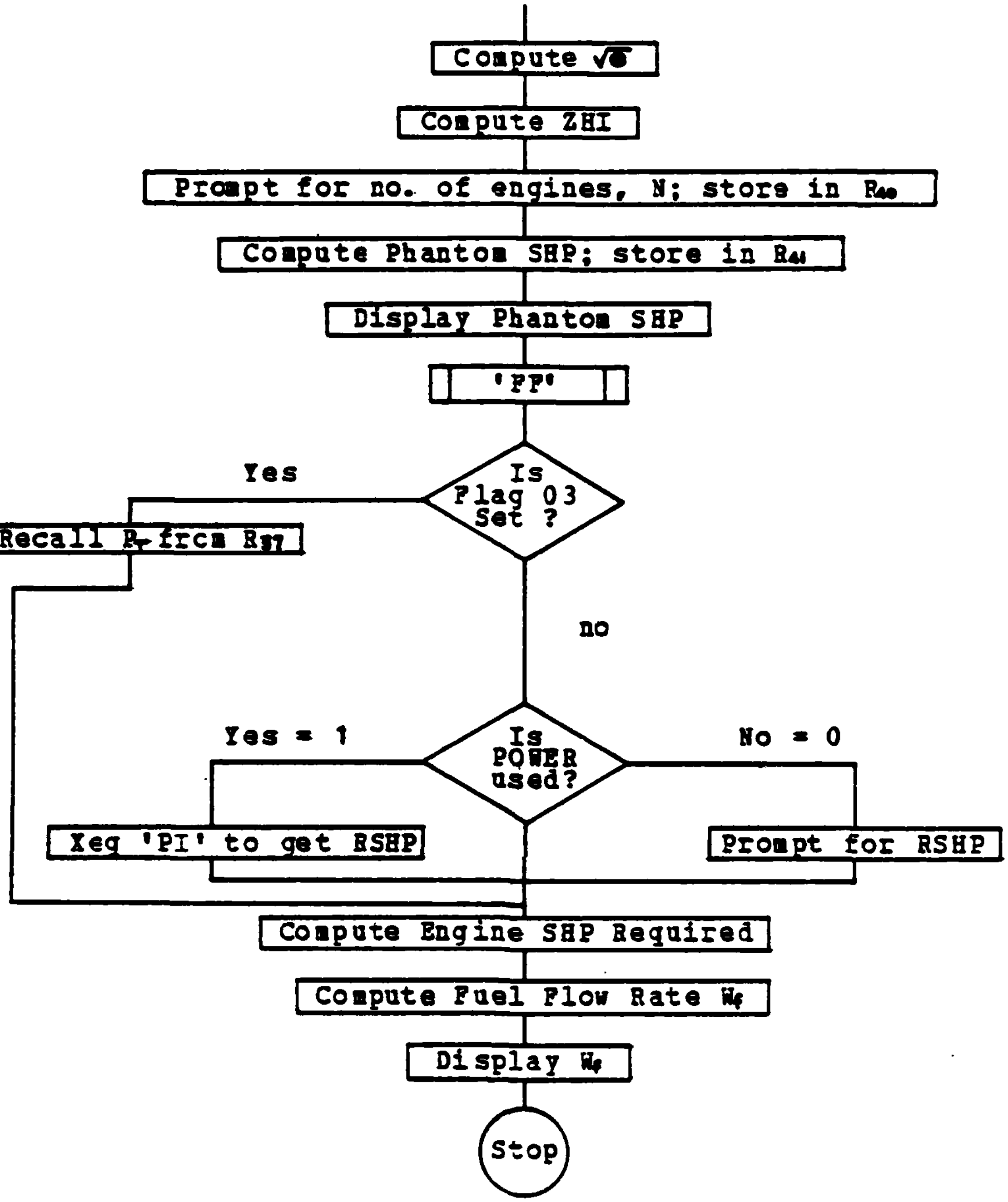
n is the number of engines

PSHP is the zero velocity horsepower (Phantom SHP)

ESHP is the engine shaft horsepower required

3. Flowchart


Start
Prompt for Military SFC
Increase by 5% and store in R_{01}
Prompt for Military SHP; store in R_{02}
Prompt for Normal SFC
Increase by 5% and store in R_{03}
Prompt for Normal SHP; store in R_{04}
Prompt for Cruise SFC
Increase by 5% and store in R_{05}
Prompt for Cruise SHP; store in R_{06}
Compute β; store in R_{38}
Display β
Compute α; store in R_{39}
Display α
LBL 'OPCON'
LBL 'PRATIO'
Prompt for PA (ft); store in R_{19}
Compute δ
LBL 'TRATIO'
Prompt for T (F); store in R_{18}
next page


Compute √σ
Compute ZHI
Prompt for no. of engines, N; store in R40
Compute Phantom SHP; store in R41
Display Phantom SHP
'FF'
Is Flag 03 Set ?
Yes
Recall R from R37
no
Is POWER used?
Yes = 1
No = 0
Xeq 'PI' to get RSHP
Prompt for RSHP
Compute Engine SHP Required
Compute Fuel Flow Rate Wf
Display Wf
Stop

4. Example Problem and User Instructions

Find the fuel flow rate for a helicopter under the following conditions:

<u>Engine Data</u>	SHP	SFC	<u>Operating conditions</u>:
Military	1561	.460	Standard Sea Level
Normal	1310	.470	PA = 0
Cruise	989	.510	T = 59 F

Two engines (N = 2)

a. Assume "POWER" will not be used:

RSHP = 500 hp

Keystrokes:	Display:
(XEQ) (ALPHA) FUELFL (ALPHA)	SFC-M?
0.460 (R/S)	SHP-M?
1561 (R/S)	SFC-N?
0.470 (R/S)	SHP-N?
1310 (R/S)	SFC-C?
0.510 (R/S)	SHP-C?
989 (R/S)	B = 0.3948
(R/S)	ALPHA = 135.32
(R/S)	PA=?
0 (R/S)	T(F)=?
59 (R/S)	ZHI = 135.32
(R/S)	N=?
2 (R/S)	PSHP = 685.46
(R/S)	POWER?

0 (R/S)	RSHP=?
500 (R/S)	WF = 497.68

Now use "FF" to compute the fuel flow rate for the same engine at the same altitude and temperature but with:

RSHP = 700 shp

Keystrokes:	Display:
(XEQ) (ALPHA) FF (ALPHA)	POWER?
0 (R/S)	RSHP=?
700 (R/S)	WF = 586.91

Now use "OPCON" to compute the fuel flow rate for the same engine at:

PA = 4000 ft

T = 95 F

RSHP = 700 shp

Keystrokes:	Display:
(XEQ) (ALPHA) OPCON (ALPHA)	PA. FT.?
4000 (R/S)	T <F>?
95 (R/S)	ZHI = 120.86
(R/S)	N=?
2 (R/S)	PSHP = 612.20
(R/S)	POWER?
0 (R/S)	RSHP=?
700 (R/S)	WF = 557.99

b. If "POWER" is loaded and executed using the sample helicopter design data included as an example with the "POWER" user instructions, run "FUELFL" again with the same engines and operating conditions but with:

VF = 95 kts

Keystrokes:	Display:
(XEQ) (ALPHA) FUELFL (ALPHA)	SFC-M?
0.460 (R/S)	SHP-M?
1561 (R/S)	SFC-N?
0.470 (R/S)	SHP-N?
1310 (R/S)	SFC-C?
0.510 (R/S)	SHP-C?
989 (R/S)	B = 0.3948
(R/S)	ALPHA = 135.32
(R/S)	PA=?
0 (R/S)	T(F)=?
59 (R/S)	ZHI = 135.32
(R/S)	N=?
2 (R/S)	PSHP = 685.46
(R/S)	POWER?
1 (R/S)	PA=?
0 (R/S)	T<F>=?
59 (R/S)	VF=?
95 (R/S)	PT = 499.17
(R/S)	PT = 499.17
(R/S)	WF = 497.31

Note: When "POWER" is used, the user is prompted for PA and T twice. This is to insure that both engine performance and rotor power required are computed at the same atmospheric conditions.

Now use "FF" to compute the fuel flow rate for the same engine at the same altitude and temperature but with

VF = 120 kts

Keystrokes:	Display:
(XEQ) (ALPHA) FF (ALPHA)	POWER?
1 (R/S)	PA=?
0 (R/S)	T<F>=?
59 (R/S)	VF=?
120 (R/S)	PT = 706.50
(R/S)	PT = 706.50
(R/S)	WF = 589.82

Now use "OPCON" to compute the fuel flow rate for the same engine at:

PA = 4000 ft

T = 95 F

VF = 120 kts

Keystrokes:	Display:
(XEQ) (ALPHA) OPCON (ALPHA)	PA. FT.?
4000 (R/S)	T<F>?
95 (R/S)	ZHI = 120.86
(R/S)	N=?
2 (R/S)	PSHP = 612.20
(R/S)	POWER?
1 (R/S)	PA=?
4000 (R/S)	T<F>=?
95 (R/S)	VF=?

120 (R/S) PT = 634.12

(R/S) PT = 634.12

(R/S) WF = 528.60

5. Programs and Subroutines Used

"FUELFL"

"OPCON"

"PRATIO"

"TRATIO"

"FF"

6. Storage Register Utilization

Table V shows specific storage register contents.

TABLE V

FUELFL Storage Register Utilization

Storage Register		Stored Quantity
00	blank	- used for computations
01	SFC_M	- specific fuel consumption at military power at sea level (lb/hr/hp)
02	SHP_M	- shaft horsepower output at military power at sea level (hp)
03	SFC_N	- specific fuel consumption at normal power at sea level (lb/hr/hp)
04	SHP_N	- shaft horsepower output at normal power at sea level (hp)
05	SFC_C	- specific fuel consumption at cruise power at sea level (lb/hr/hp)
06	SHP_C	- shaft horsepower output at cruise power at sea level (hp)
07	W_{f_M}	- fuel flow rate at sea level military power with 5% increase (lb/hr)
08	W_{f_N}	- fuel flow rate at sea level normal power with 5% increase (lb/hr)
09	W_{f_c}	- fuel flow rate at sea level cruise power with 5% increase (lb/hr)
10-37		- used by program "POWER"
38	$\hat{\beta}$	- average slope of the fuel flow line
39	$\hat{\alpha}$	- average zero horsepower intercept at standard sea level conditions (lb/hr)
40	n	- number of engines in the helicopter
41	PSHP	- zero velocity shaft horsepower (phantom shp)

Note: registers 00-09 are also used by other programs.

7. Program Listings

```
♦LBL "FUELFL"
"SFC-M?"
PROMPT
STO 01
.05
*
ST+ 01
"SHP-M?"
PROMPT
STO 02
"SFC-N?"
PROMPT
STO 03
.05
*
ST+ 03
"SHP-N?"
PROMPT
STO 04
"SFC-C?"
PROMPT
STO 05
.05
*
ST+ 05
"SHP-C?"
PROMPT
STO 06
RCL 01
RCL 02
*
STO 07
RCL 03
RCL 04
*
STO 08
RCL 05
RCL 06
*
STO 09
CLX
RCL 07
RCL 08
-
RCL 02
RCL 04
-
/
ABS
STO 38
CLX
RCL 07
RCL 09
-
RCL 02
RCL 06
-
/
ABS
ST+ 38
CLX
RCL 08
RCL 09
-
RCL 04
RCL 06
-
/
ABS
ST+ 38
3
ST/ 38
RCL 38
FIX 4
"B="
ARCL X
AVIEW
STOP
FIX 2
RCL 02
*
CHS
RCL 07
+
STO 39
CLX
RCL 38
RCL 04
*
CHS
RCL 08
+
ST+ 39
CLX
RCL 38
RCL 06
*
CHS
RCL 09
+
```

```
101 ST÷ 39
102 3
103 ST/ 39
104 RCL 39
105 CLA
106 "ALPHA="
107 ARCL X
108 AVIEW
109 STOP
110◆LBL "OPCON"
111◆LBL "PRATIO"
112 "P.A. FT?"
113 PROMPT
114 6.8754 E-6
115 *
116 CHS
117 1
118 +
119 ENTER↑
120 5.256
121 Y↑X
122 STO 02
123◆LBL "TRATIO"
124 "T (F)?"
125 PROMPT
126 459.688
127 +
128 518.688
129 /
130 SQRT
131 STO 03
132 RCL 39
133 RCL 02
134 *
135 RCL 03
136 *
137 "ZHI="
138 ARCL X
139 AVIEW
140 STOP
141 RCL 38
142 /
143 "N=?"
144 PROMPT
145 STO 40
146 *
147 STO 41
148 CLA
149 "PSHP="
150 ARCL X
151 AVIEW
152 STOP
153 CLX
154◆LBL "FF"
155 FS? 03
156 GTO 02
157 "POWER?"
158 PROMPT
159 X=0?
160 GTO 01
161 XEQ "DA"
162 GTO 02
163◆LBL 01
164 "RSHP= ?"
165 PROMPT
166 GTO 03
167◆LBL 02
168 RCL 37
169◆LBL 03
170 RCL 40
171 1
172 -
173 .1
174 *
175 1.03
176 +
177 *
178 10
179 +
180 RCL 41
181 +
182 RCL 38
183 *
184 CLA
185 "WF="
186 ARCL X
187 AVIEW
188 END
```

WEIGHT

1. Purpose

This program computes the estimated total weight of an installed engine plus the weight of fuel consumed for a design mission profile by a helicopter with that engine(s) installed. The fuel weight calculation requires computation of maximum endurance velocity and the power associated with operation at both cruise and maximum endurance velocities. The program offers the option of direct input of rotor shaft horsepower required (previously computed by the user) or the use of program "POWER" to calculate the required power using a velocity input. The user must already have determined the maximum endurance velocity in either case. Program "VE" can be used in conjunction with "POWER" for this purpose. If "POWER" is to be used, it must be executed first so that geometric data for the helicopter may be calculated. "WEIGHT" enters program "POWER" at subroutine "DA" so that the correct altitude and temperature for the design may be selected as well as to save computation time. "WEIGHT" also utilizes subroutine "OPCON" from program "FUELFL" to calculate fuel flow rates. The calculated values are displayed as follows:

Display:	Explanation:
WEI =	Weight of engine-installed (lb)
FL WT =	Fuel weight for mission (lb)

WTT =	Total weight of installed engine plus mission fuel (lb)

2. Equations

$$W_{EI} = 45 + 1.2 \cdot W_{ED}$$

$$W_{tf} = .05\ W_f<NRP> + \frac{MAX\ RANGE}{V_{CRUISE}}\ (W_f<V_{CRUISE}>)$$

$$+\ .25\ W_f<V_{END}> + .05\ W_f<NRP>$$

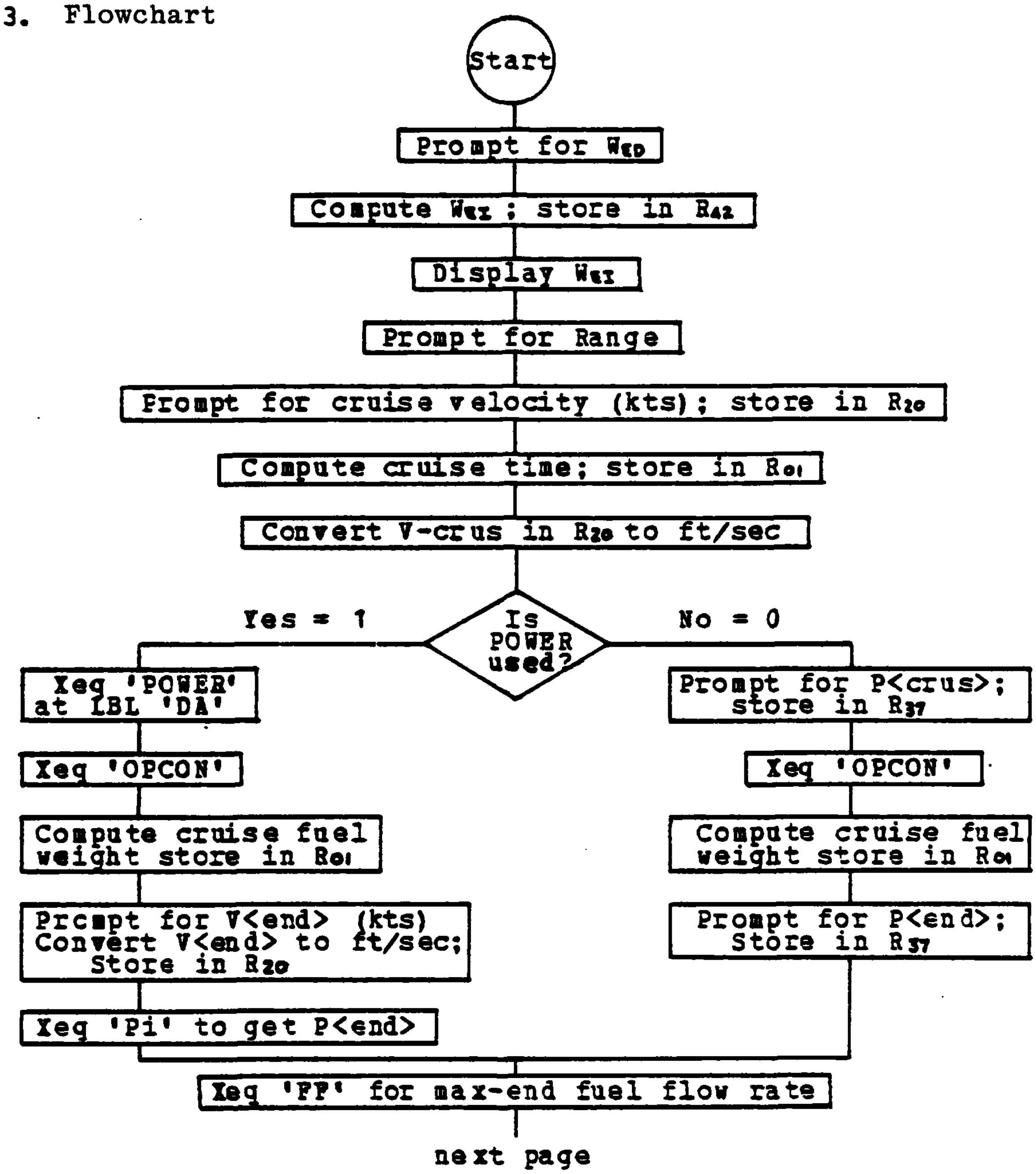
$$W_{tt} = W_{EI} + W_{tf}$$

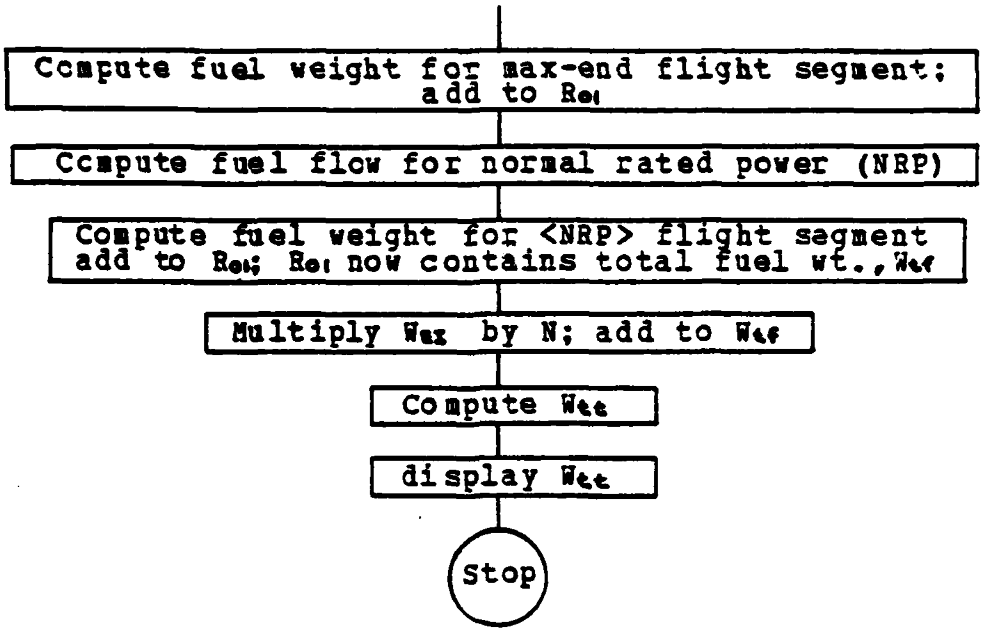
$$W_f = (PSHP + ESHP)\hat{\beta}$$

where:

W_{ED}	is the engine dry weight (lb)
W_{EI}	is the engine installed weight (estimated) (lb)
W_{tf}	is the total fuel weight for the mission
W_{tt}	is the total weight of installed engine plus mission fuel (lb)
V_{CRUISE}	is the specification cruise velocity (KTS)
PSHP	is the shaft horsepower required at zero velocity (phantom shp)
$W_f<NRP>$	is the fuel flow rate of the engine at normal rated power (lb/hr)
$W_f<V_{CRUISE}>$	is the fuel flow rate of the engine at cruise velocity (lb/hr)
$W<V_{END}>$	is the fuel flow rate of the engine at maximum endurance velocity (lb/hr)
W_f	is fuel flow rate (general) (lb/hr)
ESHP	is engine shaft horsepower (hp)
$\hat{\beta}$	is the slope of the fuel flow line for the engine

3. Flowchart


Start
Prompt for WED
Compute WEZ ; store in R42
Display WEZ
Prompt for Range
Prompt for cruise velocity (kts); store in R20
Compute cruise time; store in R01
Convert V-crus in R20 to ft/sec
Is POWER used?
Yes = 1
No = 0
Xeq 'POWER' at LBL 'DA'
Xeq 'OPCON'
Compute cruise fuel weight store in R01
Prompt for V<end> (kts) Convert V<end> to ft/sec; Store in R20
Xeq 'Pi' to get P<end>
Prompt for P<crus>; store in R37
Xeq 'OPCON'
Compute cruise fuel weight store in R01
Prompt for P<end>; Store in R37
Xeq 'FF' for max-end fuel flow rate
next page


Compute fuel weight for max-end flight segment; add to R_{ei}
Compute fuel flow for normal rated power (NRP)
Compute fuel weight for <NRP> flight segment add to R_{ei}; R_{ei} now contains total fuel wt., W_{tf}
Multiply W_{ex} by N; add to W_{tf}
Compute W_{tt}
display W_{tt}
Stop

4. Example Problem and User Instructions

Find the total weight of the installed engine plus fuel weight for the preliminary design of a helicopter under the following conditions:

WED = 400 lb	Operating Conditions:
Range = 350 nm	PA = 0
V<crus> = 100 kts; P<crus> = 531.87 shp	T = 59 F
V<end> = 58 kts; P<end> = 383.42 shp	

Note: If it has not already been done, execute program "FUELFL" now using the engine data included with the "FUELFL" sample problem.

a. Assume "POWER" will not be used:

Keystrokes:	Display:
(XEQ) (ALPHA) WEIGHT (ALPHA)	WED=?
400 (R/S)	WEI = 525.0
(R/S)	RANGE=?
350 (R/S)	V<CRUS>=?
100 (R/S)	POWER?
0 (R/S)	P<CRUS>=?
531.87 (R/S)	PA FT ?
0 (R/S)	T(F) ?
59 (R/S)	ZHI = 135.2
(R/S)	N = ?
2 (R/S)	PSHP = 685.46
(R/S)	WF = 511.90
	P<END>=?

383.42 (R/S)	WF = 445.67
	FL WT = 1930.37
(R/S)	WTT = 2980.37

b. If "POWER" is loaded and executed using the sample helicopter design data included as an example with the "POWER" user instructions, run "WEIGHT" again with the same engines and operating conditions.

Keystrokes:

(XEQ) (ALPHA) WEIGHT (ALPHA)	WED=?
400 (R/S)	WEI = 525.0
(R/S)	RANGE=?
350 (R/S)	V-CRUS=?
100 (R/S)	POWER?
1 (R/S)	PA=?
0 (R/S)	T(F)=?
59 (R/S)	PA FT ?
0 (R/S)	T(F) ?
59 (R/S)	ZHI = 135.2
(R/S)	N = ?
2 (R/S)	PSHP = 685.46
(R/S)	WF = 511.90
	V<END>=?
58(R/S)	WF = 445.67
	FL WT = 1930.36
(R/S)	WTT = 2980.36

5. Programs and Subroutines Used

"FUELFL" (entered at subroutine "OPCON" or "FF")

"POWER" (OPTIONAL)

6. Storage Register Utilization

Table VI shows specific storage register contents.

TABLE VI

Weight Storage Register Utilization

Storage Register		Stored Quantity
01	W_{tf}	- total fuel weight for mission profile (lb)
02	δ	- ratio of pressure to standard sea level pressure
03	$\sqrt{\theta}$	- square root of the ratio of absolute temperature to SSL absolute temperature
42	W_{EI}	- estimated engine installed weight (lb)

Note: programs "FUELFL" and "POWER" utilize registers 00-41. The quantities stored in registers 01-03 above are lost after the execution of "WEIGHT."

7. Program Listings

```
♦LBL "WEIGHT"
SF 03
"WED=?"
PROMPT
1.2
*
45
+
STO 42
"WEI="
ARCL X
AVIEW
STOP
"RANGE?"
PROMPT
"V-CRUS?"
PROMPT
STO 20
/
STO 01
1.68889
ST* 20
"POWER?"
PROMPT
X=0?
GTO 01
XEQ "DA"
XEQ "OPCON"
PSE
RCL 01
*
STO 01
"V-END?"
PROMPT
1.68889
*
STO 20
XEQ "PI"
GTO 02
♦LBL 01
"P(CRUS)?"
PROMPT
STO 37
XEQ "OPCON"
PSE
RCL 01
*
STO 01
"P(END)?"
PROMPT
STO 37
♦LBL 02
XEQ "FF"
PSE
.25
*
ST+ 01
RCL 04
RCL 40
*
RCL 41
+
RCL 38
*
.1
*
ST+ 01
CF 03
RCL 01
"FL WT="
ARCL X
AVIEW
STOP
RCL 42
RCL 40
*
+
"WTT="
ARCL X
AVIEW
END
```

APPENDIX D

FORTRAN ENGINE OPTIMIZER

This appendix contains an interactive computer program written to optimize the selection of a turboshaft engine for the preliminary design of a helicopter. The program is written in FORTRAN and implemented on the IBM 3033 computer. Optimization is accomplished by the selection of the powerplant which results in the minimum total weight of installed engine(s) and fuel for a specific mission profile. The mission profile used for calculation of fuel weight is taken from the Helicopter Design Manual by Stephen G. Kee [Ref. 1] and represents a typical design flight profile. Computation of fuel flow characteristics is based upon equations developed in Chapter 14 of [Ref. 22] but also include a 5 percent increase in the engine manufacturer's published fuel flow data. This procedure coincides with preliminary design criteria established for military helicopters [Ref. 2].

The program uses data which must first be generated by the user using the Helicopter Power Computation Package [Ref. 21]. This data provides rotor shaft horsepower required for the specific helicopter being designed.

This program accomplishes the same results as the programs developed for use on the hand-held calculator

(Appendix C), but it has three main advantages over those programs:

1. Much less computation time.
2. Neat, hard copy output.
3. Up to five engines may be compared and an optimum engine selected.

A. PURPOSE

The program allows the user to rapidly calculate the fuel flow rate of an engine (or engines) for any power setting (or velocity from hover to maximum velocity) desired, at any temperature and altitude up to 36,000 feet. The only engine performance data required from the user for these calculations are the standard sea level shaft horsepower available and fuel consumption at military, normal, and cruise power settings (Appendix B). The program also provides a method of engine selection based upon weight of installed engine and mission fuel. This optimization may then be used in conjunction with cost analysis to make a final selection of the powerplant to be used in the design.

B. INPUT REQUIRED

1. Specific fuel consumption and engine shaft horsepower available at standard sea level conditions at normal, military, and cruise power settings.
2. Manufacturer's engine dry weight in pounds.
3. Pressure altitude in feet and temperature in degrees fahrenheit.
4. Number of engines to be used in the helicopter design.

5. Required rotor shaft horsepower (RSHP) or velocity in knots for the RSHP at which the fuel flow rate is to be computed.

6. Design maximum range.

7. Design cruise velocity.

C. OUTPUT

See sample problem data output. Note: SFC are increased by 5 percent in the output data.

D. EXAMPLE PROBLEM AND USER INSTRUCTIONS

1. Input the basic helicopter design parameters using EXEC "HPLINK" (use of this EXEC file is quite simple and is explained in detail in [Ref. 21]). For this example use the following design parameters:

Main Rotor	Tail Rotor	Aircraft
C = 1.5 ft	C = 0.50 ft	L<tail> = 23.50 ft
R = 20.0 ft	R = 3.00 ft	W<gross> = 7,000 lbs
b = 4	b = 2	F.P.A.(FF) = 21.2
CdO = 0.01	CdO = 0.014	Vmax = 120 kts
RPM = 296	RPM = 1332	

Environmental: PA = 4000 ft

T = 95 F (design conditions)

The above procedure results in the creation of file "HPWRPIP DATA" on the user's disk. This file contains rotor power requirements in level flight for the helicopter being designed.

2. From CMS run program "FUELFLO" FORTRAN by typing:

Global Txtlib Fortmod2 Mod2eeh Nonimsl

Load FUELFLO (START

Note: No file definitions (FILEDEF) are necessary, the program defines read and write files internally.

3. Respond to interactive prompts written on the terminal screen. Use the following data:

--- Engine 1 ---

	SHP	SFC
Military	1561	.46
Normal	1310	.47
Cruise	989	.51

Dry Weight: 423 lb

Pressure altitude: 4000 ft

Temperature: 95 F

Number of engines in powerplant, N: 2

Select the velocity option (option 2) for determination of Rotor Shaft Horsepower Required (RSHP) for the fuel flow rate calculation; then use:

Velocity: 75 kts

Select "N" to skip computation for different conditions or engine.

Select "Y" to compute the mission fuel weight; use:

Range: 350 nm

Cruise Velocity: 100 kts

Select "Y" to compare a second engine; use the following data:

--- Engine 2 ---

	SHP	SFC
Military	1561	.46
Normal	1310	.47
Cruise	1000	.55

Dry Weight: 375 lb

Number of engines in powerplant, N: 2

Select "N" (No) to skip additional engine comparison. The optimum engine selection will be displayed and the program terminated.

4. Hard copy results will be available in file "FUELFLO DATA" which is created by the program onto the user's disk. A copy of this file is presented in paragraph F below.

E. ALGORITHM

Algorithm FUELFLO

Read helicopter design and power required data

Assign engine number

Write user instructions

Prompt for engine data

Prompt for engine SSL performance characteristics

Check SFC < 1.0

Reenter SFC if not < 1.0

Check SHP > 1.0

Reenter SHP if not > 1.0

Prompt for engine dry weight

Calculate slope of fuel flow line and the zero horsepower increment (SSL)

Call subroutine FUELSL

Output engine SSL data

Do if J = 1

Input PA and T

Calculate pressure and temperature ratios

Call PRATIO

Call TRATIO

End Do

Input number of engines to be used in the helicopter

Calculate zero horsepower intercept at operating conditions

Call ZHIALT

Calculate the zero velocity horsepower (Phantom SHP) at operating conditions.

Call ZVHP

If J = 1

Input rotor power requirement

RSHP directly

Else

Velocity at which RSHP desired

Check that PA and T are the same for power calculations as those at which the engine is being evaluated; if not print a caution message

Get RSHP from "HPWRPIP DATA"

Else use power required entered for engine 1

Calculate fuel flow rate at operating conditions

    Call FLOALT

Output fuel flow data

Give options for doing additional fuel flow calculations

    If desired, calculate fuel flow rate with different PA and T

    If desired, calculate fuel flow rate with a different engine

Calculate fuel weight for the mission profile

    If J = 1

        Input design maximum range

        Input design cruise velocity

    Else use range and cruise velocity previously entered

    Read cruise power required from "HPWRPIP DATA"

    Calculate maximum endurance velocity and rotor power required

        Call MAXEND

    Calculate the zero horsepower intercept at the conditions used for power required calculations

        Call PRATIO

        Call TRATIO

        Call ZHIALT

    Calculate the zero velocity shaft horsepower (phantom SHP)

        Call ZVSHP

```
Calculate fuel flow rates at cruise and maximum
endurance velocities and at normal rated power
    Compute fuel flow rate using normal rated
    power required
        Call FLOALT using cruise power required
        Call FLOALT using max endurance power required
    Calculate total fuel weight
        Call FUELW8 (Fuelwt)
    Calculate estimated installed engine weight
        Call ENGWT (W_EI)
    Calculate total weight of powerplant plus mission
    fuel
        W_tt = n(W_EI) + Fuelwt
Output mission profile data
If J<5
    Give option to try another engine
        If yes
            Return above and prompt for engine data
            Run through program again
        Else continue
If J>1
    Determine the powerplant with the minimum total
    weight of engines plus fuel
    Output recommendation for engine selection
End FUELFLO
```

F. PROGRAM RESULTS

```
************ ENGINE FUEL FLOW AND OPTIMIZATION ************


--------------- ENGINE 1 DATA ---------------
               SHP                  SFC
  MILITARY     1561.00              0.4830
  NORMAL       1310.00              0.4935
  CRUISE        989.00              0.5355

  DRY WEIGHT:    423.0 LBS
  BETA: 0.3948
  ALPHA:   135.32 LB/HR

          ------- FUEL FLOW RATE -------
  PA:   4000.0 FT                      N:  2
  TEMP:      95.0 F                    PSHP:      612.21 SHP
  ZHI:  120.86 LB/HR                   RSHP:      385.70 SHP
          FUEL FLOW RATE:    417.76 LB/HR


  ---------- MISSION PROFILE CONDITIONS -------------
  PA:           4000. FT        TEMP:                    95. F
  MAX RANGE:    350.00 NM
  CRUISE VEL:   100 KTS         CRUISE PWR REQD:    471.20 SHP
  MAX END VEL:  65 KTS          MAX END PWR REQD:   377.30 SHP

  INSTALLED ENGINE WEIGHT <EA>:    552.60 LB
  FUEL WEIGHT:  1826.80 LB
  WEIGHT OF INSTALLED POWERPLANT 1 AND FUEL:    2932.00 LB
```

