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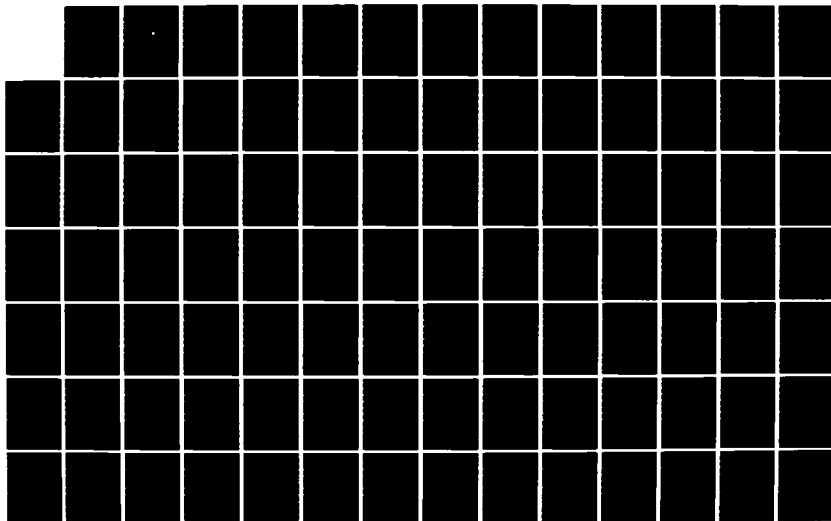
POWERPLANT SELECTION FOR CONCEPTUAL HELICOPTER DESIGN
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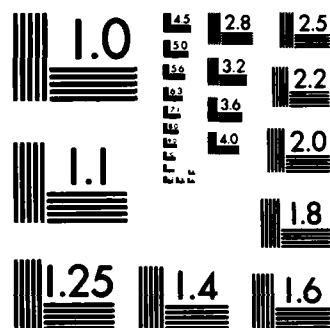
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NAVAL POSTGRADUATE SCHOOL
Monterey, California



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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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Powerplant Selection for Conceptual Helicopter Design

by

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Captain, United States Army
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Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN AERONAUTICAL ENGINEERING

from the

NAVAL POSTGRADUATE SCHOOL
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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 relevant 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:

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

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]:

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

Where n is the number of engines used.

TABLE I

Analytical vs. Actual Engine Performance

<u>20000 ft.</u>		<u>-12 F</u>	
<u>Engine</u>	<u>SHP Actual</u>	<u>SHP Analytical</u>	<u>% Difference</u>
A	214	208	3
B	369	350	5
C	914	772	15
D	1000	891	11
E	1378	1237	10
F	2070	1682	19

<u>4000 ft.</u>		<u>95 F</u>	
<u>Engine</u>	<u>SHP Actual</u>	<u>SHP Analytical</u>	<u>% Difference</u>
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 horsepower 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

<u>Engine</u>	<u>A/C</u>	<u>Dry Weight lbs.</u>	<u>Installed Weight lbs.</u>	<u>Military SHP @ SS1</u>
T63-A-5A	OH-6A	136.0	175.2	317
A11-250-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:

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

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].

Helicopter Engine Installation Weight for Helicopters in Table II

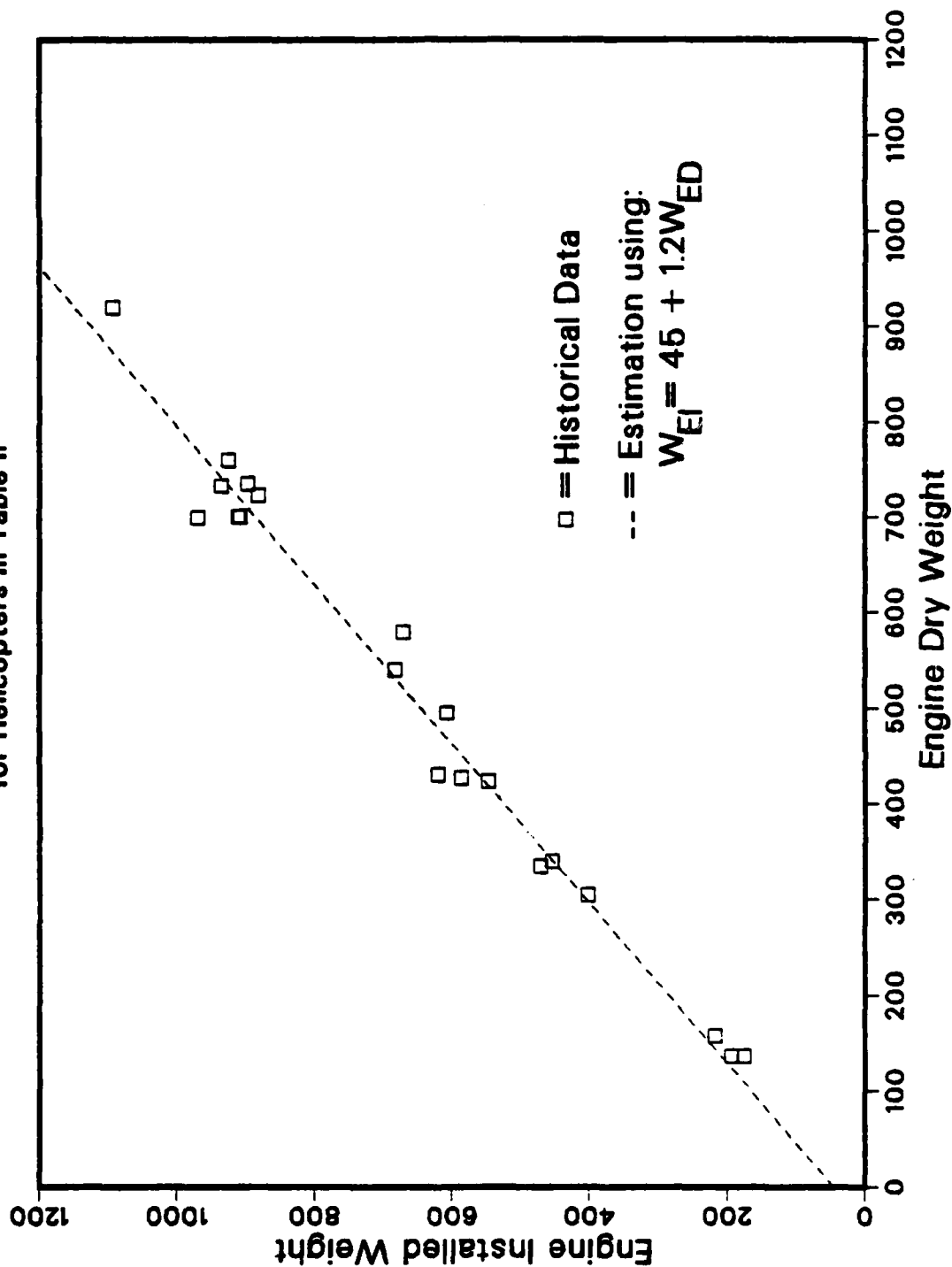


Figure 2.1 Engine Dry Weight vs. Installed Weight

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]:

$$\begin{aligned} \text{Fuel Wt.} = & .05W_f\langle\text{NRP}\rangle + W_f\langle\text{cruise}\rangle*\text{Range}\langle\text{max}\rangle/V\langle\text{cruise}\rangle \\ & + .25W_f\langle V\langle\text{end}\rangle\rangle + .05W_f\langle\text{NRP}\rangle \end{aligned} \quad (2.4)$$

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

<u>Subject Area</u>	<u>Program</u>		<u>Subroutine</u>	
	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:

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

where:

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

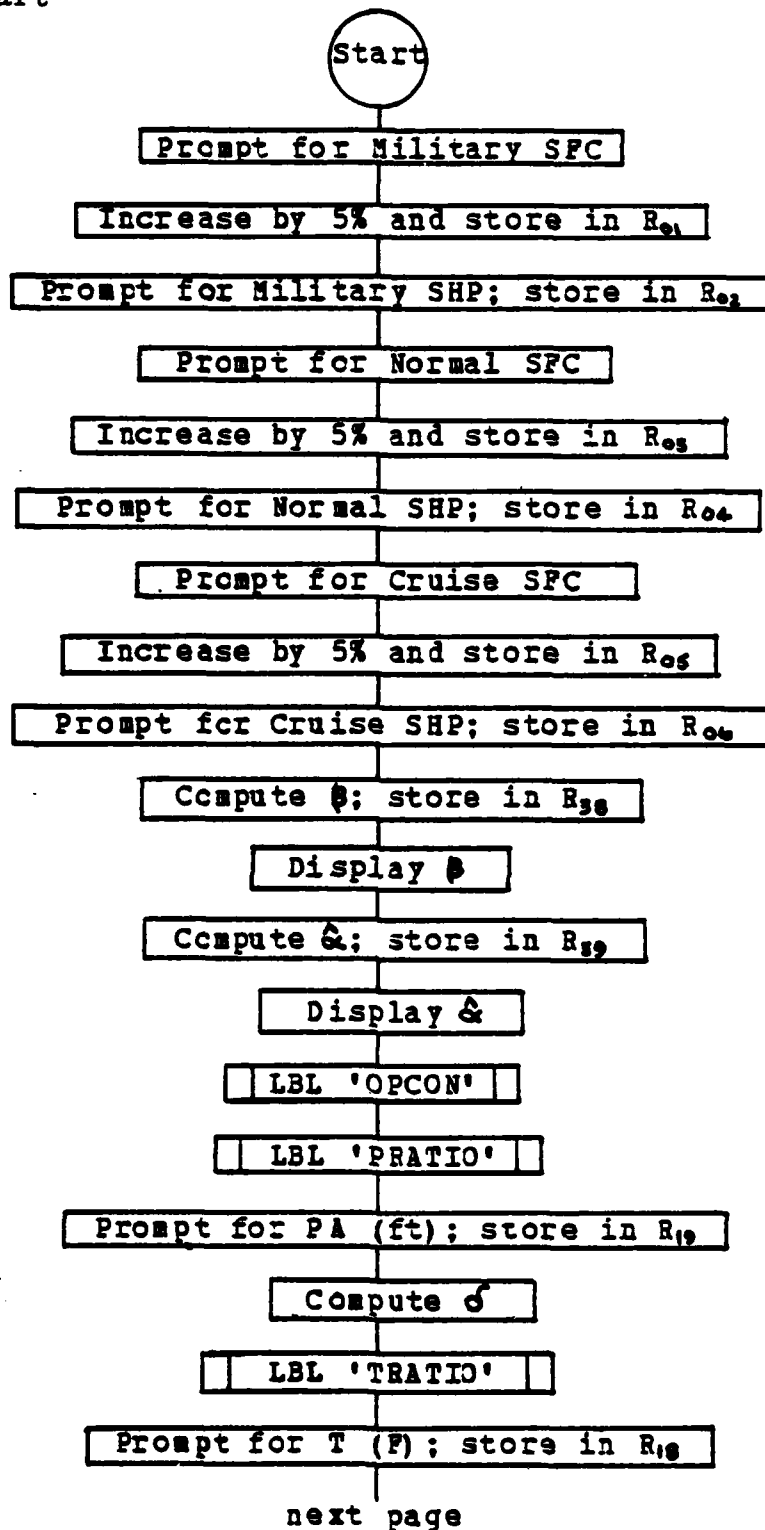
SHP is shaft horsepower of the engine

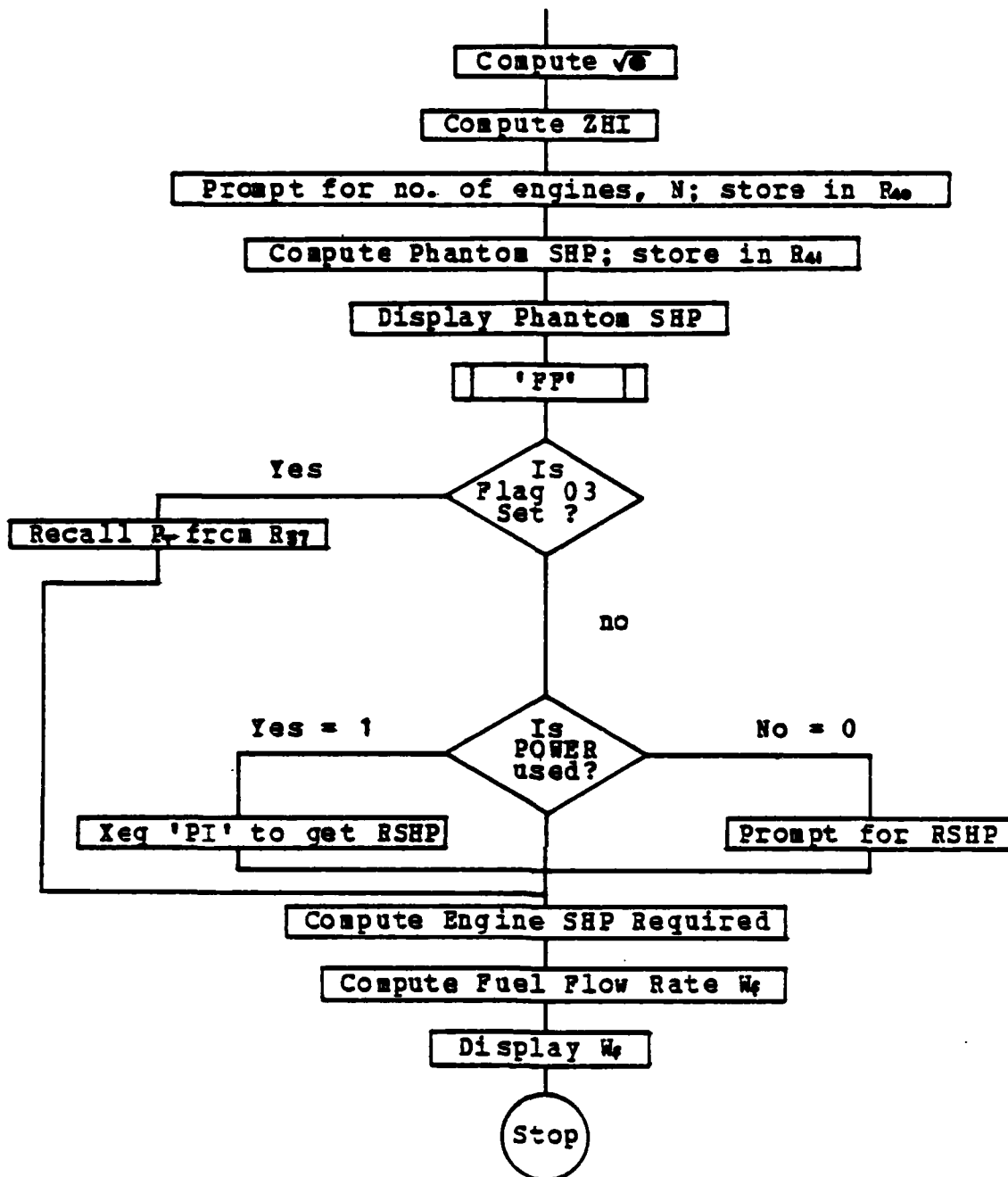
W_f is fuel flow rate (lb/hr)

$\hat{\beta}$ 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





4. Example Problem and User Instructions

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

<u>Engine Data</u>			<u>Operating conditions:</u>
	SHP	SFC	
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:

(XEQ) (ALPHA) FUEFL (ALPHA)

0.460 (R/S)

1561 (R/S)

0.470 (R/S)

1310 (R/S)

0.510 (R/S)

989 (R/S)

(R/S)

(R/S)

0 (R/S)

59 (R/S)

(R/S)

2 (R/S)

(R/S)

Display:

SFC-M?

SHP-M?

SFC-N?

SHP-N?

SFC-C?

SHP-C?

B = 0.3948

ALPHA = 135.32

PA=?

T(F)=?

ZHI = 135.32

N=?

PSHP = 685.46

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:

(XEQ) (ALPHA) FUEFL (ALPHA)

0.460 (R/S)

1561 (R/S)

0.470 (R/S)

1310 (R/S)

0.510 (R/S)

989 (R/S)

(R/S)

(R/S)

0 (R/S)

59 (R/S)

(R/S)

2 (R/S)

(R/S)

1 (R/S)

0 (R/S)

59 (R/S)

95 (R/S)

(R/S)

(R/S)

Display:

SFC-M?

SHP-M?

SFC-N?

SHP-N?

SFC-C?

SHP-C?

B = 0.3948

ALPHA = 135.32

PA=?

T(F)=?

ZHI = 135.32

N=?

PSHP = 685.46

POWER?

PA=?

T<F>=?

VF=?

PT = 499.17

PT = 499.17

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:

(XEQ) (ALPHA) FF (ALPHA)

1 (R/S)

0 (R/S)

59 (R/S)

120 (R/S)

(R/S)

(R/S)

Display:

POWER?

PA=?

T<F>=?

VF=?

PT = 706.50

PT = 706.50

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:

(XEQ) (ALPHA) OPCON (ALPHA)

4000 (R/S)

95 (R/S)

(R/S)

2 (R/S)

(R/S)

1 (R/S)

4000 (R/S)

95 (R/S)

Display:

PA. FT.?

T<F>?

ZHI = 120.86

N=?

PSHP = 612.20

POWER?

PA=?

T<F>=?

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

<u>Storage Register</u>	<u>Stored Quantity</u>
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 _{fM} - fuel flow rate at sea level military power with 5% increase (lb/hr)
08	W _{fN} - fuel flow rate at sea level normal power with 5% increase (lb/hr)
09	W _{fC} - 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

01 LBL "FUELF"	51 CLX
02 "SFC-M?"	52 RCL 07
03 PROMPT	53 RCL 09
04 STO 01	54 -
05 .05	55 RCL 02
06 *	56 RCL 06
07 ST+ 01	57 -
08 "SHP-M?"	58 /
09 PROMPT	59 ABS
10 STO 02	60 ST+ 38
11 "SFC-N?"	61 CLX
12 PROMPT	62 RCL 08
13 STO 03	63 RCL 09
14 .05	64 -
15 *	65 RCL 04
16 ST+ 03	66 RCL 06
17 "SHP-N?"	67 -
18 PROMPT	68 /
19 STO 04	69 ABS
20 "SFC-C?"	70 ST+ 38
21 PROMPT	71 3
22 STO 05	72 ST/ 38
23 .05	73 RCL 38
24 *	74 FIX 4
25 ST+ 05	75 "B="
26 "SHP-C?"	76 ARCL X
27 PROMPT	77 AVIEW
28 STO 06	78 STOP
29 RCL 01	79 FIX 2
30 RCL 02	80 RCL 02
31 *	81 *
32 STO 07	82 CHS
33 RCL 03	83 RCL 07
34 RCL 04	84 +
35 *	85 STO 39
36 STO 08	86 CLX
37 RCL 05	87 RCL 38
38 RCL 06	88 RCL 04
39 *	89 *
40 STO 09	90 CHS
41 CLX	91 RCL 08
42 RCL 07	92 +
43 RCL 08	93 ST+ 39
44 -	94 CLX
45 RCL 02	95 RCL 38
46 RCL 04	96 RCL 06
47 -	97 *
48 /	98 CHS
49 ABS	99 RCL 09
50 STO 38	100 +

```

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

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

$$W_{tf} = .05 W_f^{<NRP>} + \frac{\text{MAX RANGE}}{V_{\text{CRUISE}}} (W_f^{<V_{\text{CRUISE}}>}) \\ + .25 W_f^{<V_{\text{END}}>} + .05 W_f^{<NRP>}$$

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

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

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)

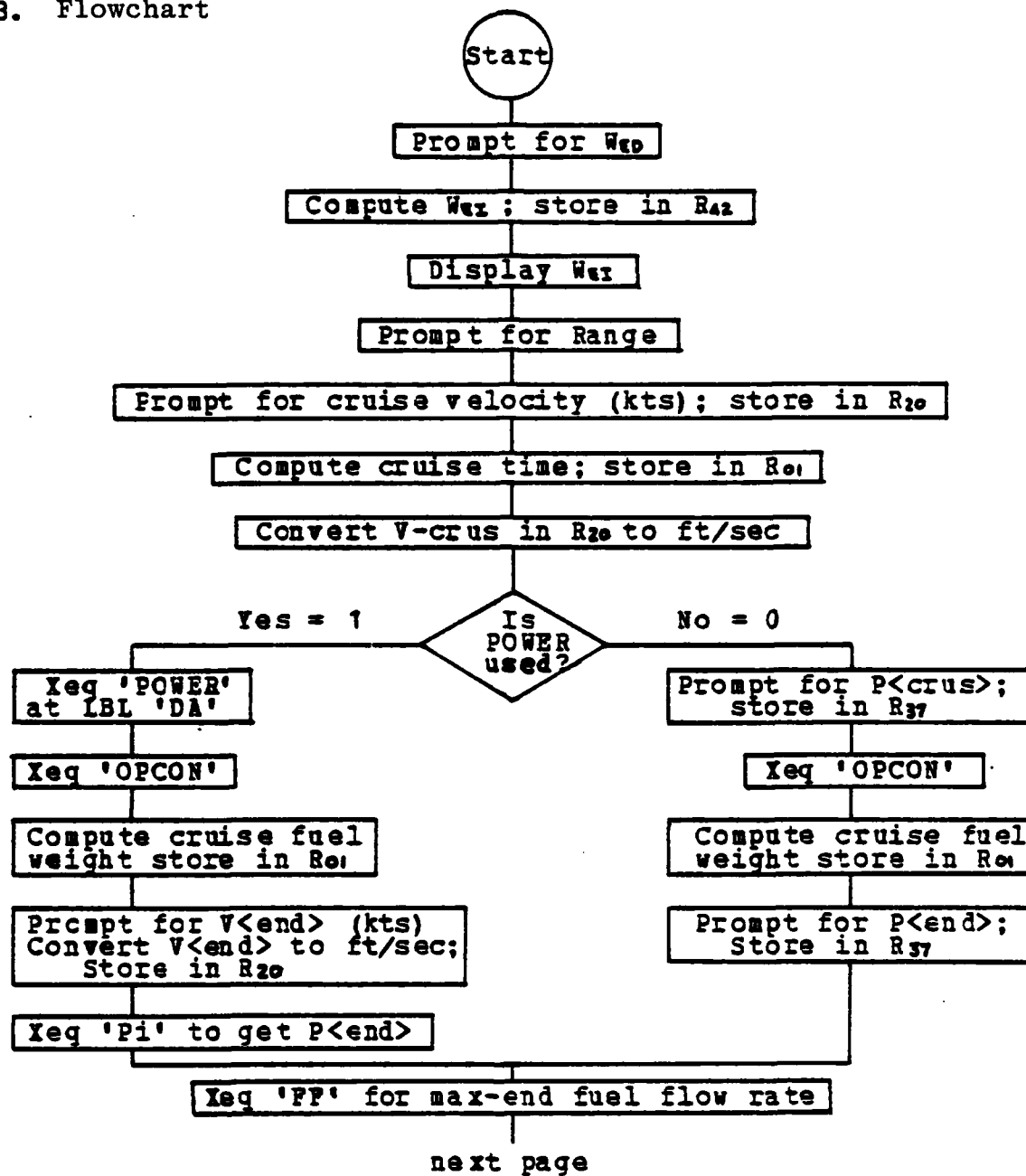
W^{<V_{END}>} is the fuel flow rate of the engine at maximum endurance velocity (lb/hr)

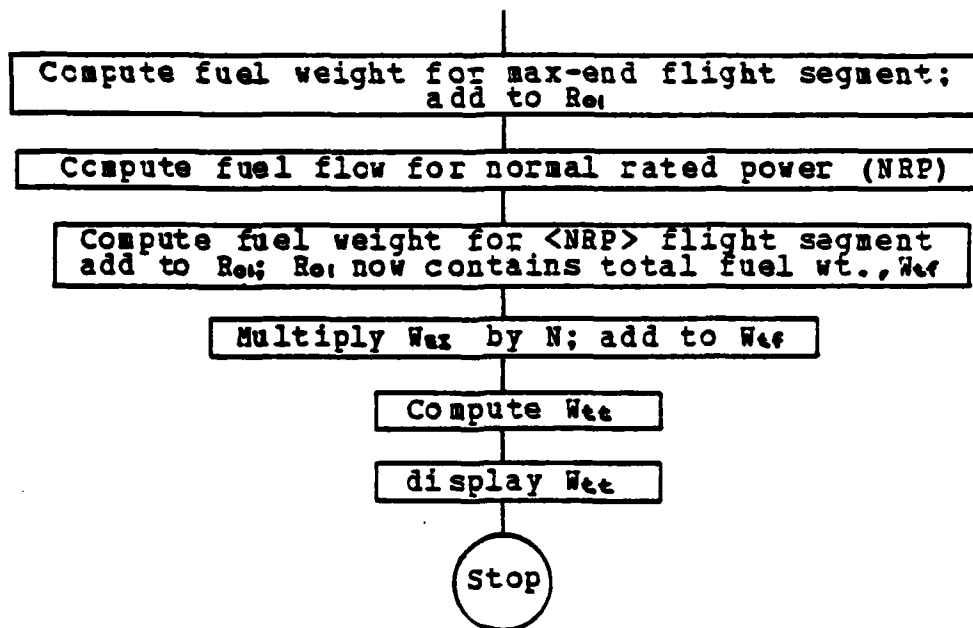
W_f is fuel flow rate (general) (lb/hr)

ESHP is engine shaft horsepower (hp)

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

3. Flowchart





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

<u>Storage Register</u>	<u>Stored Quantity</u>
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