--------------- ENGINE 2 DATA ---------------

	SHP	SFC
MILITARY	1561.00	0.4830
NORMAL	1310.00	0.4935
CRUISE	1000.00	0.5775

DRY WEIGHT: 375.0 LBS

BETA: 0.3218

ALPHA: 244.14 LB/HR

------- FUEL FLOW RATE -------

PA: 4000.0 FT   N: 2

TEMP: 95.0 F   PSHP: 1355.34 SHP

ZHI: 218.05 LB/HR   RSHP: 385.70 SHP

FUEL FLOW RATE: 579.55 LB/HR

---------- MISSION PROFILE CONDITIONS -------------

PA: 4000. FT   TEMP: 95. F

MAX RANGE: 350.00 NM

CRUISE VEL: 100 KTS   CRUISE PWR REQD: 471.20 SHP

MAX END VEL: 65 KTS   MAX END PWR REQD: 377.30 SHP

INSTALLED ENGINE WEIGHT <EA>: 495.00 LB

FUEL WEIGHT: 2409.25 LB

WEIGHT OF INSTALLED POWERPLANT 2 AND FUEL: 3399.25 LB

RECOMMEND ENGINE 1 BE SELECTED

G. COMPUTER PROGRAM

```
C**********************************************************************
C**********************************************************************
C***********                                                ***********
C*********     HELO DESIGN ENGINE FUEL FLOW CHARACTERISTICS    *********
C*********          AND ENGINE SELECTION OPTIMIZATION          *********
C*********                                                     *********
C*********                                                     *********
C*********    THIS PROGRAM IS DESIGNED TO CALCULATE ENGINE     *********
C*********    FUEL FLOW CHARACTERISTICS AND TO OPTIMIZE        *********
C*********    THE SELECTION OF A POWERPLANT BASED UPON THE     *********
C*********    INSTALLED ENGINE WEIGHT AND TOTAL FUEL WEIGHT    *********
C*********    FOR THE DESIGN MISSION PROFILE FOR THE BASIC     *********
C*********            DESIGN OF A HELICOPTER.                  *********
C*********                MAY 1, 1983                          *********
C***********                                                ***********
C**********************************************************************
C**********************************************************************
C****                                                              *****
C**                          NOMENCLATURE                           ***
C*                                                                   **
C*    VARIABLES:                                                     **
C*                                                                   **
C*    ALPHA    AVG ZERO SHP FUEL FLOW                                **
C*    BETA     SLOPE OF WF VS. SHP LINE                              **
C*    CM       MAIN ROTOR CHORD                                      **
C*    CT       TAIL ROTOR CHORD                                      **
C*    DELTA    RATIO OF PRESSURE AT ALT. TO PRESSURE AT S.L.         **
C*    DIFF     DIFFERENCE BTWN PA FOR ENGINE AND PA FOR PWR REQ      **
C*    DIFF1    DIFFERENCE BTWN TEMP FOR ENGINE AND TEMP FOR PWR REQ  **
C*    DM       MAIN ROTOR COEF OF DRAG                               **
C*    DT       TAIL ROTOR COEF OF DRAG                               **
C*    FUELWT   TOTAL WEIGHT OF FUEL FOR MISSION PROFILE              **
C*    GW       GROSS WEIGHT                                          **
C*    LT       LENGTH FROM CG TO HUB OF TAIL ROTOR                   **
C*    PAFT     PRESSURE ALTITUDE IN FEET                             **
C*    PEND     TOTAL POWER REQUIRED AT MAX ENDURANCE VELOCITY        **
C*    PSHP     PHANTOM SHAFT HORSE POWER                             **
C*    PWRC     TOTAL POWER REQUIRED AT CRUISE VELOCITY               **
C*    PWR      TOTAL POWER REQUIRED                                  **
C*    PWRM     TOTAL POWER REQUIRED BY MAIN ROTOR                    **
C*    PWRT     TOTAL POWER REQUIRED BY TAIL ROTOR                    **
C*    PWRI     INDUCED POWER                                         **
C*    PWRIM    INDUCED POWER, MAIN ROTOR                             **
C*    PWRIT    INDUCED POWER, TAIL ROTOR                             **
C*    PWRO     PROFILE POWER                                         **
C*    PWROM    PROFILE POWER, MAIN ROTOR                             **
C*    PWROT    PROFILE POWER, TAIL ROTOR                             **
```

```
C*      PWRP      PARASITE POWER                                          **
C*      RM        MAIN ROTOR RADIUS                                       **
C*      RSHP      REQUIRED ROTOR SHP                                      **
C*      RSHPMX    MAX RSHP                                                **
C*      RT        TAIL ROTOR RADIUS                                       **
C*      SFC       SPECIFIC FUEL CONSUMPTION: LB/HR/SHP                    **
C*      SHP       ENGINE SHAFT HORSEPOWER                                 **
C*      STHETA    SQR ROOT OF RATIO OF TEMP. AT ALT TO TEMP AT S.L.       **
C*      SM        MAIN ROTOR RPM                                          **
C*      ST        TAIL ROTOR RPM                                          **
C*      T         TEMP AT ALT. IN DEGREES FAHRENHEIT                      **
C*      VEND      MAX ENDURANCE VELOCITY                                  **
C*      VFK       FORWARD VELOCITY OF THE AIRCRAFT, KNOTS                 **
C*      VMR       MAX RANGE VELOCITY                                      **
C*      VR        INPUT VELOCITY                                          **
C*      WEDRY     MANUFACTURER'S DRY ENGINE WEIGHT                        **
C*      WEI       ESTIMATED INSTALLED WEIGHT OF ONE ENGINE                **
C*      WF        FUEL FLOW RATE AT KNOWN CONDITIONS                      **
C*      WFSL      FUEL FLOW RATE AT SEA LEVEL                             **
C*      WFALT     FUEL FLOW RATE AT ALT.                                  **
C*      WFA       FUEL FLOW RATE AT NORMAL RATED POWER                    **
C*      WFB       FUEL FLOW RATE AT CRUISE POWER                          **
C*      WFC       FUEL FLOW RATE AT MAX ENDURANCE POWER                   **
C*      WTOT      TOTAL WEIGHT OF POWERPLANT AND FUEL WEIGHT              **
C*      ZHI       ZERO SHP FUEL FLOW                                      **
C*      ZHIX      ZERO SHP FUEL FLOW AT DESIRED ALT. AND TEMP.            **
C*                                                                        **
C*      INTEGERS:                                                         **
C*                                                                        **
C*      J         ENGINE NUMBER                                           **
C*      LRESP     LOGICAL CONSTANT USED FOR INTERACTIVE RESPONSES         **
C*      LRESP1    LOGICAL CONSTANT USED FOR INTERACTIVE RESPONSES         **
C*      N         NUMBER OF ENGINES                                       **
C*      NM        MAIN ROTOR BLADES                                       **
C*      NUM       OPTIMUM ENGINE SELECTED                                 **
C*      NORY      LOGICAL VARIABLE USED FOR INTERACTIVE RESPONSES         **
C*      NT        TAIL ROTOR BLADES                                       **
C*      VCRUS     SPECIFICATION CRUISE VELOCITY: KTS                      **
C*      VEND      MAXIMUM ENDURANCE VELOCITY: KTS                         **
C*      VINC      INCREMENT OF FORWARD SPEED FOR PRINT OUT                **
C*      VMAX      MAXIMUM FORWARD VELOCIITY OF THE AIRCRAFT               **
C*                                                                        **
C****                                                                  *****
C**************************************************************************
```

```
C---------------- DECLARE VARIABLES ------------------------------------
      REAL BETA,DELTA,FUELWT,PSHP,RSHPMX,PAFT,SFCI(3),SHPI(3),STHETA,T,W
     1EDRY,WPA,WPB,WFC,WFSI,WPALT,ALPHA,ZHI(3),ZHIX,SFC(3),SHP(3),WTOT(5
     2),PWR,PWRM,PWRT,PWRI,PWRIM,PWRIT,PWRO,PWROM,PWROT,PWRP,VPK,VEND,DP
     3,PA,TF,FA,LT,SM,RM,DM,CM,ST,RT,DT,CT,PEND
C
      DIMENSION PWR(200),PWRM(200),PWRT(200),PWRI(200),PWRIM(200),PWRIT(
     1200),PWRO(200),PWRCM(200),PWROT(200),PWRP(200),PWRPM(200),VPK(200)
C
      INTEGER I,J,K,N,IRESP,LRESP1,NORY,VCRUS,VINC,VMAX,VCNT,VMAX,NM,NT,
     1VR
C
      DATA LRESP/'Y'/,LRESP1/'Q'/
C
C
C---------------- DEFINE FILES ---------------------------------
      CALL FRTCMS ('FILEDEF ','4         ','DISK     ','HPWRPIP ',
     1            'DATA    ','A         ')
C
C     WRITE HEADING
C
      WRITE (8,350)
C
C
C---------- READ DATA FRCM FILE: HPWRPIP DATA A -------------------
      READ (4,360) GW,PA,TF,FA,IT,VMAX,VINC
      READ (4,370) SM,RM,DM,CM,NM
      READ (4,370) ST,RT,DT,CT,NT
      READ (4,380) VCNT
      DO 10 I=1,VCNT
      K=I-1
      READ (4,390) K,VPK(I),PWR(I),PWRM(I),PWRT(I),PWRI(I),PWRO(I),PWRP(
     1I),PWRIM(I),PWRIT(I),PWROM(I),PWROT(I)
C
10    CONTINUE
      J=1
C
C
C----------------- WRITE USER INSTRUCTIONS -------------------------
      CALL FRTCMS ('CLRSCRN')
      WRITE (6,400)
      WRITE (6,410)
C
      WRITE (6,420)
      READ (5,430) NORY
C
      IF (.NOT.(NORY.EQ.IRESP)) GO TO 340
C
```

```
      CALL PRTCMS ('CLRSCRN')
      WRITE (6,440)
C
      READ (5,450) NORY
C
      IF (.NOT.(NORY.EQ.LRESP)) GO TO 340
C
20    CONTINUE
C
C
C------------------ PROMPT FOR ENGINE DATA --------------------------
      CALL PRTCMS ('CLRSCRN')
30    CONTINUE
      WRITE (6,460)
C
      READ (5,*) SFCI(1)
C
C     CHECK TO INSURE SFC < 1.0; IF NOT TRY AGAIN
C
      IF (SFCI(1).LE.1.0) GO TO 40
      WRITE (6,520)
      GO TO 30
40    CONTINUE
50    CONTINUE
      WRITE (6,470)
C
      READ (5,*) SHPI(1)
C
C     CHECK TO INSURE SHP > 1.0; IF NOT TRY AGAIN
C
      IF (SHPI(1).GE.1.0) GO TO 60
      WRITE (6,530)
      GO TO 50
60    CONTINUE
70    CONTINUE
      WRITE (6,480)
C
      READ (5,*) SFCI(2)
C
C     CHECK TO INSURE SFC < 1.0; IF NOT TRY AGAIN
C
      IF (SFCI(2).LE.1.0) GO TO 80
      WRITE (6,520)
      GO TO 70
80    CONTINUE
90    CONTINUE
      WRITE (6,490)
```

```
C
      READ (5,*) SHPI(2)
C
C     CHECK TO INSURE SHP > 1.0; IF NOT TRY AGAIN
C
      IF (SHPI(2).GE.1.0) GO TO 100
      WRITE (6,530)
      GO TO 90
100   CONTINUE
110   CONTINUE
      WRITE (6,500)
C
C
      READ (5,*) SFCI(3)
C
C     CHECK TO INSURE SFC < 1.0; IF NOT TRY AGAIN
C
      IF (SFCI(3).LE.1.0) GO TO 120
      WRITE (6,520)
      GO TO 110
120   CONTINUE
130   CONTINUE
      WRITE (6,510)
C
      READ (5,*) SHPI(3)
C
C     CHECK TO INSURE SHP > 1.0; IF NOT TRY AGAIN
C
      IF (SHPI(3).GE.1.0) GO TO 140
      WRITE (6,530)
      GO TO 130
140   CONTINUE
C
      WRITE (6,540)
C
C
      READ (5,*) WEDRY
C
C
C--------CALCULATE FUEL FLOW RATE AT GIVEN CONDITIONS --------------
      CALL FUELSL (SHPI,SFCI,BETA,ALPHA)
C
C
      CALL PRTCMS ('CLRSCRN')
      WRITE (6,550) EETA
C
      WRITE (6,560) ALPHA
```

```
C
C
C-------------------PRINT ENGINE DATA----------------------------
C      WRITE HEADING
C
       IF (J.GT.1) WRITE (8,570)
C
       WRITE (8,580) J
C
       WRITE (8,590) SHPI(1),SPCI(1)
       WRITE (8,600) SHPI(2),SPCI(2)
       WRITE (8,610) SHPI(3),SPCI(3)
C
       WRITE (8,620) WEDRY,BETA,ALPHA
C
C
C      FOR SUSEQUENT ENGINES USE THE SAME PRESSURE ALTITUDE AND
C      TEMPERATURE AS THOSE USED FOR ENGINE 1.
C
       IF (.NOT.(J.EQ.1)) GO TO 160
C
C
C-----------INPUT DESIRED CONDITIONS---------------------------------
       WRITE (6,630)
C
       READ (5,640) NORY
       IF (.NOT.(NORY.EQ.IRESP)) GO TO 340
C
       CALL FRTCMS ('CLRSCRN')
C
150    CONTINUE
       WRITE (6,650)
C
       READ (5,*) PAFT
C
       WRITE (6,660)
C
       READ (5,*) T
C
160    CONTINUE
C      CALCULATE PRESSURE RATIO,TEMP RATIO, AND ZERO SHP INCREMENT
C
       CALL PRATIO (PAFT,DELTA)
       CALL TRATIO (T,STHETA)
       CALL ZHIALT (ALPHA,DELTA,STHETA,ZHIX)
C
       WRITE (6,670) PAFT,T,ZHIX
C
```

```
C
C----------- FROMPT FOR NUMBER OF ENGINES AND CALCULATE PSHP-----------
      CALL FRTCMS ('CLSCRN')
      WRITE (6,680)
C
      READ (5,*) N
C
      CALL ZVSHP (ZHIX,EETA,N,PSHP)
      WRITE (6,690) PSHP
C
170   CONTINUE
C
C
C-------------- CALCULATE FUEL FLOW RATE ----------------------------
C  ** SUBSEQUENT ENGINE CCMPARISONS WILL BE MADE ONLY AT THE FINAL     **
C  ** ROTOR SHP REQUIRED ENTERED FOR ENGINE 1 AS WELL AS AT THE DESIGN**
C  ** MISSION FROFILE OPERATING CONCITIONS.                            **
      IF (J.EQ.1) GO TO 200
C
C     ELSE CALCULATE FUEL FLOW RATE FOR ENGINE J AT LAST ROTOR SHP
C     REQUIRED ENTERED FCR ENGINE 1
C
      CALL FLOALT (RSHPMX,EETA,N,PSHP,WFALT)
      WRITE (8,730)
      WRITE (8,740) PAFT,N,T,PSHP,ZHIX,RSHPMX,WFALT
C
C     CHECK PA AND T FOR POWER REQUIRED CALCULATIONS; PRINT A CAUTION
C     MESSAGE IF EITHER IS NOT THE SAME AS SPECIFIED BY THE USER FOR
C     FUEL FLOW CALCULATIONS.
C
      DIFF=ABS(PA-PAFT)
      DIFF1=ABS(TF-T)
      IF (DIFF.LT.1.0) GC TO 180
      WRITE (6,750)
      WRITE (8,750)
180   CONTINUE
      IF (DIFF1.LT.1.0) GO TO 190
      WRITE (6,760)
      WRITE (8,760)
190   CONTINUE
C
      GO TO 270
200   CONTINUE
C
C
```

```
C------------ WRITE CPTICNS FOR CALCULATION OF FUEL FLOW RATE ----------
      WRITE (6,700)
C
      READ (5,*) M
      IF (M.EQ.3) GO TO 340
      IF (M.EQ.1) GO TO 210
      WRITE (6,710)
      READ (5,*) VR
      RSHPMX=PWR(VR+1)
      GO TO 220
210   CONTINUE
      WRITE (6,720)
      READ (5,*) RSHPMX
220   CONTINUE
C
C
C------------------- CALCULATE FUEL FLOW RATE --------------------------
      CALL FLOALT (RSHPMX,BETA,N,PSHP,WFALT)
C
      CALL FRTCMS ('CLRSCRN')
C
C
C-------------------- PRINT FUEL FLCW DATA ----------------------------
      WRITE (6,730)
      WRITE (8,730)
      WRITE (6,740) PAFT,N,T,PSHP,ZHIX,RSHPMX,WFALT
      WRITE (8,740) PAFT,N,T,PSHP,ZHIX,RSHPMX,WFALT
C
C
C    **CHECK PA AND T FOR POWER REQUIRED CALCULATIONS; PRINT A CAUTION**
C    **MESSAGE IF EITHER IS NOT THE SAME AS SPECIFIED BY THE USER FOR  **
C    **FUEL FLOW CALCULATIONS.                                         **
      DIFF=ABS(PA-PAFT)
      DIFF1=ABS(TF-T)
      IF (DIFF.LT.1.0) GC TO 230
      WRITE (6,750)
      WRITE (8,750)
230   CONTINUE
      IF (DIFF1.LT.1.0) GO TO 240
      WRITE (6,760)
      WRITE (8,760)
240   CONTINUE
C
      WRITE (6,770)
C
C
```

```
C------ WRITE CPTIONS FCR LOING ADDITIONAL FUEL FLOW CALCULATIONS ------
C
      READ (5,780) NCRY
C
      IF (.NOT.(NORY.EC.IRESP)) GO TO 250
      GO TO 150
250   CONTINUE
      IF (NORY.EQ.LRESP1) GO TO 340
C
      WRITE (6,790)
C
      READ (5,800) NORY
C
      IF (.NOT.(NORY.EQ.IRESP)) GO TO 260
      GC TO 170
260   CONTINUE
      IF (NORY.EQ.LRESP1) GO TO 340
C
270   CONTINUE
C
C
C     FOR SUSEQUENT ENGINE COMPARISCNS, USE THE DESIGN MISSION PROFILE
C
      IF (.NOT.(J.EQ.1)) GC TO 280
C
C
C-----------CALCULATE FUEL WEIGHT FOR MISSION PROFILE-----------------
      WRITE (6,810)
C
C
      READ (5,820) NORY
C
      IF (NORY.EQ.LRESP1) GO TO 340
      IF (.NOT.(NORY.EQ.IRESP)) GO TO 290
C
C
C
C     ---- PROMPT FOR RANGE AND CRUISE VELOCITY ----
C
C
      WRITE (6,830)
C
      READ (5,*) RNGE
C
      WRITE (6,840)
C
      READ (5,*) VCRUS
```

```
C
C
C---- CALCULATE V-MAX ENDURANCE AND RSHP FOR  V-MAX ENDURANCE ----
      CALL MAXEND (PWR,VFK,VCRUS,VMAX,PWRC,PEND,VEND)
C
280   CONTINUE
C
C
C---- CALCULATE TOTAL WEIGHT OF ENGINE AND FUEL------------------------