```
01+LBL "WEIGHT"
02 SF 03
03 "WED=?"
04 PROMPT
05 1.2
06 *
07 45
08 +
09 STO 42
10 "WEI="
11 ARCL X
12 AVIEW
13 STOP
14 "RANGE?"
15 PROMPT
16 "V-CRUS?"
17 PROMPT
18 STO 20
19 /
20 STO 01
21 1.68889
22 ST* 20
23 "POWER?"
24 PROMPT
25 X=0?
26 GTO 01
27 XEQ "DA"
28 XEQ "OPCON"
29 PSE
30 RCL 01
31 *
32 STO 01
33 "V-END?"
34 PROMPT
35 1.68889
36 *
37 STO 20
38 XEQ "PI"
39 GTO 02
40+LBL 01
41 "P<CRUS>?"
```

```
42 PROMPT
43 STO 37
44 XEQ "OPCON"
45 PSE
46 RCL 01
47 *
48 STO 01
49 "P<END>?"
50 PROMPT
51 STO 37
52+LBL 02
53 XEQ "FF"
54 PSE
55 .25
56 *
57 ST+ 01
58 RCL 04
59 RCL 40
60 *
61 RCL 41
62 +
63 RCL 38
64 *
65 .1
66 *
67 ST+ 01
68 CF 03
69 RCL 01
70 "FL WT="
71 ARCL X
72 AVIEW
73 STOP
74 RCL 42
75 RCL 40
76 *
77 +
78 "WTT="
79 ARCL X
80 AVIEW
81 END
```

APPENDIX D

FORTTRAN 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 power-plant 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:

<u>Main Rotor</u>	<u>Tail Rotor</u>	<u>Aircraft</u>
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 condi-
    tions 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
         $W_{tt} = n(W_{EI}) + \text{Fuelwt}$ 
    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 CONDITICNS -----

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 PCWEFFLANT 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 FCWEERFLANT 2 AND FUEL: 3399.25 LB	

RECOMMEND ENGINE 1 BE SELECTED

[illegible]


```

C----- DECLARE VARIABLES -----
REAL BETA, DELTA, FUELHT, PSHP, RSHPMX, PAFT, SPCI(3), SHPI(3), STHETA, T, W
1EDRY, WPA, WFB, WFC, WFSI, WFA, WFT, ALEHA, ZHI(3), ZHIY, SPC(3), SHP(3), WTOT(5
2) , PWR, PWRM, PWRBT, PWRI, PWRIM, PWRBT, PWRO, PWROH, PWROT, PWRP, VPK, VPK, VPK, VPK, VPK, VPK
3, PA, TF, PA, LT, SE, RH, DA, CH, ST, RT, DT, CT, PEND
C
C DIMENSION PWR(200), PWRM(200), PWRBT(200), PWRI(200), PWRIM(200), PWRIT(
1200), PWRO(200), PWRCH(200), PWRROT(200), PWRP(200), PWRPM(200), VPK(200)
C
C INTEGER I, J, K, N, IRESP, LRESP1, NORV, VCRUS, VINC, VMAX, VCNT, VMAX, NM, NT,
1VR
C
C DATA LRESP/'Y'//, LRESP1/'Q'//
C
C----- DEFINE FILES -----
CALL FRTCHS ('FILEDEF', 4, 'DISK', 'HPWRPIP',
1
C
C WRITE HEADING
C
C WRITE (8, 350)
C
C----- READ DATA FROM FILE: HPWRPIP DATA A -----
READ (4, 360) GW, PA, TF, FA, IT, VMAX, VINC
READ (4, 370) SM, RH, DM, CH, 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), PWRBT(I), PWRI(I), PWRO(I), PWRP(
1I), PWRIM(I), PWRIT(I), PWRCH(I), PWRROT(I), PWRPM(I), PWRBT(I)
C
10 CONTINUE
J=1
C
C----- WRITE USER INSTRUCTIONS -----
CALL FRTCHS ('CLRSCRN')
WRITE (6, 400)
WRITE (6, 410)
C
C WRITE (6, 420)
READ (5, 430) NORV
C
C IF (.NOT. (NORV.EQ.LRESP)) GO TO 340
C

```

A 920
A 930
A 940
A 950
A 960
A 970
A 980
A 990
A 1000
A 1010
A 1020
A 1030
A 1040
A 1050
A 1060
A 1070
A 1080
A 1090
A 1100
A 1110
A 1120
A 1130
A 1140
A 1150
A 1160
A 1170
A 1180
A 1190
A 1200
A 1210
A 1220
A 1230
A 1240
A 1250
A 1260
A 1270
A 1280
A 1290
A 1300
A 1310
A 1320
A 1330
A 1340
A 1350
A 1360
A 1370
A 1380
A 1390

A1400
A1410
A1420
A1430
A1440
A1450
A1460
A1470
A1480
A1490
A1500
A1510
A1520
A1530
A1540
A1550
A1560
A1570
A1580
A1590
A1600
A1610
A1620
A1630
A1640
A1650
A1660
A1670
A1680
A1690
A1700
A1710
A1720
A1730
A1740
A1750
A1760
A1770
A1780
A1790
A1800
A1810
A1820
A1830
A1840
A1850
A1860

```

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

```

C
C
C
20
C
C
C
30
C
C
C
C
40
50
C
C
C
C
60
70
C
C
C
C
80
90

```

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

```

```

A1870
A1880
A1890
A1900
A1910
A1920
A1930
A1940
A1950
A1960
A1970
A1980
A1990
A2000
A2010
A2020
A2030
A2040
A2050
A2060
A2070
A2080
A2090
A2100
A2110
A2120
A2130
A2140
A2150
A2160
A2170
A2180
A2190
A2200
A2210
A2220
A2230
A2240
A2250
A2260
A2270
A2280
A2290
A2300
A2310
A2320
A2330

```

```

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

```

A2340
A2350
A2360
A2370
A2380
A2390
A2400
A2410
A2420
A2430
A2440
A2450
A2460
A2470
A2480
A2490
A2500
A2510
A2520
A2530
A2540
A2550
A2560
A2570
A2580
A2590
A2600
A2610
A2620
A2630
A2640
A2650
A2660
A2670
A2680
A2690
A2700
A2710
A2720
A2730
A2740
A2750
A2760
A2770
A2780
A2790
A2800
A2810

```

C----- PROMPT FOR NUMBER OF ENGINES AND CALCULATE PSHP-----
C CALL FRTCHS ('CLSCRN')
C WRITE (6,680)
C
C READ (5,*) N
C
C CALL ZVSHF (ZHIX,EETA,N,PSHP)
C WRITE (6,690) PSHP
C
170 CONTINUE
C
C----- CALCULATE FUEL FLOW RATE -----
C ** SUBSEQUENT ENGINE COMPARISONS WILL BE MADE ONLY AT THE FINAL **
C ** ROTOR SHP REQUIRED ENTERED FOR ENGINE 1 AS WELL AS AT THE DESIGN **
C ** MISSION PROFILE OPERATING CONDITIONS. **
C IF (J.EQ.1) GO TO 200
C
C ELSE CALCULATE FUEL FLOW RATE FOR ENGINE J AT LAST ROTOR SHP
C REQUIRED ENTERED FOR ENGINE 1
C
C CALL FLOAT (RSHPMY,EETA,N,PSHF,WPALT)
C WRITE (8,730)
C WRITE (8,740) PAFT,N,T,PSHP,ZHIX,RSHPMY,WPALT
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
C DIFF=ABS(PA-PAFT)
C DIFF1=ABS(TP-T)
C IF (DIFF.LT.1.0) GC TO 180
C WRITE (6,750)
C WRITE (8,750)
C CONTINUE
180 IF (DIFF1.LT.1.0) GO TO 190
C WRITE (6,760)
C WRITE (8,760)
C CONTINUE
190
C GO TO 270
C CONTINUE
200
C
C

```

A2820
A2830
A2840
A2850
A2860
A2870
A2880
A2890
A2900
A2910
A2920
A2930
A2940
A2950
A2960
A2970
A2980
A2990
A3000
A3010
A3020
A3030
A3040
A3050
A3060
A3070
A3080
A3090
A3100
A3110
A3120
A3130
A3140
A3150
A3160
A3170
A3180
A3190
A3200
A3210
A3220
A3230
A3240
A3250
A3260

```

C----- WRITE OPTICNS FOR CALCULATION OF FUEL FLOW RATE -----
C      WRITE (6,700)
      READ (5,*) M
      IF (M.EQ.3) GO TO 240
      IF (M.EQ.1) GO TO 210
      WRITE (6,710)
      READ (5,*) VR
      RSHPMX=PMK(VR+1)
      GO TO 220
210    CONTINUE
      WRITE (6,720)
      READ (5,*) RSHPMX
      CONTINUE
C----- CALCULATE FUEL FLOW RATE -----
C      CALL FLOAT (RSHPMX,BETA,N,PSHP,WFALT)
C      CALL FRTCMS ('CLRSCRN')
C----- PRINT FUEL PLW DATA -----
C      WRITE (6,730)
C      WRITE (8,730)
C      WRITE (6,740)
C      WRITE (8,740)
C      EAPT,N,T,PSHP,ZHIX,RSHPMX,WFALT
C      EAPT,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-PAPT)
C      DIFF1=ABS(TF-T)
C      IF (DIFF.LT.1.0) GC TO 230
C      WRITE (6,750)
C      WRITE (8,750)
C      CONTINUE
230    IF (DIFF1.LT.1.0) GO TO 240
      WRITE (6,760)
      WRITE (8,760)
      CONTINUE
240    WRITE (6,770)
C
C

```

A3270
A3280
A3290
A3300
A3310
A3320
A3330
A3340
A3350
A3360
A3370
A3380
A3390
A3400
A3410
A3420
A3430
A3440
A3450
A3460
A3470
A3480
A3490
A3500
A3510
A3520
A3530
A3540
A3550
A3560
A3570
A3580
A3590
A3600
A3610
A3620
A3630
A3640
A3650
A3660
A3670
A3680
A3690
A3700
A3710
A3720

```

C----- WRITE OPTIONS FOR DOING ADDITIONAL FUEL FLOW CALCULATIONS -----
C
C      READ (5,780) NCRY
C
C      IF (.NOT.(NORY.EQ.LRESP)) GO TO 250
250  GO TO 150
C      CONTINUE
C      IF (NORY.EQ.LRESP1) GO TO 340
C      WRITE (6,790)
C
C      READ (5,800) NORY
C
C      IF (.NOT.(NORY.EQ.LRESP)) GO TO 260
260  GO TO 170
C      CONTINUE
C      IF (NORY.EQ.LRESP1) GO TO 340
C      CONTINUE
270
C
C      FOR SUSEQUENT ENGINE COMPARISONS, USE THE DESIGN MISSION PROFILE
C
C      IF (.NOT.(J.EQ.1)) GC TO 280
C
C----- CALCULATE FUEL WEIGHT FOR MISSION PROFILE-----
C      WRITE (6,810)
C
C      READ (5,820) NORY
C
C      IF (NORY.EQ.LRESP1) GO TO 340
C      IF (.NOT.(NORY.EQ.LRESP)) GO TO 290
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

```

A3730
A3740
A3750
A3760
A3770
A3780
A3790
A3800
A3810
A3820
A3830
A3840
A3850
A3860
A3870
A3880
A3890
A3900
A3910
A3920
A3930
A3940
A3950
A3960
A3970
A3980
A3990
A4000
A4010
A4020
A4030
A4040
A4050
A4060
A4070
A4080
A4090
A4100
A4110
A4120
A4130
A4140
A4150
A4160
A4170
A4180
A4190

```

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

```

A4 200
A4 210
A4 220
A4 230
A4 240
A4 250
A4 260
A4 270
A4 280
A4 290
A4 300
A4 310
A4 320
A4 330
A4 340
A4 350
A4 360
A4 370
A4 380
A4 390
A4 400
A4 410
A4 420
A4 430
A4 440
A4 450
A4 460
A4 470
A4 480
A4 490
A4 500
A4 510
A4 520
A4 530
A4 540
A4 550
A4 560
A4 570
A4 580
A4 590
A4 600
A4 610
A4 620
A4 630
A4 640
A4 650
A4 660

```

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

```

A4670
A4680
A4690
A4700
A4710
A4720
A4730
A4740
A4750
A4760
A4770
A4780
A4790
A4800
A4810
A4820
A4830
A4840
A4850
A4860
A4870
A4880
A4890
A4900
A4910
A4920
A4930
A4940
A4950
A4960
A4970
A4980
A4990
A5000
A5010
A5020
A5030
A5040
A5050
A5060
A5070
A5080
A5090
A5100
A5110
A5120
A5130
A5140

```

410 1H1. CALCULATION OF ENGINE FUEL FLOW, 45H CHARACTERISTICS USING INPUT
2T VALUES OF ENGINE, 2X, 58HSSL SPECIFIC FUEL CONSUMPTION AND SHAFT
3 HORSEPOWER AVAILABLE AT THREE, 2X, 15HPOWER SETTING, 2X, 21H2.
4 CALCULATION OF THE 48H SHAFT HORSEPOWER, 2X, 35H3. CALCULATION OF
5 URE ESTIMATED ENGINE, 39HINE INSTALLED WEIGHT, 2X, 35H4. CALCULATION OF
6 THE ESTIMATED ENGINE, 35HINE INSTALLED WEIGHT, 2X, 35H4. CALCULATION OF
7 F ESTIMATED ENGINE, 35HINE INSTALLED WEIGHT, 2X, 35H4. CALCULATION OF
8 WEIGHT FUEL, 4H AND 2X, 49HPOWERPLANT WEIGHT, 2X, 35H4. CALCULATION OF
9 OPTIMUM FUEL, 4H AND 2X, 49HPOWERPLANT WEIGHT, 2X, 35H4. CALCULATION OF
$ WRITTEN BOT 38H TO THE TERMINAL AND TO FILE, -FUELFLO, 2X, 10H LIST
$ 50H WHICH IS CREATED BY THE PROGRAM, ENTER ONE OF THE FOLLOWING
$ 1H1, 51H THROUGHOUT THE PROGRAM, EXECUTION: 1X, 6HY: YES, 1X
1. 1X, 41H: NO, 1X, 7HQ: CUIT, 1X, 32HNOV ENTER Y TO CONTINUE OR Q TO, 1
2. 1X, 41H: NO, 1X, 7HQ: CUIT, 1X, 32HNOV ENTER Y TO CONTINUE OR Q TO, 1
3. 1X, 41H: NO, 1X, 7HQ: CUIT, 1X, 32HNOV ENTER Y TO CONTINUE OR Q TO, 1
4. 1X, 41H: NO, 1X, 7HQ: CUIT, 1X, 32HNOV ENTER Y TO CONTINUE OR Q TO, 1
420 1H1. 48H THIS SEGMENT OF THE PROGRAM CALCULATES THE FUEL, 1
430 1H1. 48H THIS SEGMENT OF THE PROGRAM CALCULATES THE FUEL, 1
440 1H1. 48H THIS SEGMENT OF THE PROGRAM CALCULATES THE FUEL, 1
450 1H1. 48H THIS SEGMENT OF THE PROGRAM CALCULATES THE FUEL, 1
460 1H1. 48H THIS SEGMENT OF THE PROGRAM CALCULATES THE FUEL, 1
470 1H1. 48H THIS SEGMENT OF THE PROGRAM CALCULATES THE FUEL, 1
480 1H1. 48H THIS SEGMENT OF THE PROGRAM CALCULATES THE FUEL, 1
490 1H1. 48H THIS SEGMENT OF THE PROGRAM CALCULATES THE FUEL, 1
500 1H1. 48H THIS SEGMENT OF THE PROGRAM CALCULATES THE FUEL, 1
510 1H1. 48H THIS SEGMENT OF THE PROGRAM CALCULATES THE FUEL, 1
520 1H1. 48H THIS SEGMENT OF THE PROGRAM CALCULATES THE FUEL, 1
530 1H1. 48H THIS SEGMENT OF THE PROGRAM CALCULATES THE FUEL, 1
540 1H1. 48H THIS SEGMENT OF THE PROGRAM CALCULATES THE FUEL, 1
550 1H1. 48H THIS SEGMENT OF THE PROGRAM CALCULATES THE FUEL, 1
560 1H1. 48H THIS SEGMENT OF THE PROGRAM CALCULATES THE FUEL, 1
570 1H1. 48H THIS SEGMENT OF THE PROGRAM CALCULATES THE FUEL, 1
580 1H1. 48H THIS SEGMENT OF THE PROGRAM CALCULATES THE FUEL, 1
590 1H1. 48H THIS SEGMENT OF THE PROGRAM CALCULATES THE FUEL, 1
600 1H1. 48H THIS SEGMENT OF THE PROGRAM CALCULATES THE FUEL, 1
610 1H1. 48H THIS SEGMENT OF THE PROGRAM CALCULATES THE FUEL, 1
620 1H1. 48H THIS SEGMENT OF THE PROGRAM CALCULATES THE FUEL, 1

```

```

630  FORMAT (//7X,45H"THE PROGRAM CAN NOW CALCULATE THE ZERO SHAFT-//2X,
145H"HORSEPOWER INCREMENT AT ANY DESIRED PRESSURE//2X,41H"ALTITUDE A
2ND TEMPERATURE UP TO 36,000 FT.//2X,6H"ENTER ,27HY TO CONTINUE OR
30 TO QUIT.",//)
640  FORMAT (A1)
650  FORMAT (2X,31H"ENTER PRESSURE ALTITUDE IN FEET//")
660  FORMAT (2X,31H"ENTER TEMPERATURE IN DEGREES F.")
670  FORMAT (2X,41H"THE ZERO SHP INCREMENT FOR THIS ENGINE AT//5X,7HP
1.A. = ,F8.2,4H FT.//5X,7HTEMP = ,F8.2,4H LB/HR//
2)
680  FORMAT (2X,45H"TO CALCULATE THE PHANTOM HORSEPOWER FOR THESE//51H C
10NDITION S ENTER THE NUMBER OF ENGINES BEING USED://")
690  FORMAT (2X,14H"PHANTOM SHP = ,F10.2,3H HP//")
700  FORMAT (5X,52H"THE PROGRAM CAN NOW CALCULATE THE FUEL FLOW RATE FOR
1/59H THIS POWER REQUIREMENT//2X,32H2. INPUT THE VELOCITY AT WHICH T.19
251H POWER REQUIREMENT DIRECTLY.,/2X,34H"THE PROGRAM WILL READ THE APPROPRI,25H
31H INPUT RSHP IS DESIRED.,/2X,34H"THE PROGRAM WILL READ THE APPROPRI,25H
4HHE RSHP IS DESIRED.,/2X,34H"THE PROGRAM WILL READ THE APPROPRI,25H
5ATE POWER FROM DATA FILE.,/2X,8HHPWRPF.,/2X,14HNOTE: THIS FILE,40H
6E MUST ALREADY RESIDE ON THE USER'S DISK.,/2X,8H3. QUIT.,/5X,15H"EN
7TER 1, OR 3)
710  FORMAT (1X,32H"ENTER FORWARD VELOCITY IN KNOTS.")
720  FORMAT (1X,38H"ENTER ROTOR SHAFT HORSEPOWER REQUIRED.")
730  FORMAT (10X,30H"----- FUEL FLOW RATE -----")
740  FORMAT (2X,4H"PA: ,F8.1,3H FT,20X,3HN: ,I2,2,2X,7HTEMP: ,F7.1,2H F
1.19X,6HPSHP: ,F10.2,4H SHP,15H"FUEL FLOW RATE: ,F10.2,6H LB/HR,17X,2HRS,4HHP
2: ,F10.2,4H SHP,15H"CAUTION: ALTITUDE FOR ENGINE FUEL FLOW RATE IS N,1
11HOT THE SAME.,/1X,48H"CAUTION: ALTITUDE AT WHICH POWER REQUI,18HRED W
2AS CALCULATED//")
750  FORMAT (//1X,48H"CAUTION: TEMPERATURE FOR ENGINE FUEL FLOW RATE I,1
14HS NOT THE SAME.,/1X,31H"AS THE ALTITUDE AT WHICH POWER ,23HREQUIRE
2D WAS CALCULATED//")
760  FORMAT (2X,53HDO YOU WANT TO TRY THE SAME ENGINE AT NEW CONDITIONS
1?//5X,8HY,N,OR Q)
770  FORMAT (A1)
780  FORMAT (2X,40HDO YOU WANT TO TRY THE SAME ENGINE AT A ,28HDIFFEREN
790  FORMAT (2X,40HDO YOU WANT TO TRY THE SAME ENGINE AT A ,28HDIFFEREN
800  FORMAT (A1)
810  FORMAT (2X,44H"THE MISSION PROFILE SPECIFIED FOR THE DESIGN,26H OF
1A BASIC HELICOPTER IS:////5X,21H1. 5 MINUTES @ NORMAL,13H"RATED
2POWER.,/5X,34H3. 5 MINUTES @ NORMAL,13H"RATED VELOC
3ITY.,/5X,34H3. 5 MINUTES @ NORMAL,13H"RATED VELOC
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)

```

```

A5610
A5620
A5630
A5640
A5650
A5660
A5670
A5680
A5690
A5700
A5710
A5720
A5730
A5740
A5750
A5760
A5770
A5780
A5790
A5800
A5810
A5820
A5830
A5840
A5850
A5860
A5870
A5880
A5890
A5900
A5910
A5920
A5930
A5940
A5950
A5960
A5970
A5980
A5990
A6000
A6010
A6020
A6030
A6040
A6050
A6060
A6070

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```

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
3HR REQD:,,2X,F8.2,4H SHP,//2X,12HMAX END VEL:,,1X,I3,4H KTS,8X,17HMA
4X END PWR REQD:,,1X,F8.2,4H SHEF//)
860 FORMAT (2X,36HINSTALLED 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 COMPARE ANOTHER ENGINE?.,//.5X,6HY OR
1N)
880 FORMAT (A1)
890 FORMAT (2X,17HRECOMMEND 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)
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)
CONTINUE
10 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
CONTINUE
BETA1=ABS ((WF(1)-WF(2))/(SHP(1)-SHP(2)))
CONTINUE
IF (.NOT. (SHP(1).EQ.SHP(3))) GO TO 40
BETA2=0.0
J=J-1
GO TO 50
CONTINUE
BETA2=ABS ((WF(1)-WF(3))/(SHP(1)-SHP(3)))
40 C

```