C--------------- CALCULATE  ZERO HORSEPOWER INCREMENT -----------------
C             AT CONDITIONS USED FOR POWER REQUIRED CALCULATIONS ----------
      CALL PRATIO (PA,DELTA)
      CALL TRATIO (TF,STHETA)
      CALL ZHIALT (ALPHA,DELTA,STHETA,ZHIX)
C
C
C-----CALCULATE ZERO VELOCITY HORSEPOWER (PHANTOM SHAFT HORSEPOWER)-----
      CALL ZVSHP (ZHIX,EETA,N,PSHP)
C
C
C-----CALCULATE FUEL FLOW RATES -----------------------------------------
      WFA=(FLOAT(N)*SHPI(2) + PSHP)*EETA
      CALL FLOALT (PWRC,BETA,N,PSHP,WFB)
      CALL FLOALT (PEND,EETA,N,PSHP,WFC)
C
C
C-----CALCULATE TOTAL FUEL WEIGHT----------------------------------------
      CALL FUELW8 (RNGE,VCRUS,WFA,WFB,WFC,FUELWT)
C
C
C-----CALCULATE ESTIMATED INSTALLED ENGINE WEIGHT------------------------
      CALL ENGWT (WEDRY,WEI)
C
C
C-----CALCULATE TOTAL WEIGHT OF ENGINE AND FUEL
      WTOT(J)=FLOAT(N)*WEI+FUELWT
C
C
C---------------PRINT MISSION PROFILE DATA--------------------------
      WRITE (6,850) PA,TF,RNGE,VCRUS,PWRC,VEND,PEND
      WRITE (8,850) PA,TF,RNGE,VCRUS,PWRC,VEND,PEND
C
      WRITE (6,860) WEI,FUELWT,J,WTCT(J)
      WRITE (8,860) WEI,FUELWT,J,WTCT(J)
C
290   CONTINUE
C
```

```
C
C---------------- GIVE CPTION TO TRY ANOTHER ENGINE ----------------
      WRITE (6,870)
C
      READ (5,880) NCRY
C
      IF (.NOT.(NORY.EQ.LRESP)) GO TO 300
      J=J+1
C
C        RETURN ABOVE TC INPUT NEW ENGINE DATA
C
      GO TO 20
300   CONTINUE
      IF (NORY.EQ.LRESP1) GO TO 340
C
C
C-------------- DETERMINE OPTIMUM ENGINE SELECTION -------------------
      IF (.NOT.(J.GT.1)) GO TO 330
      MINWT=WTCT(1)
      NUM=1
      DO 320 I=2,J
      IF (.NOT.(WTOT(I).LT.WTOT(I-1))) GO TO 310
      MINWT=WTCT(I)
      NUM=I
310   CONTINUE
320   CONTINUE
C
      WRITE (6,890) NUM
      WRITE (8,890) NUM
C
330   CONTINUE
C
340   CONTINUE
C
      STOP
350   FORMAT (1X,48H************* ENGINE FUEL FLOW AND OPTIMIZATION *,11H
     1***********///)
360   FORMAT (F10.2,F9.2,F8.1,F8.2,F8.2,I5,I5)
370   FORMAT (F8.3,F8.2,F8.4,F8.3,I5)
380   FORMAT (I4)
390   FORMAT (1H ,I5,F4.C,10F7.1)
400   FORMAT (/5X,52HTHIS PROGRAM CCMPUTES FUEL FLOW AND FUEL WEIGHT DAT
     1A,17H USING USER INPUT,/,39H VALUES OF ENGINE PERFORMANCE CHARACTE
     2R,32HISTICS FOR A SELECTED TURBOSHAFT,/,21H ENGINE. THE PROGRAM ,4
     32HUSES POWER REQUIRED DATA FOR A PRELIMINARY,/,12H HELICOPTER ,53H
     4DESIGN PREVIOUSLY CALCULATED AND STORED IN DATA FILE ,/1X,59HHPWRP
     5IP. THIS DATA FILE MUST BE RESIDING ON THE USERS DISK ,/1X,43HIF F
     6UEL WEIGHT CALCULATICNS ARE TO BE MADE.)
```

```
410   FORMAT (/5X,44HTHE PROGRAM HAS FOUR COMPUTATIONAL SEGMENTS:,/2X,34  A5150
     1H1. CALCULATION OF ENGINE FUEL FLOW,45H CHARACTERISTICS USING INPU  A5160
     2T VALUES OF ENGINE,/2X,58HSSL SPECIFIC FUEL CONSUMPTION AND SHAFT   A5170
     3HORSEPOWER AVAILAB,11HLE AT THREE,/2X,15HPOWER SETTINGS.,/2X,21H2.  A5180
     4 CALCULATION OF THE,48H FUEL FLOW RATE AT A SPECIFIED VALUE OF REQ  A5190
     5UIRED,/2X,5H ROTO,19HR SHAFT HORSEPOWER.,/2X,35H3. CALCULATION OF   A5200
     6THE ESTIMATED ENG,39HINE INSTALLED WEIGHT AND THE TOTAL FUEL,/2X,1  A5210
     76HWEIGHT FOR A DES,20HIGN MISSION PROFILE.,/2X,35H4. CALCULATION O  A5220
     8F ESTIMATED ENGINE ,35HINSTALLED WEIGHT AND THE TOTAL FUEL,/2X,20H  A5230
     9WEIGHT FCR UP TO FIV,53HE ENGINES. THE ENGINE WITH THE MINIMUM RES  A5240
     $ULTING FUEL,4H AND,/2X,49HPOWERPLANT WEIGHT IS THEN RECOMMENDED AS  A5250
     $ OPTIMUM ,26HFCR USE IN THE HELICOPTER.,//5X,29HPROGRAM OUTPUT IS   A5260
     $WRITTEN BOT,38HH TC THE TERMINAL AND TO FILE -FUELFLO,/2X,10H LIST  A5270
     $ING- ,50H WHICH IS CREATED BY THE PROGRAM ON THE USER DISK.)        A5280
420   FORMAT (1H1,51HTHROUGHOUT THE PROGRAM, ENTER ONE OF THE FOLLOWING   A5290
     1,/1X,41HRESPONSES TO CONTINUE PROGRAM EXECUTION :,/1X,6HY: YES,/1X  A5300
     2,5HN: NO,/1X,7HQ: CUIT,//1X,32HNOW ENTER Y TO CONTINUE OR Q TO ,/1  A5310
     3X,4HQUIT)                                                           A5320
430   FORMAT (A1)                                                         A5330
440   FORMAT (1H1,48HTHIS SEGMENT OF THE PROGRAM CALCULATES THE FUEL ,/1  A5340
     1X,60HFLOW CARACTERISTICS FOR A TURBOSHAFT ENGINE OPERATING IN THE,  A5350
     2/1X,29HTROPOSPHERE --BELOW 36000 FT: ,//1X,23HREQUIRED INPUT DATA I A5360
     3S:,//1X,55H    (1) SHP AND SFC AT NORMAL,MILITARY,AND CRUISE POWER  A5370
     4,/1X,41H    (2) DESIRED PRESSURE ALTITUDE IN FEET ,/1X,41H   (3) DE A5380
     5SIRED TEMPERATURE IN DEGREES F. ,/1X,33H    (4) ENGINE DRY WEIGHT I A5390
     6N LBS. //1X,11HENTER Y TO ,21HCONTINUE OR Q TO QUIT)                A5400
450   FORMAT (A1)                                                         A5410
460   FORMAT (1H ,36HENTER SFC FOR MILITARY POWER SETTING)                A5420
470   FORMAT (1H ,36HENTER SHP FOR MILITARY POWER SETTING)                A5430
480   FORMAT (1H ,34HENTER SFC FOR NORMAL POWER SETTING)                  A5440
490   FORMAT (1H ,34HENTER SHP FOR NORMAL POWER SETTING)                  A5450
500   FORMAT (1H ,34HENTER SFC FOR CRUISE POWER SETTING)                  A5460
510   FORMAT (1H ,34HENTER SHP FOR CRUISE POWER SETTING)                  A5470
520   FORMAT (//2X,38HTRY AGAIN, SFC SHOULD BE LESS THAN 1.0//)           A5480
530   FORMAT (//2X,41HTRY AGAIN, SHP SHOULD BE GREATER THAN 1.0//)        A5490
540   FORMAT (1H1,23HENTER ENGINE DRY WEIGHT)                             A5500
550   FORMAT (1X,10H   BETA =  ,F8.5/)                                    A5510
560   FORMAT (//2X,8HALPHA = ,F10.4,4H SHP///)                            A5520
570   FORMAT (1H1)                                                        A5530
580   FORMAT (1X,//23H-------------- ENGINE ,I1,22H DATA -------------    A5540
     1--//,16X,3HSHP,15X,3HSFC/)                                          A5550
590   FORMAT (2X,12HMILITARY    ,F8.2,10X,F8.4/)                          A5560
600   FORMAT (2X,12HNORMAL      ,F8.2,10X,F8.4/)                          A5570
610   FORMAT (2X,12HCRUISE      ,F8.2,10X,F8.4/)                          A5580
620   FORMAT (/2X,12HDRY WEIGHT: ,F8.1,4H LBS,//2X,6HBETA: ,F6.4,//2X,1H  A5590
     1A,6HLPHA: ,F8.2,6H LB/HR///)                                        A5600
```

```
630   FORMAT (//7X,45HTHE PROGRAM CAN NOW CALCULATE THE ZERO SHAFT-,/2X,
     145HHORSEPOWER INCREMENT AT ANY DESIRED PRESSURE ,/2X,41HALTITUDE A
     2ND TEMPERATURE UP TO 36,000 FT.,//2X,6HENTER ,27HY TO CONTINUE OR
     3Q TO QUIT.)
640   FORMAT (A1)
650   FORMAT (2X,31HENTER PRESSURE ALTITUDE IN FEET//)
660   FORMAT (//2X,31HENTER TEMPERATURE IN DEGREES F.)
670   FORMAT (//2X,41HTHE ZERO SHP INCREMENT FOR THIS ENGINE AT,//5X,7HP
     1.A. = ,F8.2,4H FT.,//5X,7HTEMP = ,F8.2,//5X,3HIS ,F10.2,6H LB/HR//
     2/)
680   FORMAT (2X,45HTO CALCULATE THE PHANTOM HORSEPOWER FOR THESE,/51H C
     1ONDITIONS ENTER THE NUMBER OF ENGINES BEING USED://)
690   FORMAT (//2X,14HPHANTOM SHP = ,F10.2,3H HP///)
700   FORMAT (5X,52HTHE PROGRAM CAN NOW CALCULATE THE FUEL FLOW RATE FOR
     1,/59H THIS POWER PLANT AT ANY DESIRED VALUE OF ROTOR SHAFT HORSE,/
     251H POWER REQUIRED<RSHP>. THE USER HAS THREE OPTIONS: ,//2X,2H1.,2
     31H INPUT RSHP DIRECTLY.,/2X,32H2. INPUT THE VELOCITY AT WHICH T,19
     4HHE RSHP IS DESIRED.,/2X,34HTHE PROGRAM WILL READ THE APPROPRI,25H
     5ATE POWER FROM DATA FILE ,/2X,8HHPWRPIP.,/2X,14HNOTE! THIS FIL,40H
     6E MUST ALREADY RESIDE ON THE USERS DISK.,/2X,8H3. QUIT.,//5X,15HEN
     7TER 1,2, OR 3)
710   FORMAT (1X,32HENTER FORWARD VELOCITY IN KNOTS.)
720   FORMAT (1X,38HENTER ROTOR SHAFT HORSEPOWER REQUIRED.)
730   FORMAT (10X,30H------- FUEL FLOW RATE -------/)
740   FORMAT (2X,4HPA: ,F8.1,3H FT,20X,3HN: ,I2,//2X,7HTEMP: ,F7.1,2H F
     1,19X,6HPSHP: ,F10.2,4H SHP,//2X,4HZHI: ,F8.2,6H LB/HR,17X,2HRS,4HHP
     2: ,F10.2,4H SHP,//10X,15HFUEL FLOW RATE: ,F10.2,6H LB/HR//)
750   FORMAT (//1X,48HCAUTION: ALTITUDE FOR ENGINE FUEL FLOW RATE IS N,1
     11HOT THE SAME,/1X,36HAS THE ALTITUDE AT WHICH POWER REQUI,18HRED W
     2AS CALCULATED/)
760   FORMAT (//1X,48HCAUTION: TEMPERATURE FOR ENGINE FUEL FLOW RATE I,1
     14HS NOT THE SAME,/1X,31HAS THE ALTITUDE AT WHICH POWER ,23HREQUIRE
     2D WAS CALCULATED/)
770   FORMAT (2X,53HDO YOU WANT TO TRY THE SAME ENGINE AT NEW CONDITIONS
     1?,//,5X,8HY,N,OR Q)
780   FORMAT (A1)
790   FORMAT (2X,40HDO YOU WANT TO TRY THE SAME ENGINE AT A ,28HDIFFEREN
     1T POWER REQUIREMENT?,//,5X,8HY,N,OR Q)
800   FORMAT (A1)
810   FORMAT (/2X,44HTHE MISSION PROFILE SPECIFIED FOR THE DESIGN,26H OF
     1 A BASIC HELICOPTER IS:////,5X,21H1. 5 MINUTES @ NORMAL,13H RATED
     2POWER./,5X,35H2. TIME TO FLY THE MAXIMUM RANGE AT,17H CRUISE VELOC
     3ITY./,5X,34H3. 5 MINUTES @ NORMAL RATED POWER./,5X,43H4. 15 MINUTE
     4S @ MAXIMUM ENDURANCE VELOCITY.///,2X,46HDO YOU WANT TO CALCULATE
     5THE TOTAL FUEL WEIGHT,35H FOR THE SPECIFIED MISSION PROFILE?,//5X,
     68HY N,OR Q)
820   FORMAT (A1)
```

```
830   FORMAT (2X,48HENTER SPECIFIED MAXIMUM RANGE IN NAUTICAL MILES.//)
840   FORMAT (//2X,42HENTER SPECIFIED CRUISE VELOCITY IN KNOTS. )
850   FORMAT (//2X,51H---------- MISSION PROFILE CONDITIONS ------------
     1-,//2X,3HPA:,8X,F6.0,3H FT,8X,5HTEMP:,13X,F6.0,2H F,//2X,10HMAX RA
     2NGE:,1X,F8.2,3H NM,//2X,11HCRUISE VEL:,1X,I4,4H KTS,8X,16HCRUISE P
     3WR REQD:,2X,F8.2,4H SHP,//2X,12HMAX END VEL:,1X,I3,4H KTS,8X,17HMA
     4X END PWR REQD:,1X,F8.2,4H SHP//)
860   FORMAT (2X,30HINSTALLED ENGINE WEIGHT <EA>: ,F8.2,3H LB,//2X,4HFUE
     1L,9H WEIGHT:  ,F8.2,3H LB,//2X,29HWEIGHT OF INSTALLED POWERPLAN,2HT
     2 ,I1,11H AND FUEL: ,F10.2,3H LB,///)
870   FORMAT (2X,38HDO YOU WANT TO CCMPARE ANOTHER ENGINE?,//,5X,6HY OR
     1N)
880   FORMAT (A1)
890   FORMAT (2X,17HRECCMMEND ENGINE ,I1,12H BE SELECTED)
      END
C***********************************************************************
C**                           SUBROUTINES                             **
C***********************************************************************
C-----------------------------------------------------------------------
C  SUBROUTINE FUELSL: CALCULATES SLOPE OF FUELFLOW LINE AND THE
C                     SSI ZERO HORSEPOWER INCREMENT.
C-----------------------------------------------------------------------
C
      SUBROUTINE FUELSL (SHP,SFC,BETA,ALPHA)
C
      REAL SHP(3),SFC(3),WF(3),ZHI(3),BETA,ALPHA,BETA1,BETA2,BETA3
      DO 10 I=1,3
      SFC(I)=SFC(I)+.05*SFC(I)
      WF(I)=SHP(I)*SFC(I)
10    CONTINUE
C
C     CALCULATE AVG SLOPE,BETA
C
      J=3
      IF (.NOT.(SHP(1).EQ.SHP(2)))  GO TO 20
      BETA1=0.0
      J=J-1
      GO TO 30
20    CONTINUE
      BETA1=ABS((WF(1)-WF(2))/(SHP(1)-SHP(2)))
30    CONTINUE
      IF (.NOT.(SHP(1).EQ.SHP(3)))  GO TO 40
      BETA2=0.0
      J=J-1
      GO TO 50
40    CONTINUE
      BETA2=ABS((WF(1)-WF(3))/(SHP(1)-SHP(3)))
```

```
50    CONTINUE
      IF (.NOT.(SHP(2).EQ.SHP(3))) GO TO 60
      BETA3=0.0
      J=J-1
      GO TO 70
60    CONTINUE
      BETA3=ABS((WF(2)-WF(3))/(SHP(2)-SHP(3)))
70    CONTINUE
      IF (.NOT.(FLOAT(J).LT.0.0)) GO TO 80
      BETA=0.0
      GO TO 90
80    CONTINUE
      BETA=(BETA1+BETA2+BETA3)/FLOAT(J)
90    CONTINUE
C
C
      DO 100 I=1,3
      ZHI(I)=WF(I)-(BETA*SHP(I))
100   CONTINUE
      ALPHA=(ZHI(1)+ZHI(2)+ZHI(3))/3.
C
      RETURN
      END
C------------------------------------------------------------------------
C  SUBROUTINE PRATIO: CALCULATES RATIO OF PRESSURE AT ALTITUDE
C                     TO THE PRESSURE AT SEA LEVEL.
C------------------------------------------------------------------------
C
      SUBROUTINE PRATIO (PAFT,DELTA)
C
      REAL PAFT,DELTA
C
      IF (.NOT.(PAFT.EQ.0.0)) GO TO 10
      DELTA=1.0
      GO TO 20
10    CONTINUE
      DELTA=(1.0-(6.8754E-06*PAFT))**5.256
20    CONTINUE
      RETURN
      END
C------------------------------------------------------------------------
C  SUBROUTINE TRATIO: CALCULATES RATIO OF TEMPERATURE AT OPERATING
C                     CONDITIONS TO SSL TEMPERATURE.
C------------------------------------------------------------------------
C
      SUBROUTINE TRATIO (T,STHETA)
C
      REAL T,STHETA
```

```
C
      STHETA=SQRT((T + 459.688)/518.688)
C
      RETURN
      END
C-----------------------------------------------------------------------
C  SUBROUTINE ZHIALT: CALCULATES THE ZERO HORSEPOWER INCREMENT AT
C                     OPERATING CONDITIONS.
C-----------------------------------------------------------------------
C
      SUBROUTINE ZHIALT (ALPHA,DELTA,STHETA,ZHIX)
C
      REAL ALPHA,DELTA,STHETA,ZHIX
C
      ZHIX=ALPHA*DELTA*STHETA
C
      RETURN
      END
C-----------------------------------------------------------------------
C  SUBROUTINE ZVSHP: CALCULATES THE ZERO VELOCITY HORSEPOWER (PHANTOM
C                    SHAFT HORSEPOWER) AT OPERATING CONDITIONS.
C-----------------------------------------------------------------------
C
      SUBROUTINE ZVSHP (ZHIX,BETA,N,PSHP)
C
      REAL BETA,PSHP,ZHIX
      INTEGER N
C
      PSHP=FLOAT(N)*ZHIX/BETA
C
      RETURN
      END
C-----------------------------------------------------------------------
C  SUBROUTINE FLOALT: CALCULATES THE FUEL FLOW RATE AT OPERATING
C                     CONDITIONS FOR A GIVEN TOTAL ROTOR SHAFT
C                     HORSEPOWER REQUIRED BY THE AIRCRAFT.
C-----------------------------------------------------------------------
C
      SUBROUTINE FLOALT (RSHPMX,BETA,N,PSHP,WFALT)
C
      REAL BETA,ESHP,PSHP,RSHPMX,WFALT
      INTEGER N
C
      IF (.NOT.(FLOAT(N).GT.1.0)) GO TO 10
      ESHP=(.1*(FLOAT(N)-1.0)+1.03)*RSHPMX+10.0
      GO TO 20
10    CONTINUE
      ESHP=1.03*RSHPMX+10.0
```

```
20    CONTINUE
      WFALT= (PSHP + ESHP)*BETA
C
      RETURN
      END
C----------------------------------------------------------------------
C  SUBROUTINE FUELW8: CALCULATES THE TOTAL FUEL WEIGHT FOR THE
C                     SPECIFIED MISSION PROFILE.
C----------------------------------------------------------------------
C
      SUBROUTINE FUELW8 (RNGE,VCRUS,WFA,WFB,WFC,FUELWT)
C
      REAL RNGE,WFA,WFB,WFC,FUELWT
      INTEGER N,VCRUS
C
      FUELWT=.1*WFA+WFB*RNGE/FLOAT(VCRUS)+.25*WFC
C
      RETURN
      END
C----------------------------------------------------------------------
C  SUBROUTINE ENGWT: CALCULATES THE ESTIMATED INSTALLED WEIGHT OF
C                    AN ENGINE USING DRY WEIGHT AS PARAMETER.
C----------------------------------------------------------------------
C
      SUBROUTINE ENGWT (WEDRY,WEI)
C
      WEI=45.0+1.2*WEDRY
C
      RETURN
      END
C----------------------------------------------------------------------
C  SUBROUTINE MAXEND:  CALCULATES V-MAX ENDURANCE AND RSHP FOR
C                      V-MAX ENDURANCE
C----------------------------------------------------------------------
C
      SUBROUTINE MAXEND (PWR,VFK,VCRUS,VMAX,PWRC,PEND,VEND)
C
      REAL PWR(200),VFK(200),PWRC,PEND
      INTEGER I,VCRUS,VMAX,VEND
C
      I=VCRUS
      PWRC=PWR(I+1)
```

```
      VEND=VPK(2)
      PEND=PWR(2)
      DO 20 I=2,VMAX
      IF (.NOT.(PWR(I).LE.PWR(I-1))) GO TO 20
      IF (.NOT.(PWR(I).LE.PWR(I+1))) GO TO 10
      VEND=VPK(I)
      PEND=PWR(I)
10    CONTINUE
20    CONTINUE
C
      RETURN
      END
```

APPENDIX E

HELICOPTER POWER CALCULATIONS FOR THE HP-41C

This appendix contains 3 programs developed for use with the HP-41C programmable calculator. They are:

1. "POWER" which computes the total rotor shaft horsepower required for a helicopter in forward flight or hover.

2. "VE" which utilizes "POWER" to calculate the maximum endurance velocity and power required at that velocity.

3. "VMR" which utilizes "POWER" to calculate the maximum range velocity and power required at that velocity.

POWER

1. Purpose

This program calculates the total power of a helicopter in hover or in forward flight. It links 13 basic subroutines developed in [Ref. 24] into a single program to enable quick calculation of total power after one initial input of the basic helicopter design data.

a. The program features are:

(1) One input of design data.

(2) Ability to change PA, T, and V rapidly for repetitive calculations.

(3) Single output: Total power required with tip loss.

(4) Incorporation of main rotor and tail rotor calculations in each subroutine.

(5) Easy access by other programs for calculation of power required.

(6) Designed for iterative use (e.g. calculation of maximum endurance velocity or determination of many points to generate power curve),

(7) Intermediate design and performance values (such as disk area or profile power) are stored and easily accessed if needed.

b. The program limitations are:

(1) Only a rectangular rotor blade may be used (or equivalent chord separately calculated).

(2) Only hover and forward flight powers may be calculated (climbing flight is not included).

(3) All calculations are for an out of ground effect condition.

c. The basic programming technique used is to combine main rotor and tail rotor calculations into single subroutines by one of two methods (depending upon which used the fewest bytes of program memory):

(1) Calculation of the main rotor characteristic (e.g. solidity) then calculation of the corresponding tail rotor characteristic separately.

(2) Calculation of the main rotor characteristic (e.g. tip loss factor, B), continuation of program and calculation of tail rotor thrust (which requires main rotor total power to be first computed). Then flag 02 is set and program execution is returned to the subroutines where the tail rotor characteristics are calculated. In these subroutines, the same equation steps as those for the main rotor are used but tail rotor values are recalled for the computations. The flag 02 tells each subroutine to use tail rotor values.

The calculated value of total power required is displayed as follows:

Display:	Explanation:
PT =	Helicopter total rotor shaft horsepower required (out of ground effect with tip losses)

2. Equations

All equations were taken directly from [Ref. 24]. Tip loss is assumed in the calculation of induced power and all calculations are for an out of ground effect condition. The basic equations used in each subroutine are listed below.

a. Equations used twice in each subroutine; once for the main rotor and once for the tail rotor:

$$A_D = \pi R^2 \qquad \sigma = \frac{bc}{\pi R}$$

$$V_T = \Omega R \qquad C_T = \frac{T}{A_D \rho V_T^2}$$

$$B = 1 - \frac{\sqrt{2C_T}}{b}$$

$$v_i = \left[\frac{T}{2\rho A_D}\right]^{\frac{1}{2}} \qquad V_{i_f} = \frac{-V_f^2}{2v_i^2} + \left[\frac{V_f^2}{2v_i^2}^{2} + 1\right]^{\frac{1}{2}} v_i$$

$$P_{i_{TL}} = \frac{T\ V_{if}}{B}$$

$$P_o = \frac{1}{8}\ \sigma\ \overline{C}_{dO}\rho A_D V_T^3 \left[1 + 4.3\ \frac{V_f}{V_T}^{2}\right]$$

b. Main rotor only:

$$P_p = \tfrac{1}{2}\rho f_f V_f^3$$

$$P_{T_{MR}} = P_{i_{MR}} + P_{o_{MR}} + P_p$$

$$T_{MR} = W$$

c. Tail rotor only:

$$T_{tr} = \frac{P_{T_{MR}}}{\Omega_{MR}\ell_{tr}}$$

d. Operating conditions:

$$h_\rho = \frac{1 - \left[\frac{T_{SSL}}{T}\ 1 - K_1 h_p{}^{5.2561}\right]^{.23496}}{K_1}$$

$$\rho = \rho_{SSL}[1-(K_1 h_\rho)]^{4.2561}$$

e. Total Power:

$$P_T = P_{T_{MR}} + P_{i_{tr}} + P_{o_{tr}}$$

where:

A_D is the disk area (ft)

R is the rotor radius (ft)

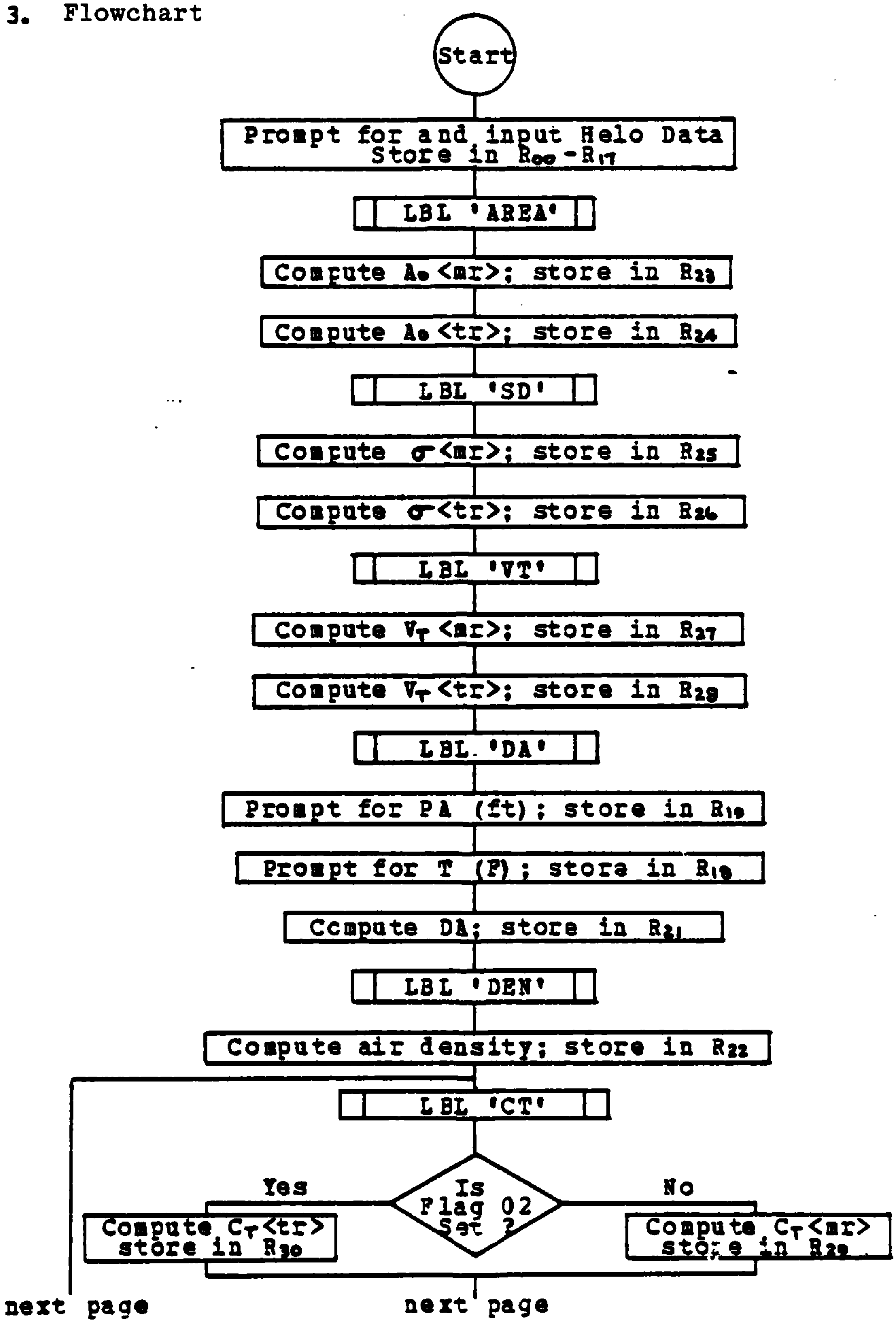
σ is the solidity

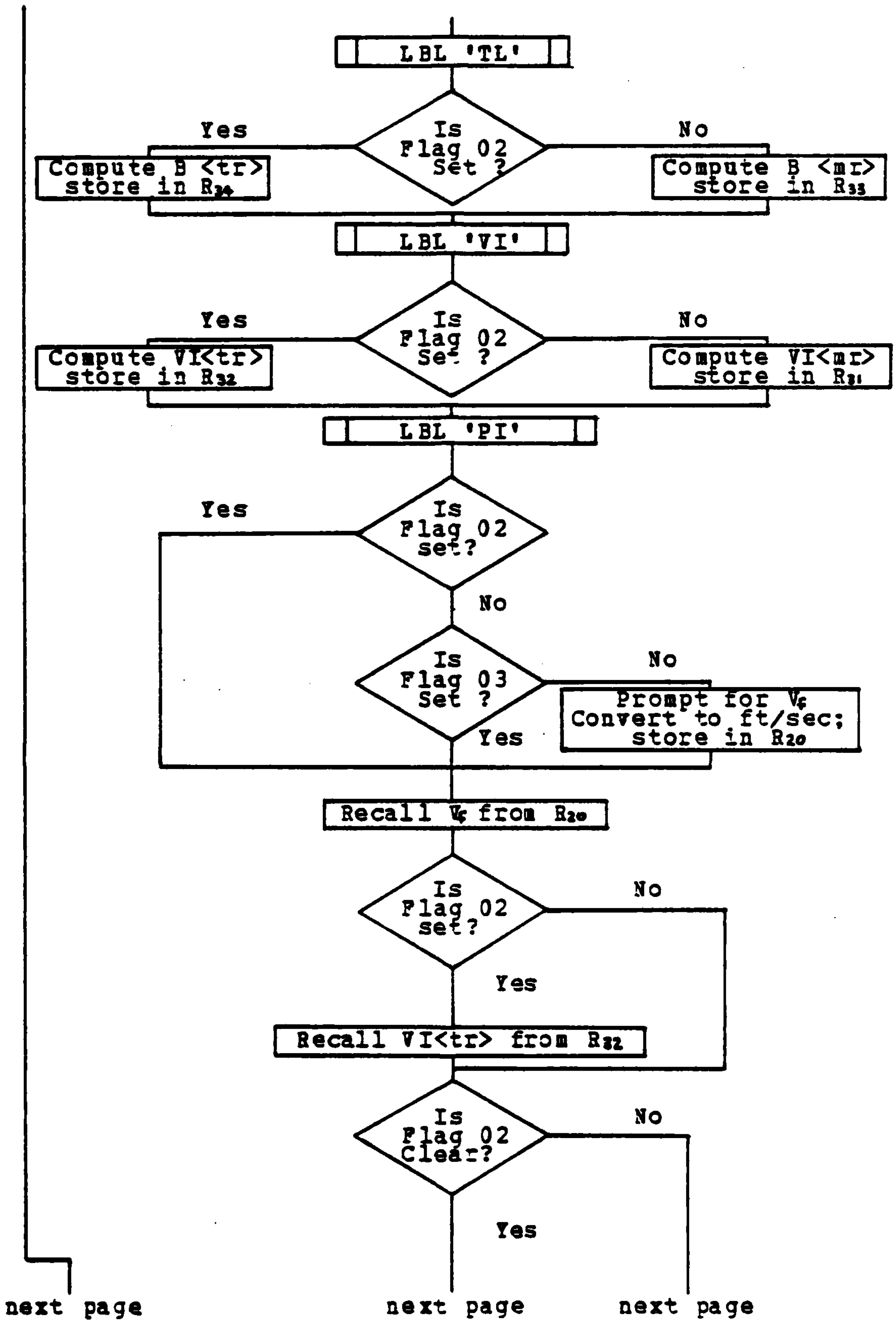
C	is the rotor chord (ft)
b	is the number of rotor blades
V_T	is the rotor tip velocity (ft/sec)
Ω	is the rotational velocity of the rotor (rad/sec)
C_T	is the coefficient of thrust
T_{tr}	is the thrust required for the tail rotor (lb)
ρ	is the air density (slugs/ft)
B	is the tiploss factor
vi	is the induced velocity (ft/sec)
Vi_f	is the induced velocity in forward flight (ft/sec)
V_f	is the forward velocity (ft/sec)
Pi_{TL}	is the induced power required with tip loss (hp)
Po	is the profile power required (hp)
$\bar{C}dO$	is the profile drag coefficient
Pp	is the parasite power required (hp)
f_f	is the equivalent flat plate area in forward flight (ft)
$P_{T_{MR}}$	is the total power required by the main rotor (hp)
T_{MR}	is the thrust of the main rotor (lb)
W	is the gross weight (lb)
l_{tr}	is the distance between tail rotor hub and main rotor mast (ft)
h_ρ	is the density altitude (ft)
T	is temperature (absolute)
T_{SSL}	is the standard sea level temperature (absolute)
K_1	is a constant = 6.875×10^{-6}
h_p	is pressure altitude (ft)

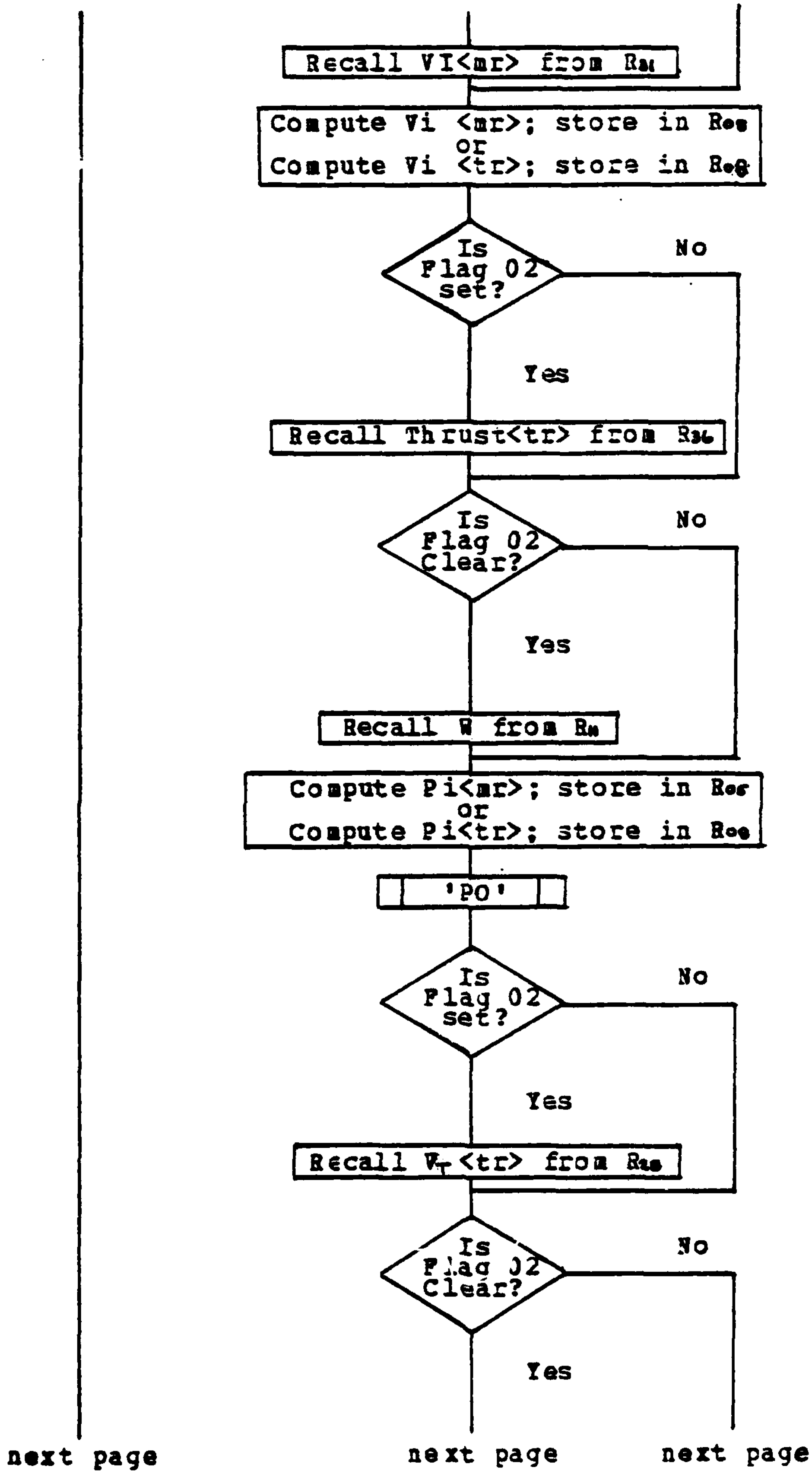
ρ_{SSL} is standard sea level density of air (slugs/ft)