```

330 CONTINUE
340 IF (.NOT. (SHP (2) .EQ. SHP (3))) GO TO 60
350 BETA3=0.0
360 J=J-1
370 GO TO 70
380 CONTINUE
390 BETA3=ABS ((WF (2) -WF (3)) / (SHP (2) -SHP (3)))
400 CONTINUE
410 IF (.NOT. (FLOAT (J) .LT. 0.0)) GO TO 80
420 BETA=0.0
430 GO TO 90
440 CONTINUE
450 BETA=(BETA1+BETA2+EETA3) /FLOAT (J)
460 CONTINUE
470
480
490 DO 100 I=1,3
500 ZHI(I)=WF(I) - (EETA*SHP(I))
510 CONTINUE
520 ALPHA=(ZHI (1) +ZHI (2) +ZHI (3)) /3.
530
540 RETURN
550 END
-----
C SUBROUTINE FRATIO: CALCULATES RATIO OF PRESSURE AT ALTITUDE
C TO THE PRESSURE AT SEA LEVEL.
C-----
C
C SUBROUTINE PRATIO (PAFT, DELTA)
C
C REAL PAFT, DELTA
C
C IF (.NOT. (PAFT.EQ.0.0)) GO TO 10
C DELTA=1.0
C GO TO 20
C CONTINUE
C DELTA=(1.0-(6.8754E-06*PAFT)) **5.256
C CONTINUE
C RETURN
C END
-----
C SUBROUTINE TRATIO: CALCULATES RATIO OF TEMPERATURE AT OPERATING
C CONDITIONS TO SSL TEMPERATURE.
C-----
C
C SUBROUTINE TRATIO (T, STHETA)
C
C REAL T, STHETA

```