P_T is the total power required (hp)

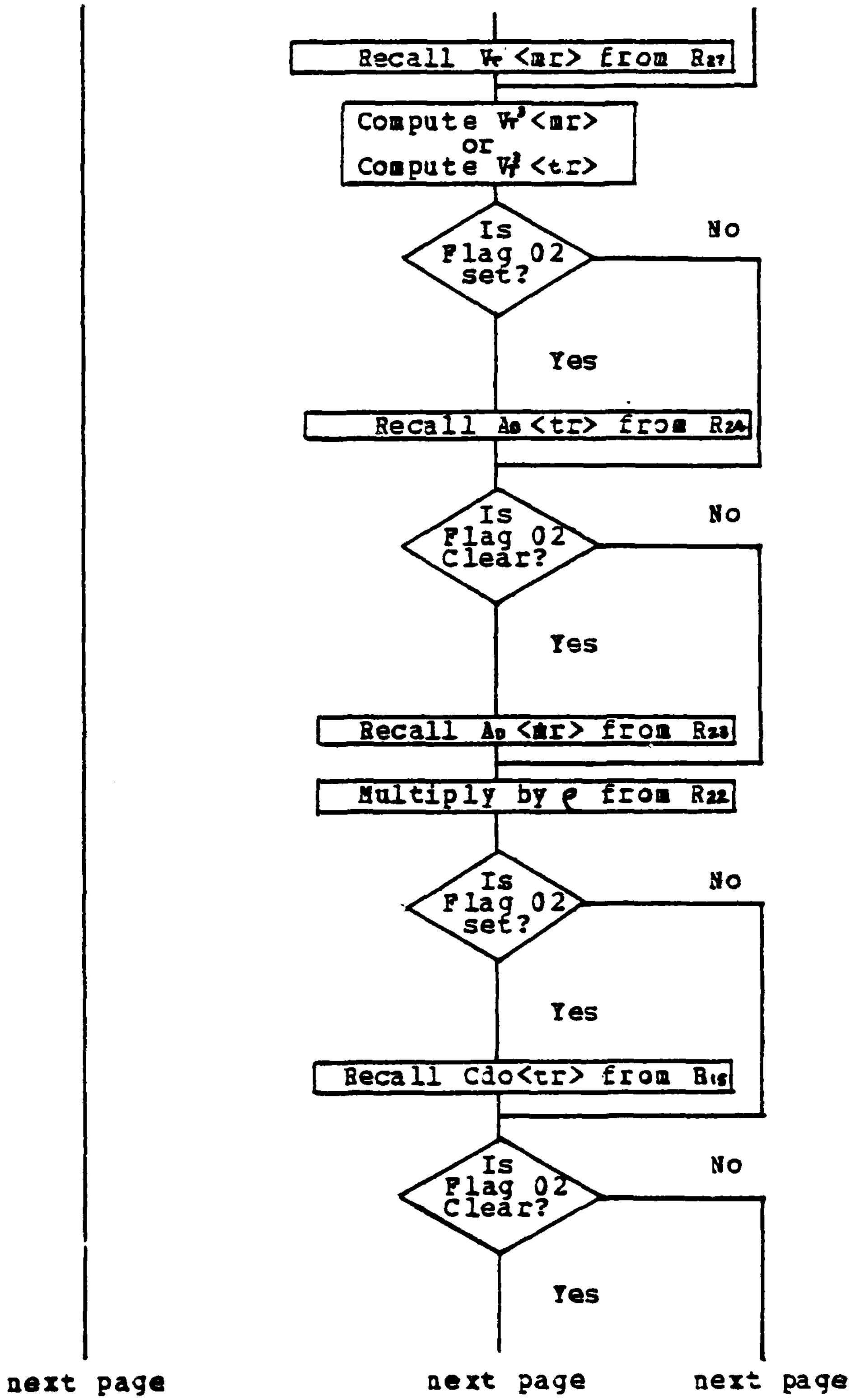
3. Flowchart


Start
Prompt for and input Helo Data Store in R00 - R17
LBL 'AREA'
Compute A0 <mr>; store in R23
Compute A0 <tr>; store in R24
LBL 'SD'
Compute σ <mr>; store in R25
Compute σ <tr>; store in R26
LBL 'VT'
Compute VT <mr>; store in R27
Compute VT <tr>; store in R28
LBL 'DA'
Prompt for PA (ft); store in R19
Prompt for T (F); store in R18
Compute DA; store in R21
LBL 'DEN'
Compute air density; store in R22
LBL 'CT'
Is Flag 02 Set ?
Yes
No
Compute CT<tr> store in R30
Compute CT<mr> store in R29
next page
next page


LBL 'TL'
Is Flag 02 Set ?
Yes
No
Compute B <tr> store in R_{34}
Compute B <mr> store in R_{33}
LBL 'VI'
Is Flag 02 Set ?
Yes
No
Compute VI<tr> store in R_{32}
Compute VI<mr> store in R_{31}
LBL 'PI'
Is Flag 02 set?
Yes
No
Is Flag 03 Set ?
No
Yes
Prompt for V_f Convert to ft/sec; store in R_{20}
Recall V_f from R_{20}
Is Flag 02 set?
No
Yes
Recall VI<tr> from R_{32}
Is Flag 02 Clear?
No
Yes
next page
next page
next page



Recall VI<mr> from R
Compute Vi <mr>; store in R
or
Compute Vi <tr>; store in R
Is Flag 02 set?
No
Yes
Recall Thrust<tr> from R
Is Flag 02 Clear?
No
Yes
Recall W from R
Compute Pi<mr>; store in R
or
Compute Pi<tr>; store in R
'PO'
Is Flag 02 set?
No
Yes
Recall V<tr> from R
Is Flag 02 Clear?
No
Yes
next page
next page
next page


Recall Wr <mr> from R27
Compute W <mr>
or
Compute W <tr>
Is Flag 02 set?
No
Yes
Recall As <tr> from R2A
Is Flag 02 Clear?
No
Yes
Recall Ao <mr> from R23
Multiply by ρ from R22
Is Flag 02 set?
No
Yes
Recall Cdo<tr> from R15
Is Flag 02 Clear?
No
Yes
next page
next page
next page

AD-A132 982 POWERPLANT SELECTION FOR CONCEPTUAL HELICOPTER DESIGN 2/2
(U) NAVAL POSTGRADUATE SCHOOL MONTEREY CA T J CASEY
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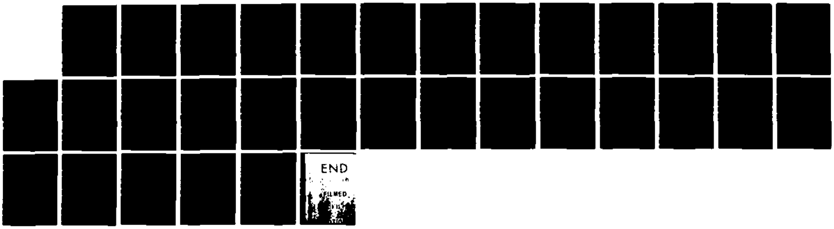
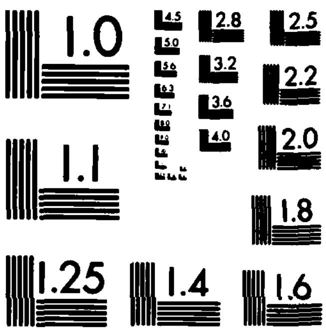
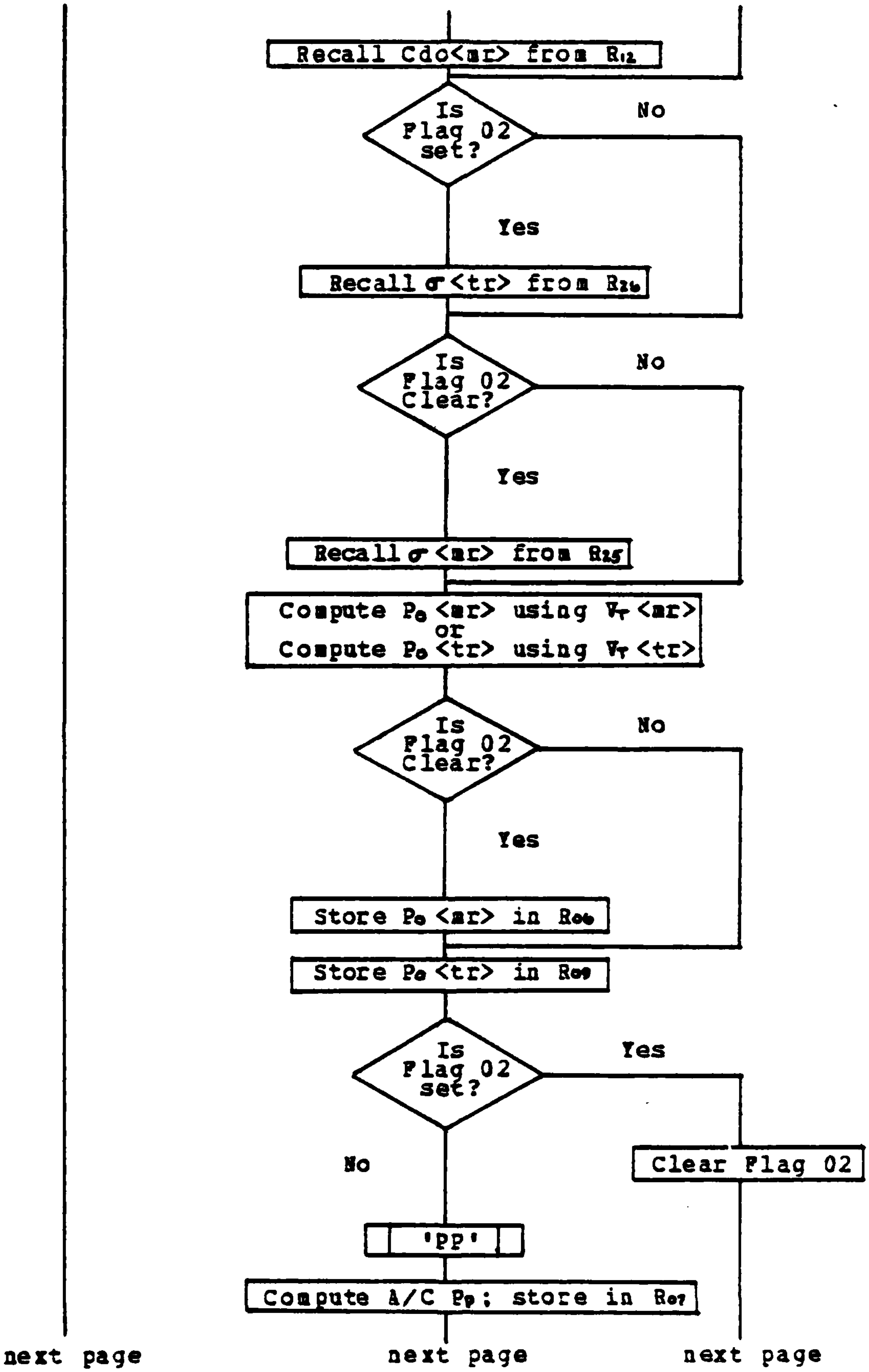
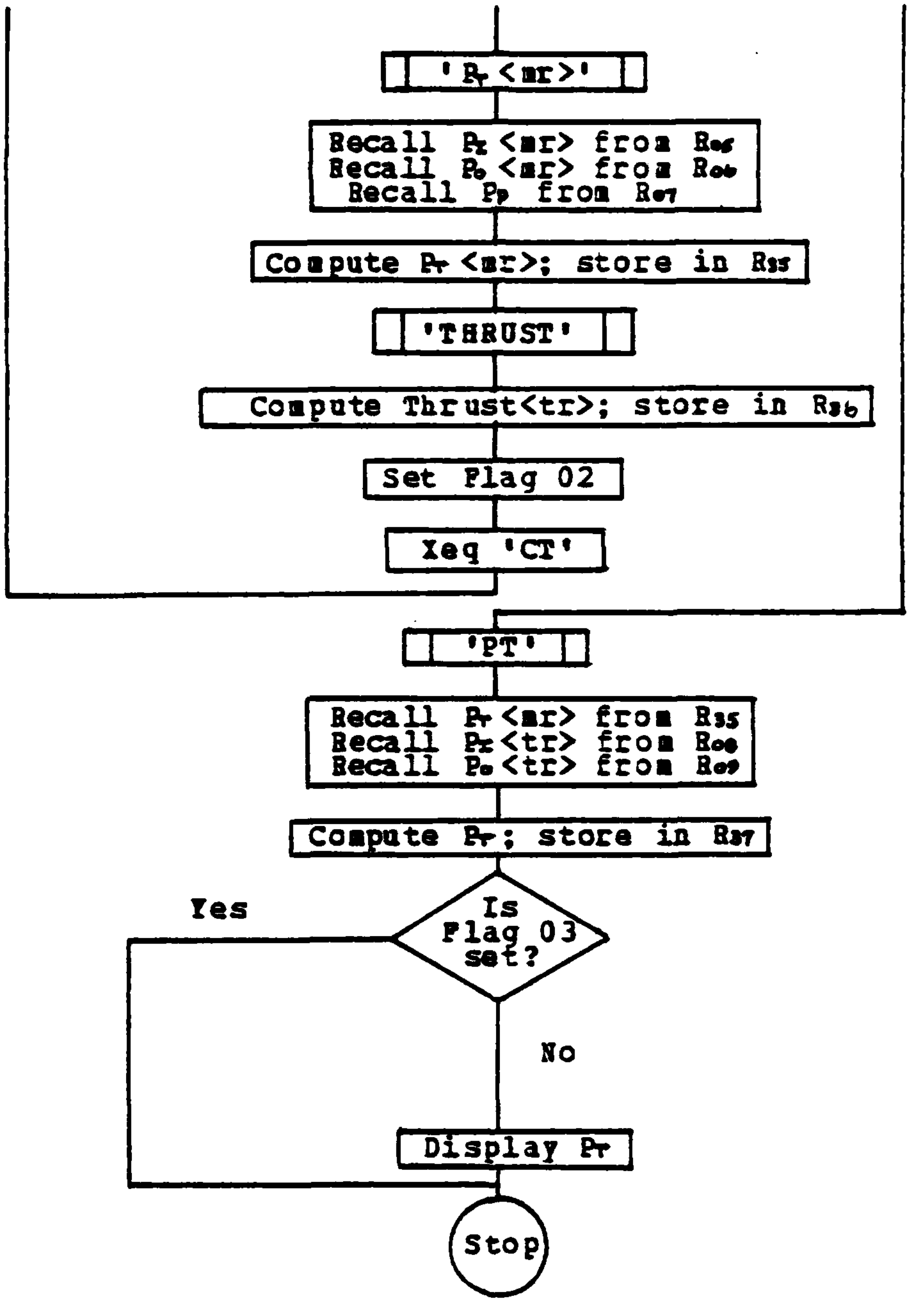




MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A


Recall Cdo<mr> from R12
Is Flag 02 set?
No
Yes
Recall σ<tr> from R26
Is Flag 02 Clear?
No
Yes
Recall σ<mr> from R25
Compute Po <mr> using VT <mr> or Compute Po <tr> using VT <tr>
Is Flag 02 Clear?
No
Yes
Store Po <mr> in R06
Store Po <tr> in R09
Is Flag 02 set?
Yes
No
Clear Flag 02
'PP'
Compute A/C Pp; store in R07
next page
next page
next page


'P_T<mr>'
Recall P_r<mr> from R_{05}
Recall P_o<mr> from R_{06}
Recall P_p from R_{07}
Compute P_T<mr>; store in R_{35}
'THRUST'
Compute Thrust<tr>; store in R_{36}
Set Flag 02
Xeq 'CT'
'PT'
Recall P_T<mr> from R_{35}
Recall P_r<tr> from R_{08}
Recall P_o<tr> from R_{09}
Compute P_T; store in R_{37}
Is Flag 03 set?
Yes
No
Display P_T
Stop

4. Example Problem and User Instructions

Find the total rotor power required for a helicopter under the following conditions:

Main Rotor	Tail Rotor	Aircraft
C = 1.50 ft	C = 0.50 ft	L<tail> = 23.50 ft
R = 20.0 ft	R = 3.00 ft	W<gross> = 7,000 lbs
b = 4	b = 2	F.P.A.(FF) = 21.2
CdO = 0.01	CdO = 0.014	VF = 0 kts (hover)
RV = 31 rad/sec	RV = 139.5 rad/sec	

Environmental: PA = 0 ft T = 59 F (standard sea level)

Keystrokes:	Display:
(XEQ) (ALPHA) POWER (ALPHA)	HELO DATA
(R/S)	W=?
7000.0 (R/S)	RV(mr)=?
31.0 (R/S)	b(mr)=?
4 (R/S)	C(mr)=?
1.50 (R/S)	CdO(mr)=?
0.01 (R/S)	R(mr)=?
20.0 (R/S)	F.P.A.(FF)=?
21.2 (R/S)	RV(tr)=?
31 (R/S)	b(tr)=?
2 (R/S)	C(tr)=?
0.50 (R/S)	CdO(tr)=?
0.014 (R/S)	R(tr)=?
3.00 (R/S)	L<TAIL>=?
23.50 (R/S)	PA=?