```

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

```

```

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

```

```

G 170
G 180
G 190
G 200
G 210-
H 10
H 20
H 30
H 40
H 50
H 60
H 70
H 80
H 90
H 100
H 110
H 120
H 130
H 140-
I 10
I 20
I 30
I 40
I 50
I 60
I 70
I 80
I 90
I 100
I 110-
J 10
J 20
J 30
J 40
J 50
J 60
J 70
J 80
J 90
J 100
J 110
J 120

```

140
150
160
170
180
190
200
210
220
230
240
250-

VEND=VFK(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=VFK(I)
PEND=PWR(I)
CONTINUE
CONTINUE
RETURN
END

10
20
C

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:

$$A_D = \pi R^2$$

$$\sigma = \frac{bc}{\pi R}$$

$$V_T = \Omega R$$

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

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

$$v_i = \left[\frac{T}{2\rho A_D} \right]^{\frac{1}{2}}$$

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

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

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

b. Main rotor only:

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

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

$$T_{MR} = W$$

c. Tail rotor only:

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

d. Operating conditions:

$$h_p = \frac{1 - \left[\frac{T_{SSL}}{T} \frac{1 - K_1 h_p}{K_1} \right]^{0.23496}}{K_1}$$

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

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)

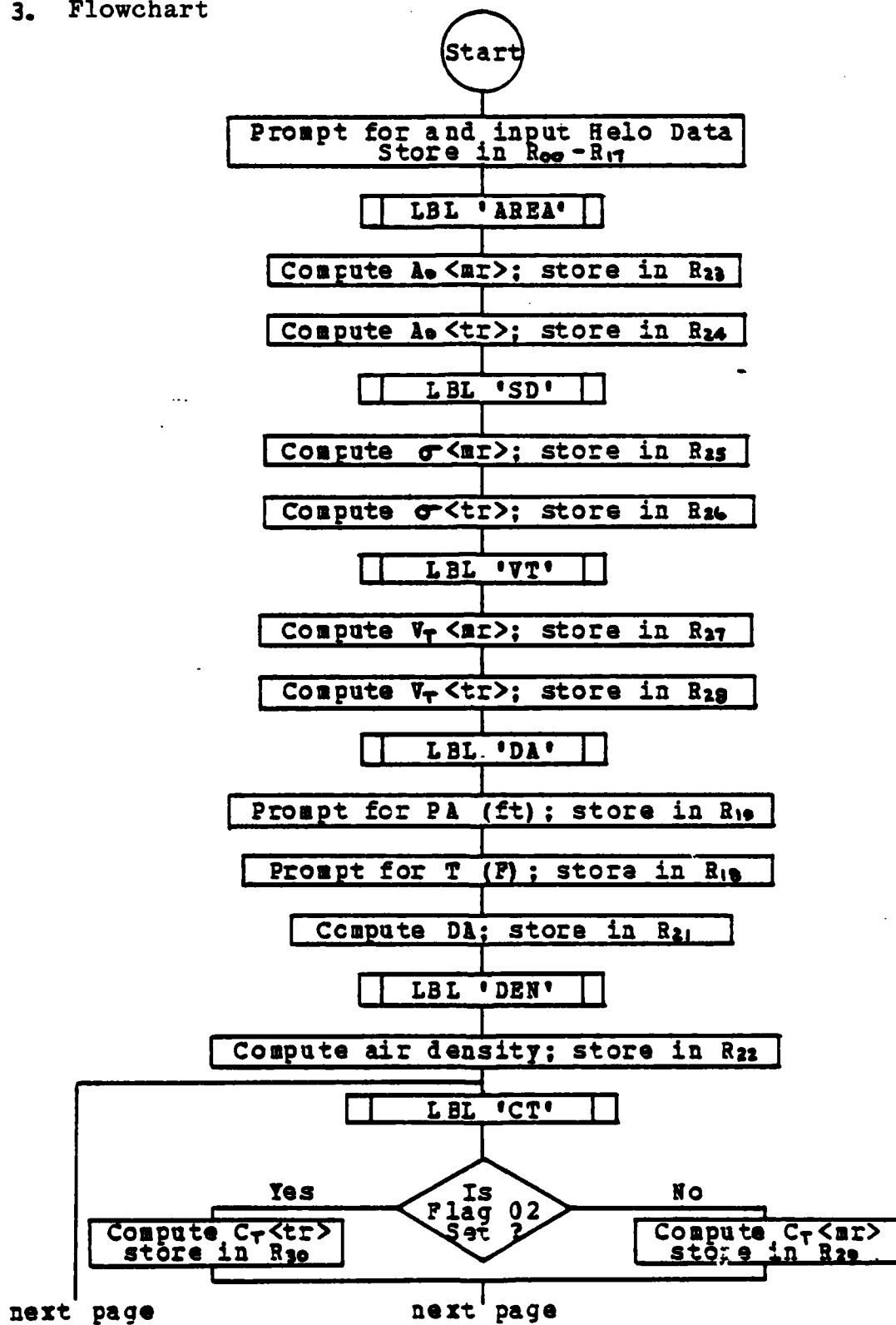
σ is the solidity

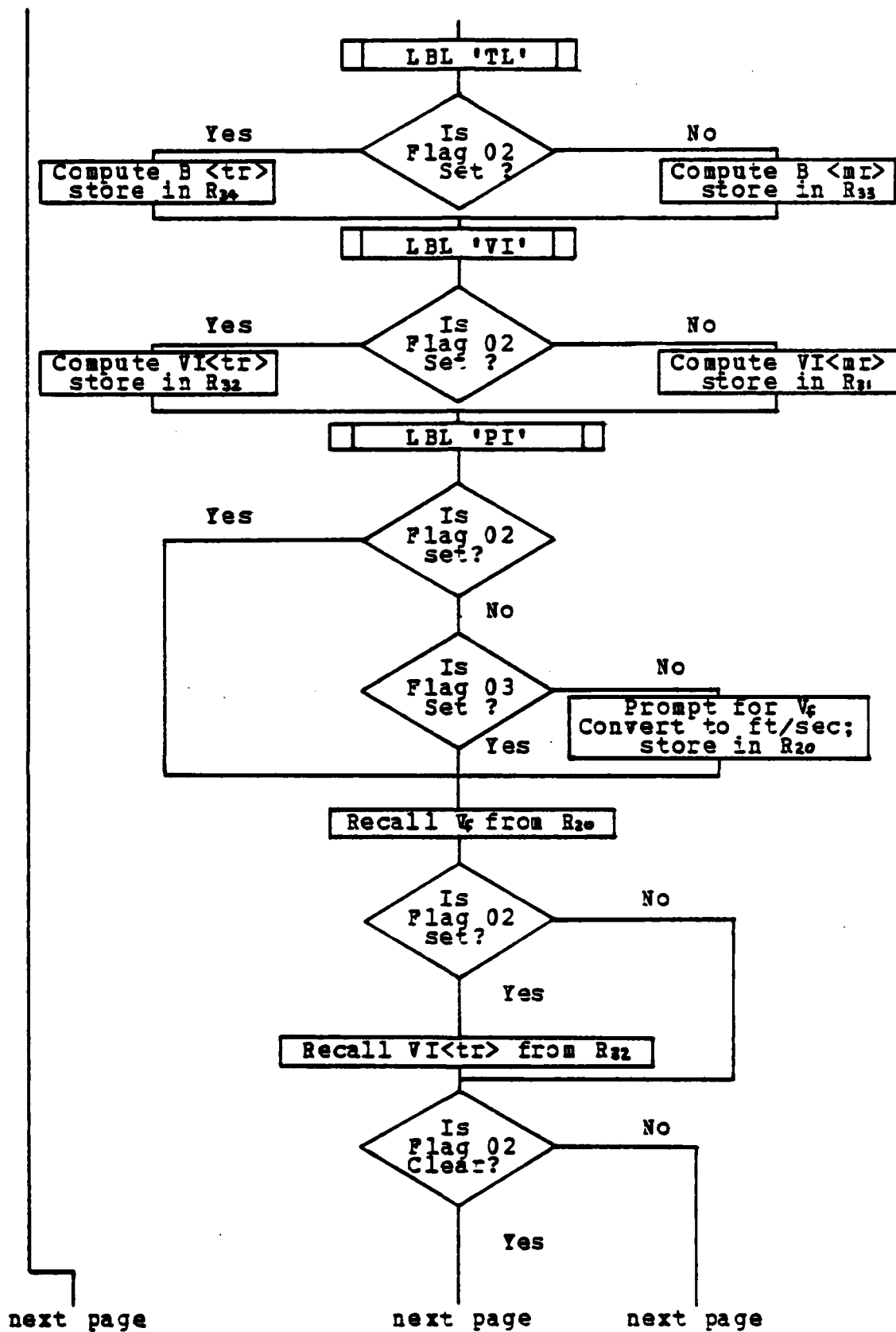
C	is the rotor chord (ft)
b	is the number of rotor blades
V_T	is the rotor tip velocity (ft/sec)
Ω	is the rotational velocity of the rotor (rad/sec)
C_T	is the coefficient of thrust
T_{tr}	is the thrust required for the tail rotor (lb)
ρ	is the air density (slugs/ft)
B	is the tiploss factor
v_i	is the induced velocity (ft/sec)
V_{i_f}	is the induced velocity in forward flight (ft/sec)
V_f	is the forward velocity (ft/sec)
$P_{i_{TL}}$	is the induced power required with tip loss (hp)
P_o	is the profile power required (hp)
$\overline{C}_{dO}$	is the profile drag coefficient
P_p	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)

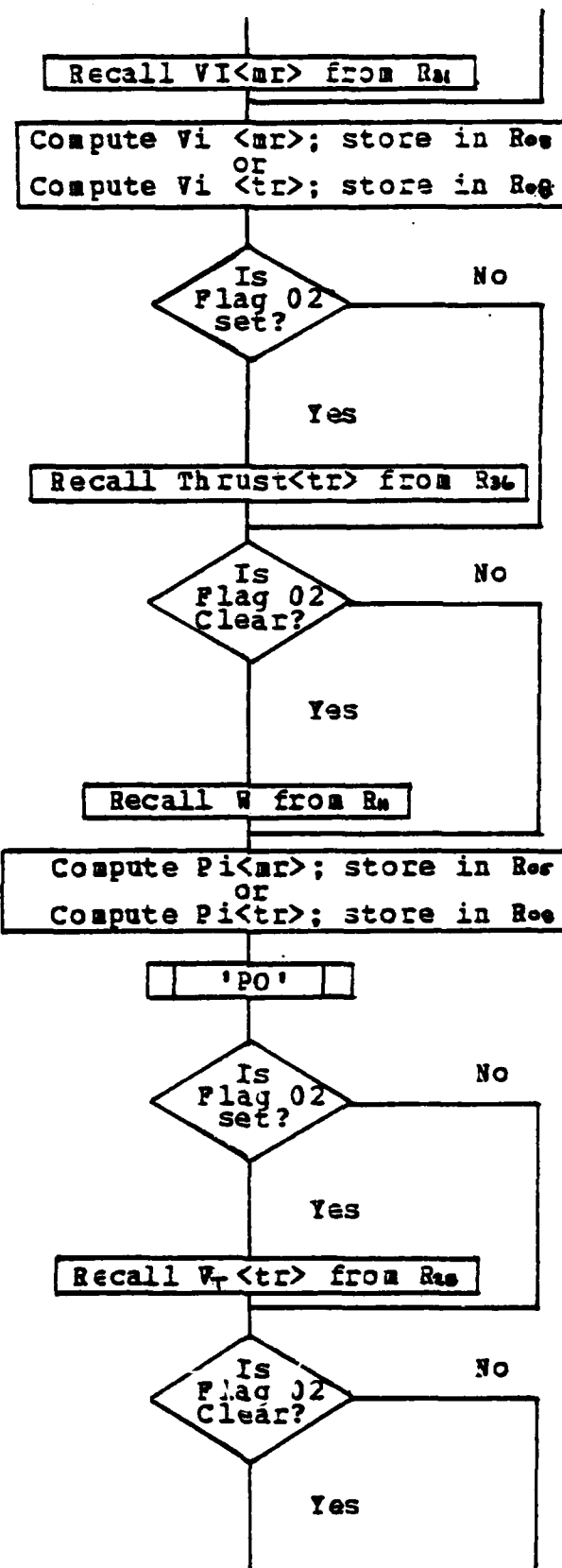
ρ_{SSL} is standard sea level density of air (slugs/ft)

P_T is the total power required (hp)

3. Flowchart



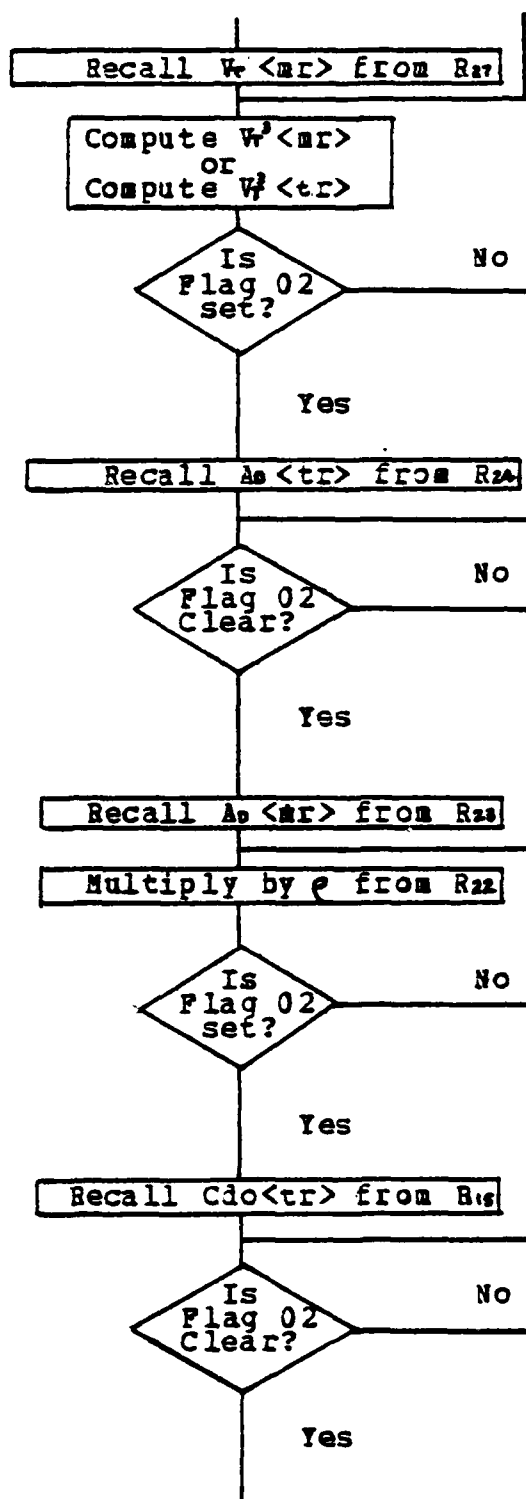




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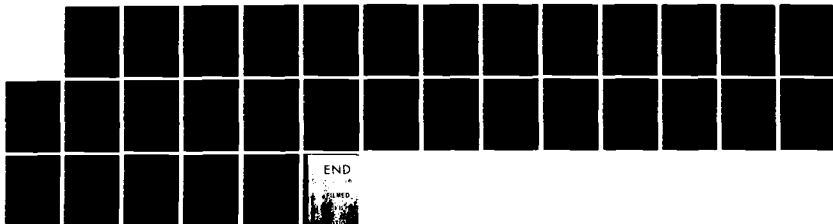
POWERPLANT SELECTION FOR CONCEPTUAL HELICOPTER DESIGN
(U) NAVAL POSTGRADUATE SCHOOL MONTEREY CA T J CASEY
JUN 83

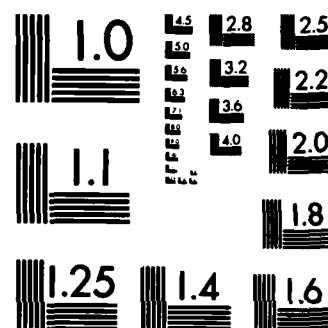
2/2

UNCLASSIFIED

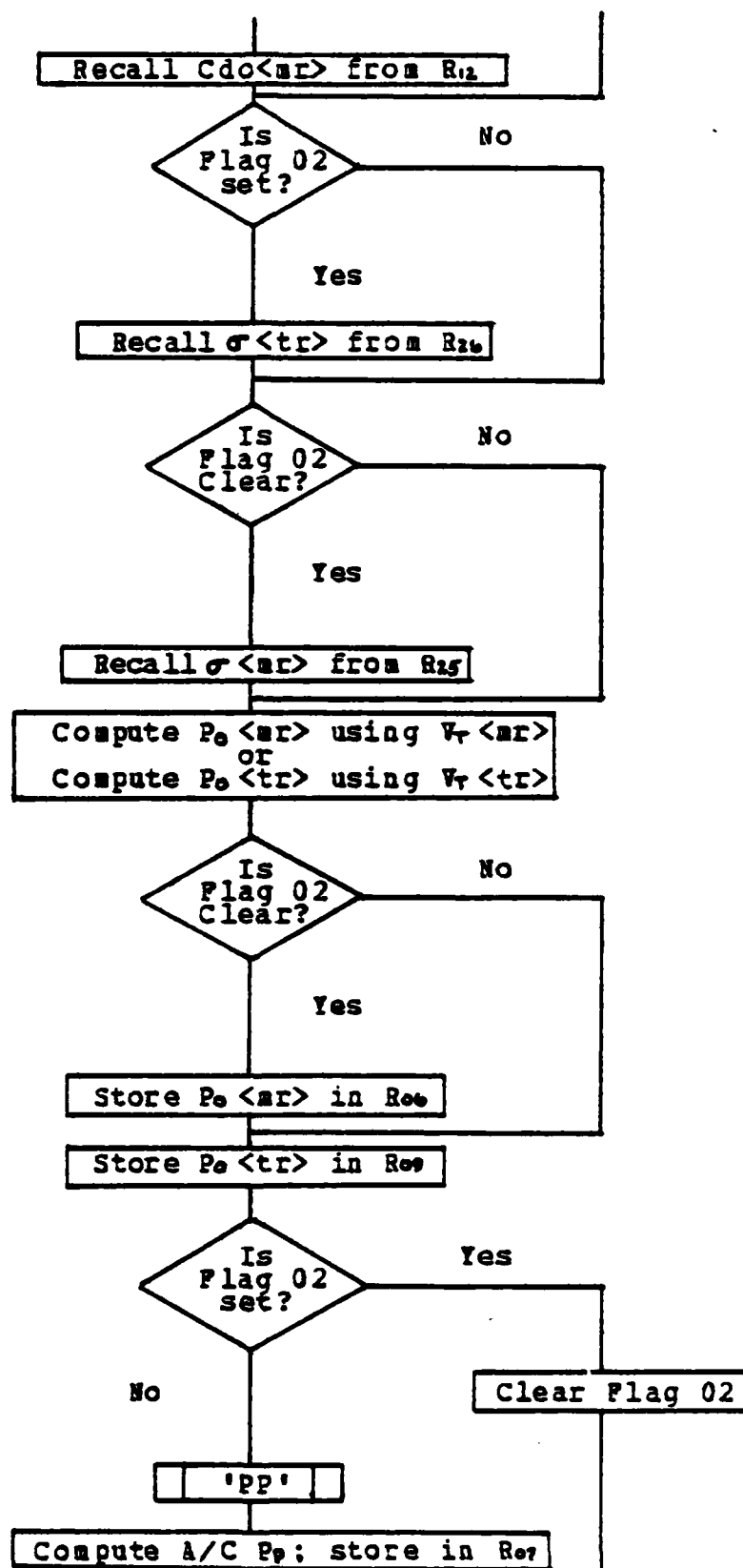
F/G 21/5

NL





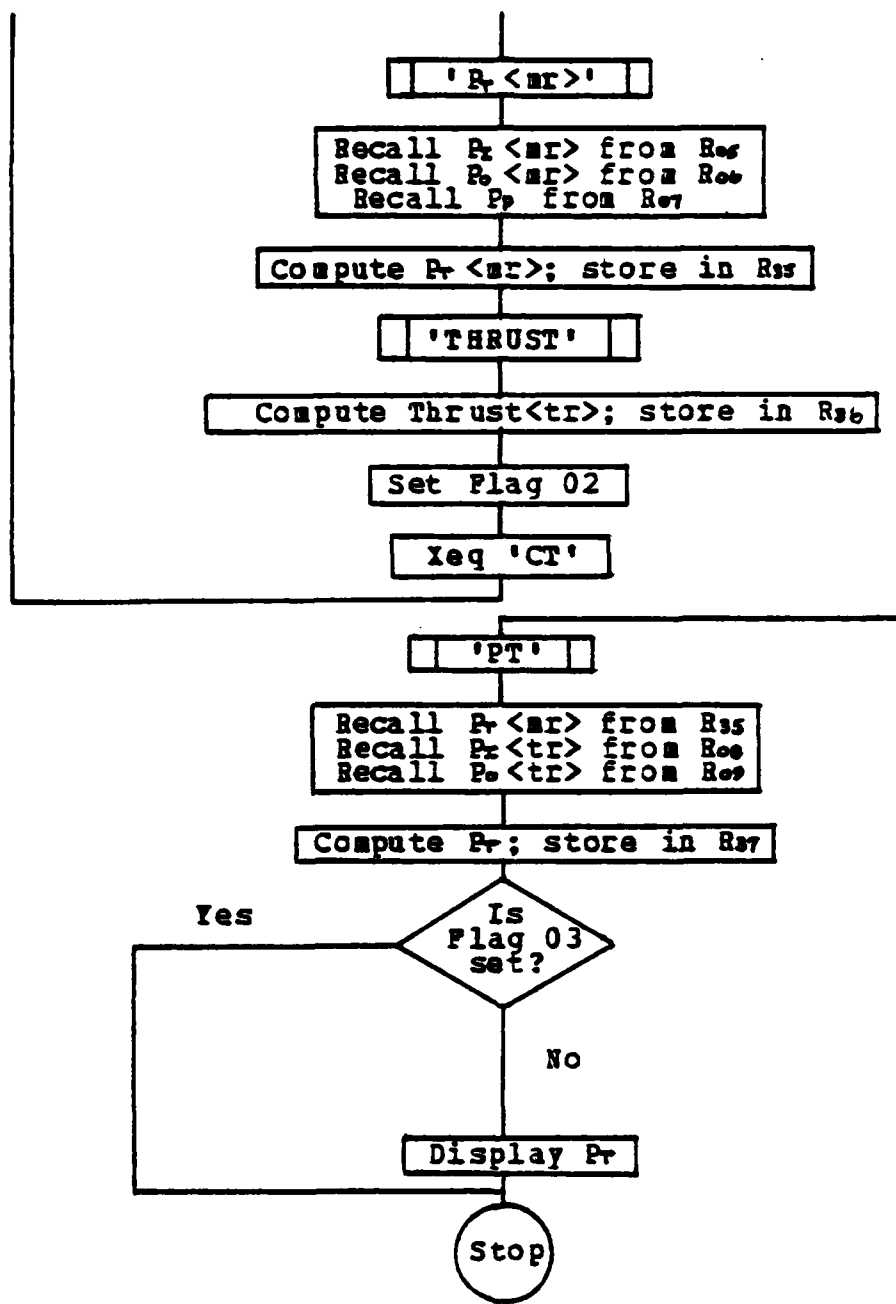
MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A



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4. Example Problem and User Instructions

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

<u>Main Rotor</u>	<u>Tail Rotor</u>	<u>Aircraft</u>
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:

(XEQ) (ALPHA) POWER (ALPHA)

(R/S)

7000.0 (R/S)

31.0 (R/S)

4 (R/S)

1.50 (R/S)

0.01 (R/S)

20.0 (R/S)

21.2 (R/S)

31 (R/S)

2 (R/S)

0.50 (R/S)

0.014 (R/S)

3.00 (R/S)

23.50 (R/S)