0.0 (R/S)	T=?
59.0 (R/S)	VF=?
0 (R/S)	PT = 660.08

To calculate the power required at a different V for the same helicopter at the same altitude and temperature, execute "PI" with:

VF = 100 kts

Keystrokes:	Display:
(XEQ) (ALPHA) PI (ALPHA)	VF = ?
100 (R/S)	PT = 531.87

To calculate the power required at any V for the same helicopter at a different altitude and temperature, execute "DA" with:

VF = 100 kts

PA = 4000 ft

T = 95 F

Keystrokes:	Display:
(XEQ) (ALPHA) DA (ALPHA)	PA = ?
4000 (R/S)	T = ?
95 (R/S)	VF = ?
100 (R/S)	PT = 471.22

5. Programs and Subroutines Used

"POWER"

"AREA" calculates Disk Area

"SD" calculates Solidity

"VT" calculates Rotor Tip Velocity

"DA"	calculates Density Altitude
"DEN"	calculates Air Density
"CT"	calculates Coefficient of Thrust
"TL"	calculates Tip Loss Factor
"VI"	calculates Induced Velocity
"PI"	calculates Profile Power with tip loss OGE
"PO"	calculates Profile Power
"PP"	calculates Parasite Power
"PT"	calculates Total Main Rotor Power
"THRUST"	calculates Tail Rotor Thrust required
"PT"	calculates Total Power required

6. Storage Register Utilization

Table VII and VIII show specific storage register contents. Note: Registers 00-09 are considered temporary and are also used by other programs.

TABLE VII

POWER Storage Register Utilization: 00-19

Storage Register	Stored Quantity
00	C_{MR} - main rotor chord (ft)
01	R_{MR} - main rotor radius (ft)
02	Ω_{MR} - rotational velocity of the main rotor (radians/sec)
03	C_{tr} - tail rotor chord (ft)
04	R_{tr} - tail rotor radius (ft)
05	$P_{i_{MR}}$ - main rotor induced power with tip losses (hp)
06	$P_{o_{MR}}$ - main rotor profile power (hp)
07	P_p - parasite power (hp)
08	$P_{i_{tr}}$ - tail rotor induced power with tip losses (hp)
09	$P_{o_{tr}}$ - tail rotor profile power (hp)
10	b_{MR} - the number of main rotor blades
11	W - the weight of the helicopter
12	$\overline{C}_{do_{MR}}$ - the average profile drag coefficient for the main rotor
13	f_f - the equivalent flat plate area for forward flight calculations (ft)
14	b_{tr} - the number of tail rotor blades
15	$\overline{C}_{do_{tr}}$ - the average profile drag coefficient for the tail rotor
16	l_{tr} - the length of the tail, from main rotor hub to the tail rotor hub (ft)
17	Ω_{tr} - rotational velocity of the tail rotor (radians/sec)
18	T - outside air temperature in degrees F
19	h_p - pressure altitude (ft)

TABLE VIII

POWER Storage Register Utilization: 20-37

Storage Register	Stored Quantity
20	V_f - forward velocity (ft/sec)
21	h_ρ - density altitude (ft)
22	ρ - air density (slugs/ft)
23	$A_{D_{MR}}$ - the main rotor disk area (ft)
24	$A_{D_{tr}}$ - the tail rotor disk area (ft)
27	$V_{T_{MR}}$ - velocity of the main rotor tip (ft/sec)
28	$V_{T_{tr}}$ - velocity of the tail rotor tip (ft/sec)
29	$C_{T_{MR}}$ - the coefficient of thrust for the main rotor
30	$C_{T_{tr}}$ - the coefficient of thrust for the tail rotor
31	$V_{i_{MR}}$ - induced velocity of the main rotor (ft/sec)
32	$V_{i_{tr}}$ - induced velocity of the tail rotor (ft/sec)
33	B_{MR} - the tip loss factor for the main rotor
34	B_{tr} - the tip loss factor for the tail rotor
35	$P_{T_{MR}}$ - the total power required for the main rotor (hp)
36	T_{tr} - thrust required for the tail rotor (ft-lb/sec)
37	P_T - total power required for the helicopter (hp)

7. Program Listings

```
♦LBL "POWER"
"⊢ELO DATA"
AVIEW
STOP
"W=?"
PROMPT
STO 11
"RV<MR>=?"
PROMPT
STO 17
"b<MR>=?"
PROMPT
STO 10
"C<MR>=?"
PROMPT
STO 00
"CdO<MR>=?"
PROMPT
STO 12
"R<MR>=?"
PROMPT
STO 01
"F.P.A<FF>=?"
PROMPT
STO 13
"RV<TR>=?"
PROMPT
STO 02
"b<TR>=?"
PROMPT
STO 14
"C<TR>=?"
PROMPT
STO 03
"CdO<TR>=?"
PROMPT
STO 15
"R<TR>=?"
PROMPT
STO 04
"L<TAIL>=?"
PROMPT
STO 16
♦LBL "AREA"
RCL 01
X↑2
PI
*
STO 23
CLX
RCL 04
X↑2
PI
*
STO 24
CLX
♦LBL "SD"
RCL 10
RCL 00
*
RCL 01
/
PI
/
STO 25
CLX
RCL 14
RCL 03
*
RCL 04
/
PI
/
STO 26
CLX
♦LBL "VT"
RCL 01
RCL 17
*
STO 27
CLX
RCL 04
RCL 02
*
STO 28
CLX
♦LBL "DA"
"PA=?"
PROMPT
STO 19
6.875 E-06
*
CHS
1
+
5.2561
Y↑X
"T<F>=?"
PROMPT
STO 18
32
-
.5555
*
273.16
+
/
288.16
*
.23496
Y↑X
CHS
1
+
6.875 E-06
/
STO 21
♦LBL "DEN"
RCL 21
6.875 E-06
*
CHS
1
+
ENTER↑
4.2561
Y↑X
.0023769
*
STO 22
CLX
♦LBL "CT"
FS? 02
GTO 07
RCL 11
RCL 23
/
RCL 22
/
RCL 27
X↑2
/
STO 29
GTO 08
♦LBL 07
RCL 36
RCL 24
/
RCL 22
/
```

```
151 RCL 28
152 X↑2
153 /
154 STO 30
155♦LBL 08
156 CLX
157♦LBL "TL"
158 FS? 02
159 GTO 09
160 RCL 29
161 2
162 *
163 SQRT
164 RCL 10
165 /
166 CHS
167 1
168 +
169 STO 33
170 GTO 10
171♦LBL 09
172 RCL 30
173 2
174 *
175 SQRT
176 RCL 14
177 /
178 CHS
179 1
180 +
181 STO 34
182♦LBL 10
183♦LBL "VI"
184 FS? 02
185 GTO 11
186 RCL 11
187 2
188 /
189 RCL 22
190 /
191 RCL 23
192 /
193 SQRT
194 STO 31
195 GTO 12
196♦LBL 11
197 RCL 36
198 2
199 /
200 RCL 22
201 /
202 RCL 24
203 /
204 SQRT
205 STO 32
206♦LBL 12
207♦LBL "PI"
208 FS? 02
209 GTO a
210 FS? 03
211 GTO a
212 "VF=?"
213 PROMPT
214 1.68889
215 *
216 STO 20
217♦LBL a
218 RCL 20
219 FS? 02
220 RCL 32
221 FC? 02
222 RCL 31
223 /
224 X↑2
225 2
226 /
227 STO 08
228 X↑2
229 1
230 +
231 SQRT
232 RCL 08
233 -
234 SQRT
235 FS? 02
236 RCL 36
237 FC? 02
238 RCL 11
239 *
240 FS? 02
241 RCL 32
242 FC? 02
243 RCL 31
244 *
245 550
246 /
247 FS? 02
248 RCL 34
249 FC? 02
250 RCL 33
251 /
252 FC? 02
253 STO 05
254 STO 08
255♦LBL "PO"
256 FS? 02
257 RCL 28
258 FC? 02
259 RCL 27
260 3
261 Y↑X
262 FS? 02
263 RCL 24
264 FC? 02
265 RCL 23
266 *
267 RCL 22
268 *
269 FS? 02
270 RCL 15
271 FC? 02
272 RCL 12
273 *
274 FS? 02
275 RCL 26
276 FC? 02
277 RCL 25
278 *
279 4400
280 /
281 STO 09
282 RCL 20
283 FS? 02
284 RCL 28
285 FC? 02
286 RCL 27
287 /
288 X↑2
289 4.3
290 *
291 1
292 +
293 RCL 09
294 *
295 FC? 02
296 STO 06
297 STO 09
298 FS?C 02
299 GTO 12
```

```
♦LBL "PP"
RCL 20
3
Y↑X
RCL 13
*
RCL 22
*
1100
/
STO 07
♦LBL "PT(MR)"
RCL 05
RCL 06
+
RCL 07
+
STO 35
♦LBL "THRUST"
RCL 35
550
*
RCL 17
/
RCL 16
/
STO 36
SF 02
XEQ "CT"
♦LBL "PT"
♦LBL 12
RCL 35
RCL 08
+
RCL 09
+
STO 37
FS? 03
GTO 13
"PT="
ARCL X
AVIEW
STOP
♦LBL 13
END
```

VE

1. Purpose

This program utilizes program "POWER" iteratively and solves for the maximum endurance velocity and power required at that velocity. The user is given the option of selecting the velocity range over which the power is calculated as well as the velocity increment to be used. Since the maximum endurance velocity for a helicopter occurs at that velocity where power required is a minimum, the program simply compares the total power required at each velocity, saves the smallest value and displays the associated velocity as that at which maximum endurance will occur. Execution of this program requires 2 minutes for ten velocity iterations. It is therefore recommended that the program be initially run at 10 knot increments over the entire velocity range from 0 to V max. The velocity displayed will be the maximum endurance velocity accurate to within ± 5 kts. The program may then be run a second time starting 5 kts below the displayed V<end> and stopping 5 kts above it using 1 kt intervals. This procedure will enable a V<end> accurate to within 1 kt to be obtained in less than 10 minutes for almost all designs. The program output displays are as follows:

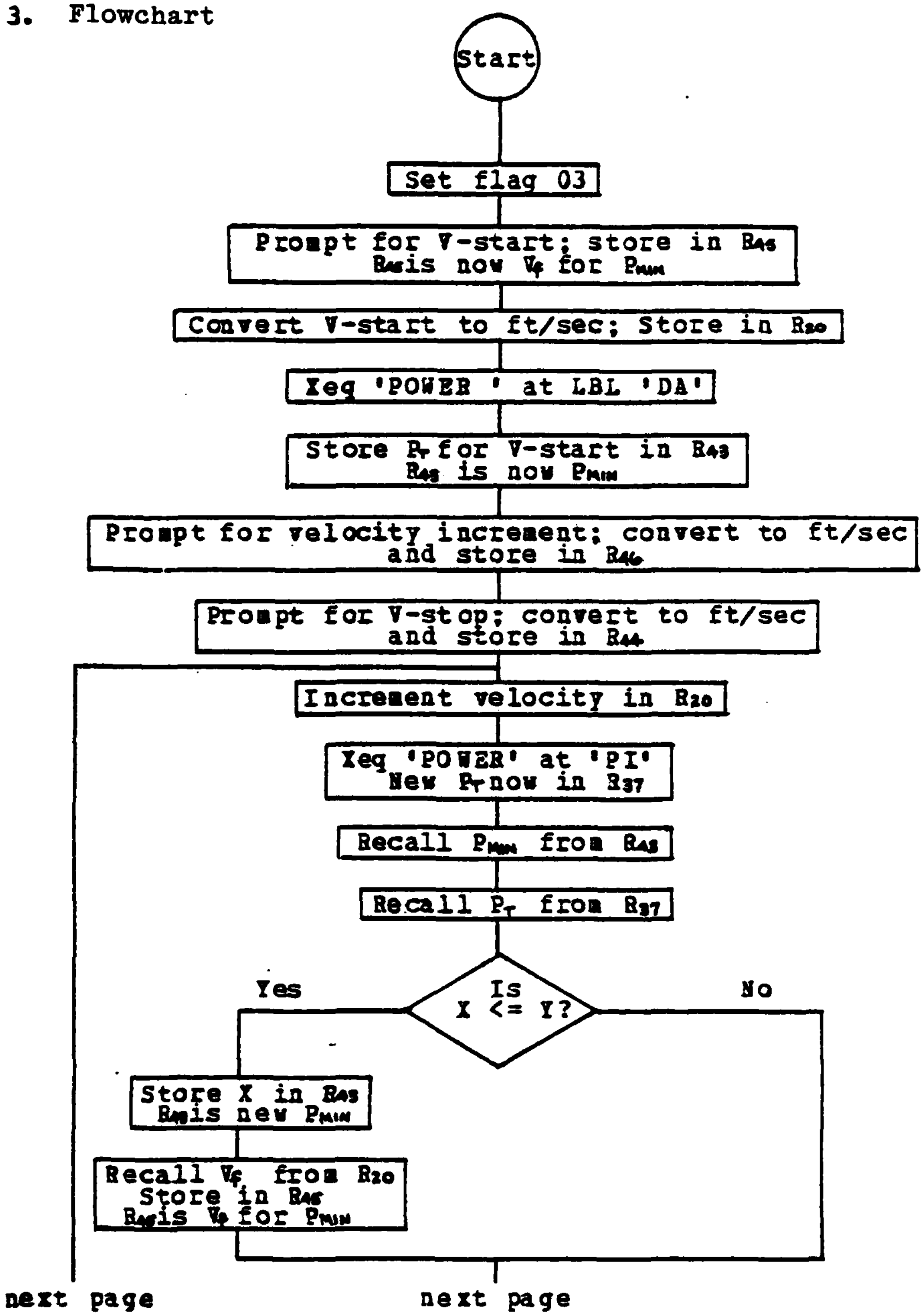
Display:	Explanation:
V<end>=	Maximum Endurance Velocity
P<V end>=	Total power required at V<end>

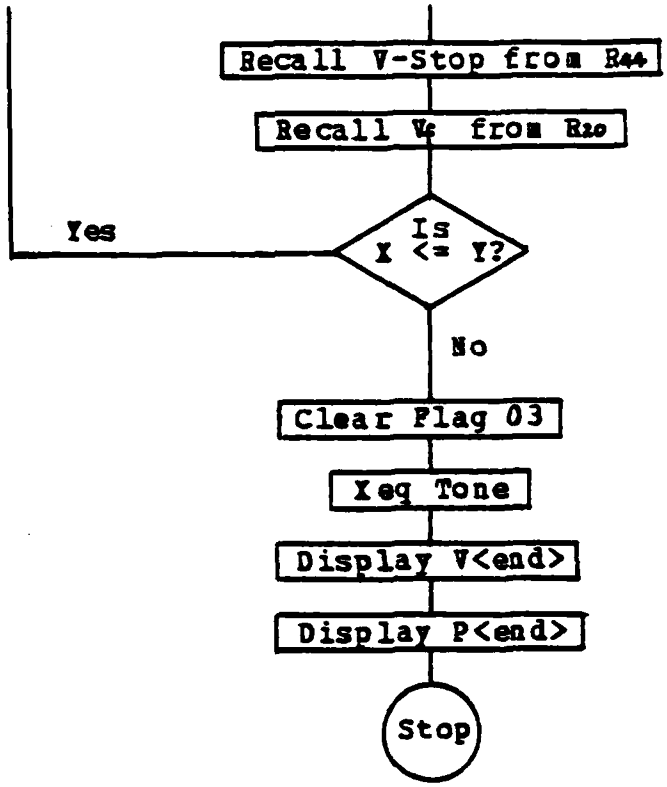
2. Equations

V_f (ft/sec) = 1.6889 x V_f (knots)

where: V_f is forward velocity

3. Flowchart


Start
Set flag 03
Prompt for V-start; store in R45
R45 is now Vf for PMIN
Convert V-start to ft/sec; Store in R20
Xeq 'POWER ' at LBL 'DA'
Store PT for V-start in R43
R43 is now PMIN
Prompt for velocity increment; convert to ft/sec and store in R46
Prompt for V-stop; convert to ft/sec and store in R44
Increment velocity in R20
Xeq 'POWER' at 'PI'
New PT now in R37
Recall PMIN from R43
Recall PT from R37
Yes
Is X <= Y?
No
Store X in R43
R43 is new PMIN
Recall Vf from R20
Store in R45
R45 is Vf for PMIN
next page
next page


Recall V-Stop from R44
Recall Vc from R20
Is X <= Y?
Yes
No
Clear Flag 03
Xeq Tone
Display V<end>
Display P<end>
Stop

4. Example Problem and User Instructions

Find the maximum endurance velocity for the sample helicopter design used for the "POWER" example problem under the following conditions:

V<max> = 120 kts

PA = 0 ft

T = 59 F

a. 10 kt increment from 0 to V<max>.

Keystrokes:	Display:
(XEQ) (ALPHA) VE (ALPHA)	V-START?
0 (R/S)	PA = ?
0 (R/S)	T<F> = ?
59 (R/S)	INCR = ?
10 (R/S)	V-STOP = ?
120 (R/S)	V<end> = 60
(R/S)	P<end> = 384

b. 1 kt increment from V = 55 kts to V = 65 kts.

Keystrokes:	Display:
(XEQ) (ALPHA) VE (ALPHA)	V-START?
55 (R/S)	PA = ?
0 (R/S)	T<F> = ?
59 (R/S)	INCR = ?
1 (R/S)	V-STOP = ?
65 (R/S)	V<end>=58
(R/S)	P<V end>= 383

5. Programs and Subroutines Used

"VE"

"POWER" (entered at subroutine "DA" or "PI")

6. Storage Register Utilization

Table IX shows specific storage register contents.