Display:

HELO DATA

W=?

RV(mr)=?

b(mr)=?

C(mr)=?

CdO(mr)=?

R(mr)=?

F.P.A.(FF)=?

RV(tr)=?

b(tr)=?

C(tr)=?

CdO(tr)=?

R(tr)=?

L<TAIL>=?

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

<u>Storage Register</u>	<u>Stored Quantity</u>
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_{iMR} - main rotor induced power with tip losses (hp)
06	P_{oMR} - 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	$\bar{C}_{do_{MR}}$ - 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	$\bar{C}_{do_{tr}}$ - 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

<u>Storage Register</u>	<u>Stored Quantity</u>
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

01*LBL "POWER"	51 RCL 04	101 32
02 "HELLO DATA"	52 X+2	102 -
03 AVIEW	53 PI	103 .5555
04 STOP	54 *	104 *
05 "W=?"	55 STO 24	105 273.16
06 PROMPT	56 CLX	106 +
07 STO 11	57*LBL "SD"	107 /
08 "RV(NR)=?"	58 RCL 10	108 288.16
09 PROMPT	59 RCL 00	109 *
10 STO 17	60 *	110 .23496
11 "b(NR)=?"	61 RCL 01	111 Y+X
12 PROMPT	62 /	112 CHS
13 STO 10	63 PI	113 1
14 "C(NR)=?"	64 /	114 +
15 PROMPT	65 STO 25	115 6.875 E-06
16 STO 00	66 CLX	116 /
17 "CdO(NR)=?"	67 RCL 14	117 STO 21
18 PROMPT	68 RCL 03	118*LBL "DEN"
19 STO 12	69 *	119 RCL 21
20 "R(NR)=?"	70 RCL 04	120 6.875 E-06
21 PROMPT	71 /	121 *
22 STO 01	72 PI	122 CHS
23 "F.P.A(FF)=?"	73 /	123 1
24 PROMPT	74 STO 26	124 +
25 STO 13	75 CLX	125 ENTER↑
26 "RV(TR)=?"	76*LBL "VT"	126 4.2561
27 PROMPT	77 RCL 01	127 Y+X
28 STO 02	78 RCL 17	128 .0023769
29 "b(TR)=?"	79 *	129 *
30 PROMPT	80 STO 27	130 STO 22
31 STO 14	81 CLX	131 CLX
32 "C(TR)=?"	82 RCL 04	132*LBL "CT"
33 PROMPT	83 RCL 02	133 FS? 02
34 STO 03	84 *	134 GTO 07
35 "CdO(TR)=?"	85 STO 28	135 RCL 11
36 PROMPT	86 CLX	136 RCL 23
37 STO 15	87*LBL "DA"	137 /
38 "R(TR)=?"	88 "PA=?"	138 RCL 22
39 PROMPT	89 PROMPT	139 /
40 STO 04	90 STO 19	140 RCL 27
41 "L(TAIL)=?"	91 6.875 E-06	141 X+2
42 PROMPT	92 *	142 /
43 STO 16	93 CHS	143 STO 29
44*LBL "AREA"	94 1	144 GTO 08
45 RCL 01	95 +	145*LBL 07
46 X+2	96 5.2561	146 RCL 36
47 PI	97 Y+X	147 RCL 24
48 *	98 "I(F)=?"	148 /
49 STO 23	99 PROMPT	149 RCL 22
50 CLX	100 STO 18	150 /

151 RCL 28	201 /	251 /
152 X+2	202 RCL 24	252 FC? 02
153 /	203 /	253 STO 05
154 STO 30	204 SQRT	254 STO 08
155+LBL 08	205 STO 32	255+LBL "P0"
156 CLX	206+LBL 12	256 FS? 02
157+LBL "TL"	207+LBL "PI"	257 RCL 28
158 FS? 02	208 FS? 02	258 FC? 02
159 GTO 09	209 GTO a	259 RCL 27
160 RCL 29	210 FS? 03	260 3
161 2	211 GTO a	261 Y+X
162 *	212 "VF=?"	262 FS? 02
163 SQRT	213 PROMPT	263 RCL 24
164 RCL 10	214 1.68889	264 FC? 02
165 /	215 *	265 RCL 23
166 CHS	216 STO 20	266 *
167 1	217+LBL a	267 RCL 22
168 +	218 RCL 20	268 *
169 STO 33	219 FS? 02	269 FS? 02
170 GTO 10	220 RCL 32	270 RCL 15
171+LBL 09	221 FC? 02	271 FC? 02
172 RCL 30	222 RCL 31	272 RCL 12
173 2	223 /	273 *
174 *	224 X+2	274 FS? 02
175 SQRT	225 2	275 RCL 26
176 RCL 14	226 /	276 FC? 02
177 /	227 STO 08	277 RCL 25
178 CHS	228 X+2	278 *
179 1	229 1	279 4400
180 +	230 +	280 /
181 STO 34	231 SQRT	281 STO 09
182+LBL 10	232 RCL 08	282 RCL 20
183+LBL "VI"	233 -	283 FS? 02
184 FS? 02	234 SQRT	284 RCL 28
185 GTO 11	235 FS? 02	285 FC? 02
186 RCL 11	236 RCL 36	286 RCL 27
187 2	237 FC? 02	287 /
188 /	238 RCL 11	288 X+2
189 RCL 22	239 *	289 4.3
190 /	240 FS? 02	290 *
191 RCL 23	241 RCL 32	291 1