TABLE IX

VE Storage Register Utilization

Storage Register	Stored Quantity
00-41	- used by "POWER"
42	- used by "WEIGHT"
43	$P_{T_{MIN}}$ - the minimum calculated total power required (hp)
44	V_B - the upper bound velocity selected for the iteration (ft/sec)
45	V_{MP} - the velocity at minimum total power required (ft/sec)
46	V_{INC} - the velocity increment selected (ft/sec)

7. Program Listings

```
01♦LBL "VE"
02 SF 03
03 "V-START?"
04 PROMPT
05 STO 45
06 1.6889
07 *
08 STO 20
09 XEQ "DA"
10 STO 43
11 "INCR ?"
12 PROMPT
13 1.68889
14 *
15 STO 46
16 "V-STOP?"
17 PROMPT
18 1.68889
19 *
20 STO 44

21♦LBL 13
22 RCL 46
23 ST+ 20
24 XEQ "PI"
25 RCL 43
26 RCL 37
27 X<=Y?
28 GTO 13
29 GTO 14
30♦LBL 12
31 STO 43
32 CLX
33 RCL 20
34 1.68889
35 /
36 STO 45

37♦LBL 14
38 RCL 44
39 RCL 20
40 X<=Y?
41 GTO 12
42 CF 03
43 TONE 2
44 RCL 45
45 FIX 0
46 "V(END)="
47 ARCL X
48 AVIEW
49 STOP
50 RCL 43
51 "P(END)="
52 ARCL Y
53 AVIEW
54 END
```

VMR

1. Purpose

This program utilizes program "POWER" iteratively and solves for the maximum range velocity and power required at that velocity for a helicopter. The user is given the option of selecting the velocity range over which the power is calculated as well as the velocity increment to be used. The maximum range velocity for a helicopter occurs at that velocity where the ratio of power required to velocity is a minimum (considering also the zero power fuel flow or phantom SHP). The graphical method for determining the maximum range velocity is illustrated in Chapter 14 of [Ref. 20]. Program "VMR" computes the slope of a line drawn from the origin (modified to include the Phantom SHP) of the Power Required vs. Velocity curve to the power curve itself. The slope is recalculated at each velocity over the velocity range designated by the user. The program compares the slope obtained at each velocity, saves the smallest value and displays the associated velocity as that at which maximum range will occur. Execution of this program requires 2 minutes for ten velocity iterations. Since the maximum range velocity will occur above the maximum endurance velocity, it is recommended that the program be initially run at 10 knot increments over the range from V<end> to V<max>. The velocity displayed will be the maximum range velocity accurate to within ± 5 kts. The program may then

be run a second time starting 5 kts below the displayed VMR and stopping 5 kts above it using 1 kt intervals. This procedure will enable a VMR accurate to within 1 kt to be obtained in less than 10 minutes for almost all designs.

The program output displays are as follows:

Display:	Explanation:
VMR=	Maximum Range Velocity
P<Vmr>=	Total power required at VMR

2. Equations

V_f (ft/sec) = 1.6889 x V_f (knots)

$$\text{slope of tangent line} = \frac{(P_T + PSHP)}{V_f \text{ (knots)}}$$

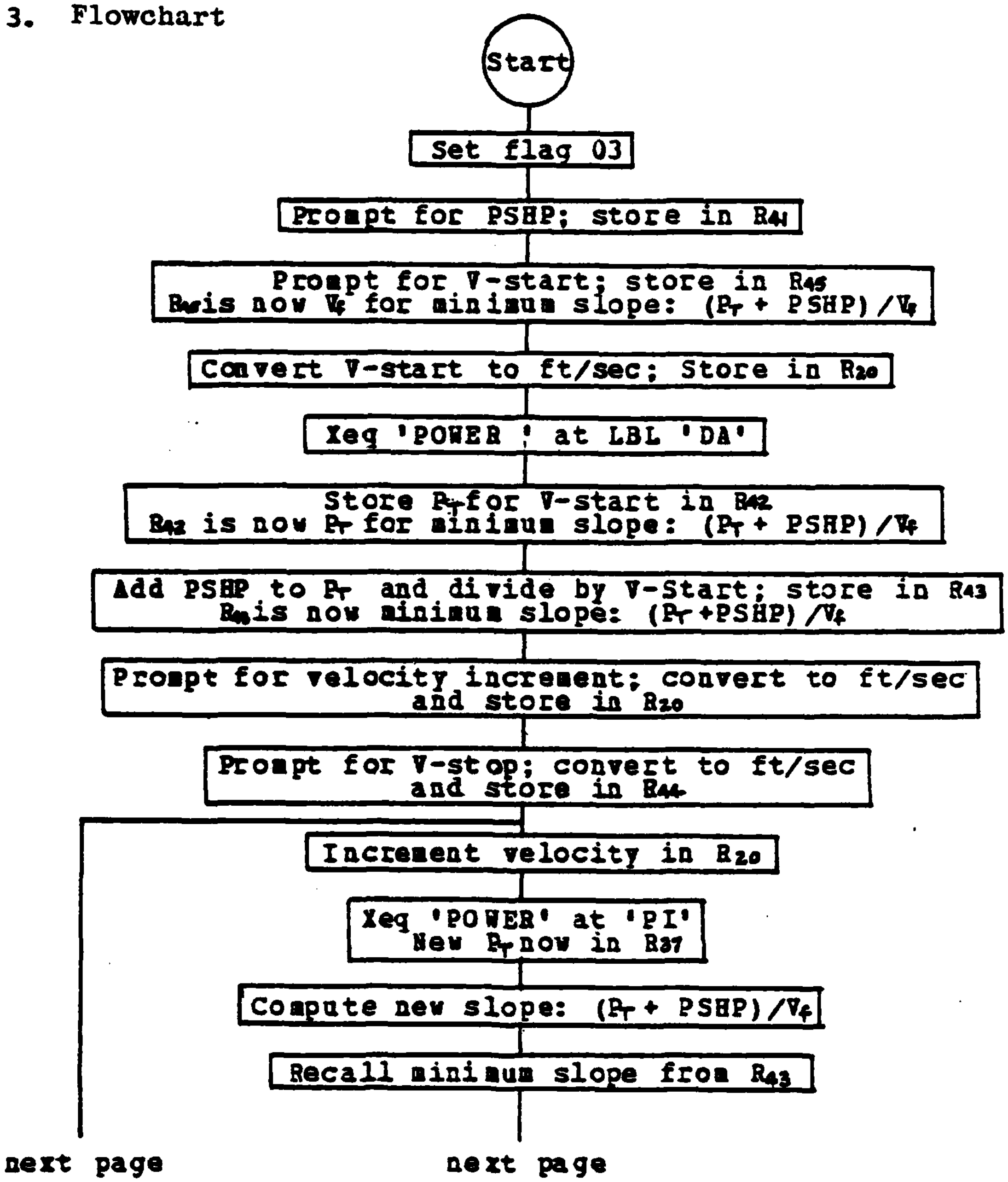
where:

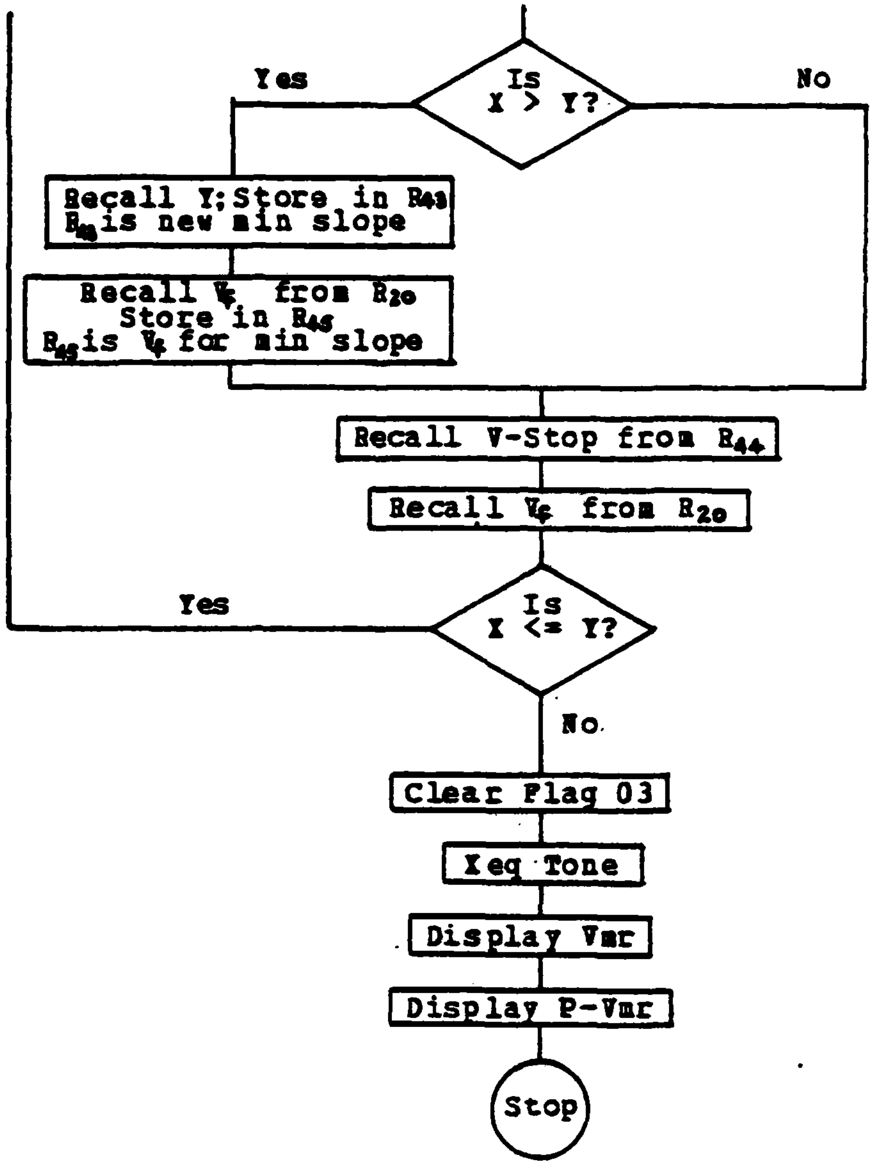
V_f is the forward velocity of the helicopter

P_T is the total power required for the helicopter at a specified V_f (hp)

PSHP is the zero velocity shaft horsepower (phantom SHP) for the powerplant used at a specified pressure altitude and temperature (hp)

3. Flowchart


Start
Set flag 03
Prompt for PSHP; store in R41
Prompt for V-start; store in R45
R45 is now Vf for minimum slope: (PT + PSHP)/Vf
Convert V-start to ft/sec; Store in R20
Xeq 'POWER' at LBL 'DA'
Store PT for V-start in R42
R42 is now PT for minimum slope: (PT + PSHP)/Vf
Add PSHP to PT and divide by V-Start; store in R43
R43 is now minimum slope: (PT +PSHP)/Vf
Prompt for velocity increment; convert to ft/sec
and store in R20
Prompt for V-stop; convert to ft/sec
and store in R44
Increment velocity in R20
Xeq 'POWER' at 'PI'
New PT now in R37
Compute new slope: (PT + PSHP)/Vf
Recall minimum slope from R43
next page
next page


Is X > Y?
Yes
No
Recall Y; Store in R43
R43 is new min slope
Recall V from R20
Store in R45
R45 is V for min slope
Recall V-Stop from R44
Recall V from R20
Is X <= Y?
Yes
No
Clear Flag 03
Xeq Tone
Display Vmr
Display P-Vmr
Stop

4. Example Problem and User Instructions

Find the maximum range velocity for the sample helicopter design used for the "POWER" example problem under the following conditions:

PSHP = 310 SHP

V<end> = 58 kts

V<max> = 120 kts

PA = 0 ft

T = 59 F

a. 10 kt increment from V<end> to V<max>.

Keystrokes:	Display:
(XEQ) (ALPHA) VMR (ALPHA)	PSHP = ?
310 (R/S)	V-START = ?
58 (R/S)	PA = ?
0 (R/S)	T<F> = ?
59 (R/S)	INCR = ?
10 (R/S)	V-STOP = ?
120 (R/S)	Vmr = 108
(R/S)	P<Vmr>= 593

b. 1 kt increment from V = 103 kts to V = 113 kts.

Keystrokes:	Display:
(XEQ) (ALPHA) VMR (ALPHA)	PSHP = ?
310 (R/S)	V-START =?
103 (R/S)	PA = ?
0 (R/S)	T<F> = ?
59 (R/S)	INCR = ?

1 (R/S)	V-STOP = ?
113 (R/S)	Vmr = 108
(R/S)	P<Vmr> = 593

5. Programs and Subroutines Used

"VMR"

"POWER" (entered at subroutine "DA" or "PI")

6. Storage Register Utilization

Table X shows specific storage register contents.

TABLE X

VMR Storage Register Utilization

Storage Register		Stored Quantity
00-37		- used by "POWER"
42	P_{MS}	- power required at minimum ratio of power to velocity (hp)
43	P/V_f	- the minimum calculated ratio of power to velocity
44	V_B	- the upper bound velocity selected for the iteration (ft/sec)
45	VMR	- the velocity at the minimum ratio of power to velocity (ft/sec)
46	V_{INC}	- the velocity increment selected (ft/sec)

7. Program Listings

```
♦LBL "VMR"
SF 03
"PSHP?"
PROMPT
STO 41
"V-START?"
PROMPT
STO 45
1.68889
*
STO 20
XEQ "DA"
STO 42
RCL 41
+
RCL 45
/
STO 43
"INCR?"
PROMPT
1.6889
*
STO 46
"V-STOP?"
PROMPT
1.6889
*
STO 44
♦LBL 01
RCL 46
ST+ 20
XEQ "PI"
RCL 41
+
RCL 20
1.6889
/
/
RCL 43
X>Y?
GTO 02
GTO 03
♦LBL 02
RCL Y
STO 43
RCL 20
STO 45
RCL 37
STO 42
♦LBL 03
RCL 44
RCL 20
X<=Y?
GTO 01
CF 03
TONE 5
RCL 45
1.6889
/
FIX 0
"VMR="
ARCL X
AVIEW
STOP
RCL 42
"P(VMR)="
ARCL X
AVIEW
STOP
END
```

APPENDIX F

EVALUATION OF ANALYTICAL SOLUTIONS

1. This appendix contains comparisons of predicted performance data from an aircraft operator's manual with analytical results obtained by the use of computational programs developed in this study. The UH-60A helicopter (Blackhawk) was selected to conduct this comparison. Performance data for the UH-60A was taken from charts in Chapter 7 of TM 55-1520-237-10 (Operator's Manual). Performance data for the T700-GE 700 engine was taken from [Ref. 19]. Analytical calculations were made based upon the standard sea level performance characteristics of the T700-GE 700 engine (Appendix B) and the following design data for the UH-60A:

Main Rotor	Tail Rotor	Aircraft
C = 1.75 ft	C = 0.81 ft	L<tail> = 31.50 ft
R = 26.8 ft	R = 5.50 ft	W<gross> = 20,250 lbs
b = 4	b = 4	F.P.A.(FF) = 25.7
CdO = 0.008	CdO = 0.008	Vmax = 156 kts
RV = 27.2 rad/sec	RV = 125 rad/sec	

Program "POWER" was used to compute total power requirements (P_T) for the aircraft and the Helicopter Power Computation Package was used to verify the calculations. Calculation of fuel flow rates, maximum endurance velocity,

maximum range velocity, and fuel weight were all made on the HP-41C and verified using program "FUELFLO" and the Helicopter Computation Package on the IBM 3033 Computer.

2. Initially it was necessary to convert the percent torque readings from the charts in the Operator's Manual to Engine Shaft Horsepower (ESHP). The method used was as follows:

From [Ref. 23]:

Maximum continuous Power at:	SHP	Output Shaft RPM	Output Torque (ft lb)
Stnd Sea Level	1310	20,000	344

Solve for the torque conversion factor:

$$\text{Torque (ft lb)} = \frac{\text{SHP}\cdot 550(\text{ft-lb/sec})(1/\text{hp})\cdot 60}{20{,}000\ \text{rev/min}(2\pi\ \text{rad/sec})}$$

$$= .263\ \text{SHP}$$

Then from TM 55-1520-237-10 Fig 7-4 at Standard Sea Level conditions:

Maximum Continuous Torque Available = 88%

Therefore 100% Torque (the transmission limit) for two engines is:

$2(344)/.88 = 792$ ft-lb

or

$792/.263 = 2973$ ESHP

This value of 2973 ESHP is a constant limit for the transmission and was used to convert chart readings of

percent torque available to engine shaft horsepower for comparison with analytical results.

3. Comparisons.

   a. ESHP and fuel flow rates: Table XI

   b. Maximum endurance and maximum range velocities: Table XII

   c. Mission profile fuel weight: Table XIII

TABLE XI

Analytical vs. Actual ESHP and Fuel Flow Rates

Standard Sea Level Conditions

	Analytical	Operator's Manual	% Error
Hover OGE			
ESHP	2399	2676	10
W_f (lb/hr)	1218	1263	4
50 knots			
ESHP	1413	1635	14
W_f (lb/hr)	829	895	7
100 knots			
ESHP	1276	1487	14
W_f (lb/hr)	775	845	8
130 knots			
ESHP	1593	1903	16
W_f (lb/hr)	900	975	8
4000 ft and 95 F			
Hover OGE			
ESHP	2575	3122*	18
W_f (lb/hr)	1259	1400*	10
50 knots			
ESHP	1551	1932	20
W_f (lb/hr)	854	970	12
100 knots			
ESHP	1245	1605	22
W_f (lb/hr)	733	850	14
130 knots			
ESHP	1452	2021	28
W_f (lb/hr)	815	1010	19

*Approximate; exceeds maximum continuous power available.

TABLE XII

Analytical vs. Actual Max Endurance and Range Velocities

	Analytical	Operator's Manual	% Error
Standard Sea Level Conditions			
Maximum Endurance Velocity (kts)	81	80	1
Maximum Range Velocity (kts)	140	142	1
4000 ft and 95 F			
Maximum Endurance Velocity (kts)	90	88	2
Maximum Range Velocity (kts)	149	129*	16

*Exceeds maximum continuous power available.

TABLE XIII

Analytical vs. Actual Mission Fuel Weight

Conditions

PA = 4000 ft

Temp = 95 F

Range = 275 nm

Cruise Velocity = 110 kts

Max Endurance Velocity:

= 88 kts (actual)

= 90 kts (analytical)

Normal Rated Power (2 engines):

= 2620 ESHP

Mission Fuel Weight Profile Equation

$$\text{Fuel Weight} = .05W_f<NRP> + W_f<cruise>*Range/V<cruise> + .25W_f<V<end>> + .05W_f<NRP>$$

Results

	Analytical	Operator's Manual	% Error
Fuel Weight (lbs)	2184	2343	7

Note: Fuel capacity for the UH-60A is 2345 lbs. This limited the cruise velocity which could be used to 110 knots for this comparison.

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