192 /	242 FC? 02	292 +
193 SQRT	243 RCL 31	293 RCL 09
194 STO 31	244 *	294 *
195 GTO 12	245 550	295 FC? 02
196+LBL 11	246 /	296 STO 06
197 RCL 36	247 FS? 02	297 STO 09
198 2	248 RCL 34	298 FS?C 02
199 /	249 FC? 02	299 GTO 12
200 RCL 22	250 RCL 33	

300+LBL "PP"
301 RCL 20
302 3
303 Y+X
304 RCL 13
305 *
306 RCL 22
307 *
308 1100
309 /
310 STO 07
311+LBL "PT(MR)"
312 RCL 05
313 RCL 06
314 +
315 RCL 07
316 +
317 STO 35
318+LBL "THRUST"
319 RCL 35
320 550
321 *
322 RCL 17
323 /
324 RCL 16
325 /
326 STO 36
327 SF 02
328 XEQ "CT"
329+LBL "PT"
330+LBL 12
331 RCL 35
332 RCL 08
333 +
334 RCL 09
335 +
336 STO 37
337 FS? 03
338 GTO 13
339 "PT="
340 ARCL X
341 RVIEW
342 STOP
343+LBL 13
344 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>=

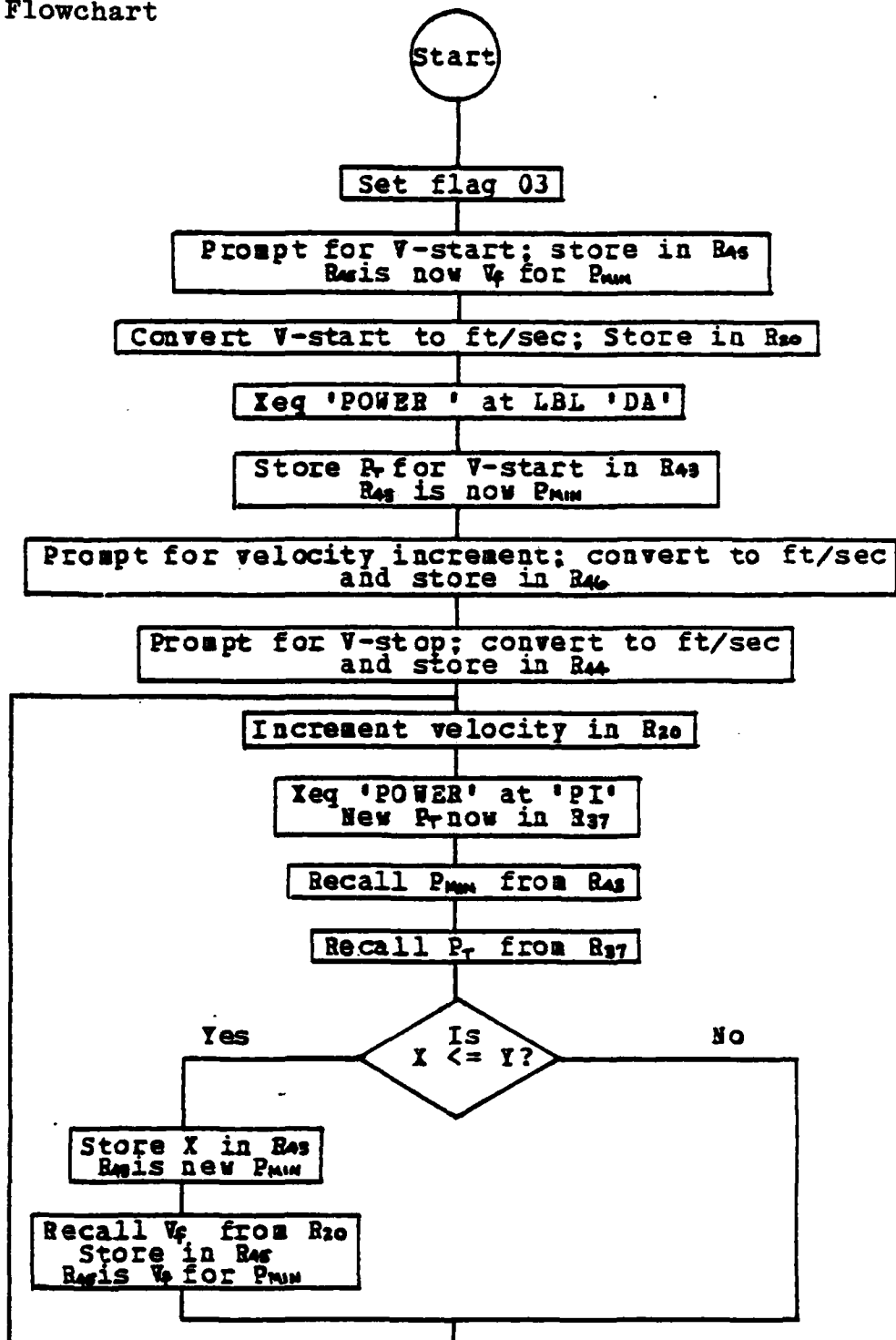
Total power required at V<end>

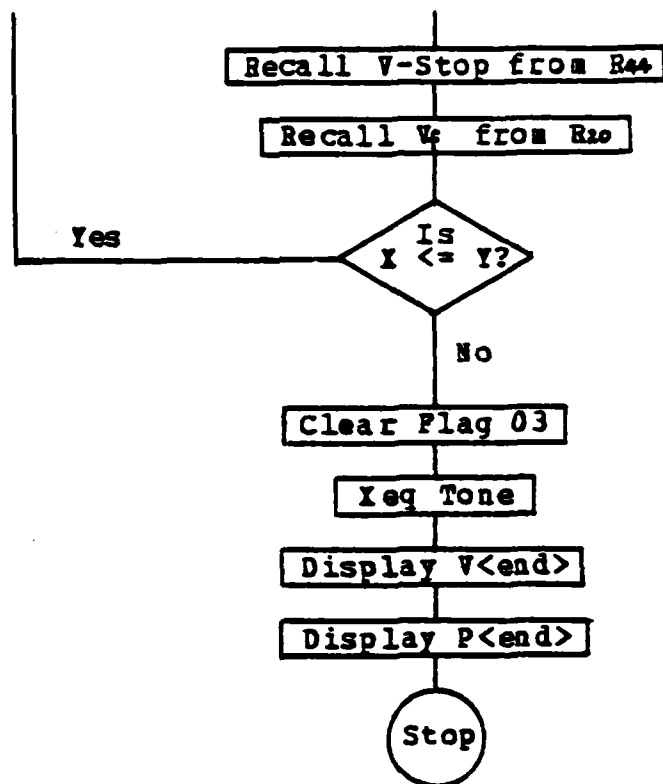
2. Equations

$$V_f \text{ (ft/sec)} = 1.6889 \times V_f \text{ (knots)}$$

where: V_f is forward velocity

3. Flowchart





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:

$V_{\text{max}} = 120 \text{ kts}$

$PA = 0 \text{ ft}$

$T = 59 \text{ F}$

a. 10 kt increment from 0 to V_{max} .

Keystrokes:

(XEQ) (ALPHA) VE (ALPHA)

0 (R/S)

0 (R/S)

59 (R/S)

10 (R/S)

120 (R/S)

(R/S)

Display:

V-START?

PA = ?

T_{F} = ?

INCR = ?

V-STOP = ?

V_{end} = 60

P_{end} = 384

b. 1 kt increment from $V = 55 \text{ kts}$ to $V = 65 \text{ kts}$.

Keystrokes:

(XEQ) (ALPHA) VE (ALPHA)

55 (R/S)

0 (R/S)

59 (R/S)

1 (R/S)

65 (R/S)

(R/S)

Display:

V-START?

PA = ?

T_{F} = ?

INCR = ?

V-STOP = ?

$V_{\text{end}} = 58$

$P_{\text{V end}} = 383$

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

<u>Storage Register</u>	<u>Stored Quantity</u>
00-41	- used by "POWER"
42	- used by "WEIGHT"
43	P_{TMIN} - 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 "00"
10 STO 43
11 "INCR 2"
12 PROMPT
13 1.6889
14 *
15 STO 46
16 "V-STOP"
17 PROMPT
18 1.6889
19 *
20 STO 44

21*LBL 12
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 17
31 STO 43
32 CLX
33 RCL 20
34 1.6889
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 X
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

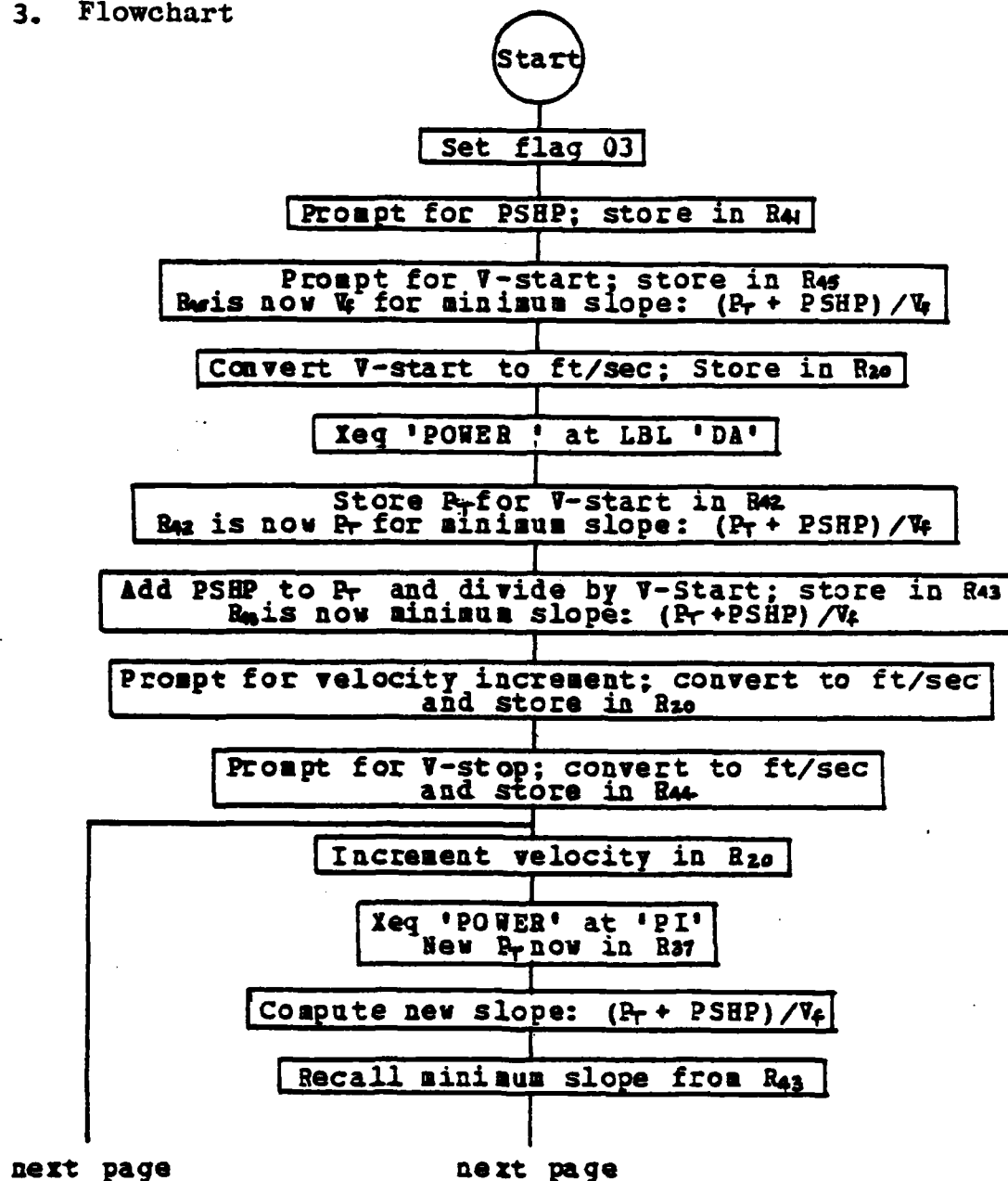
$$V_f \text{ (ft/sec)} = 1.6889 \times V_f \text{ (knots)}$$

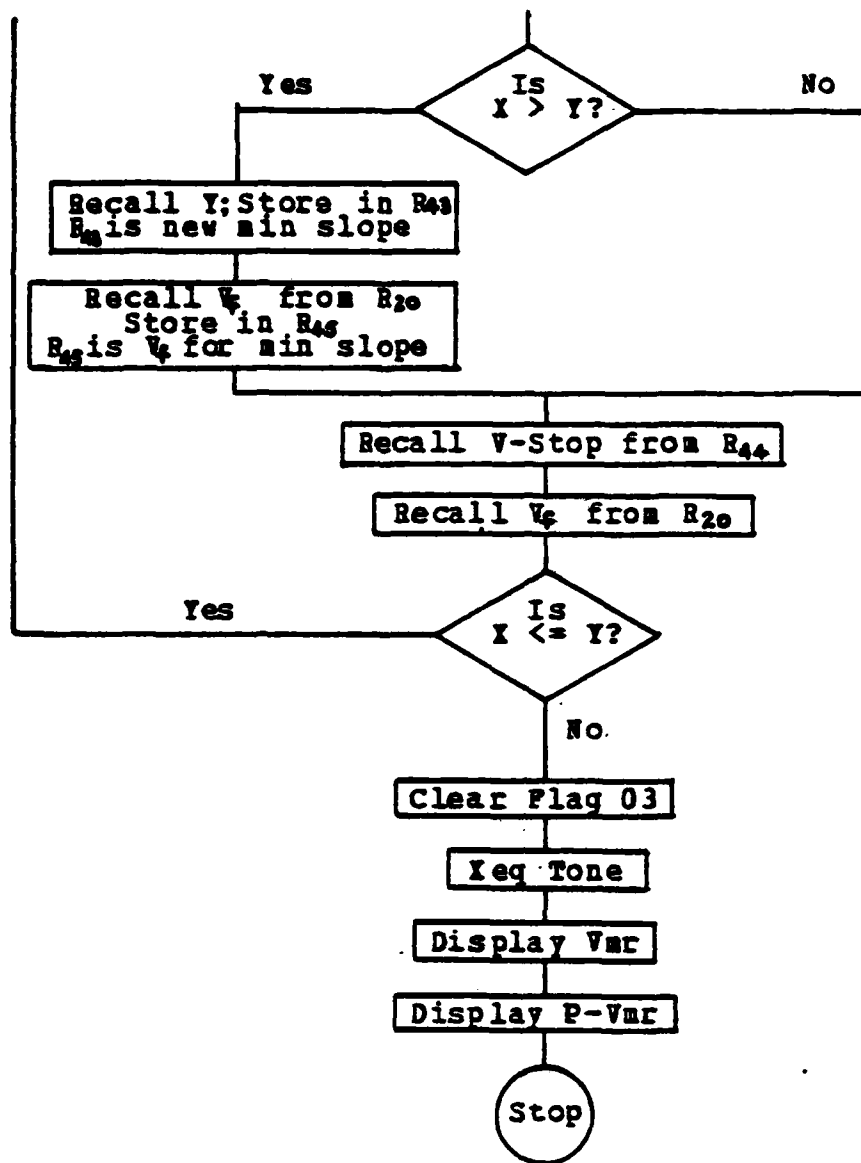
$$\text{slope of tangent line} = \frac{(P_T + \text{PSHP})}{V_f \text{ (knots)}}$$

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





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:

(XEQ) (ALPHA) VMR (ALPHA)

310 (R/S)

58 (R/S)

0 (R/S)

59 (R/S)

10 (R/S)

120 (R/S)

(R/S)

Display:

PSHP = ?

V-START = ?

PA = ?

T<F> = ?

INCR = ?

V-STOP = ?

Vmr = 108

P<Vmr>= 593

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

Keystrokes:

(XEQ) (ALPHA) VMR (ALPHA)

310 (R/S)

103 (R/S)

0 (R/S)

59 (R/S)

Display:

PSHP = ?

V-START = ?

PA = ?

T<F> = ?

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

<u>Storage Register</u>	<u>Stored Quantity</u>
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

```
01+LBL "VMR"
02 SF 03
03 "PSHP?"
04 PROMPT
05 STO 41
06 "V-START?"
07 PROMPT
08 STO 45
09 1.68889
10 *
11 STO 20
12 XEQ "DA"
13 STO 42
14 RCL 41
15 +
16 RCL 45
17 /
18 STO 43
19 "INCR?"
20 PROMPT
21 1.6889
22 *
23 STO 46
24 "V-STOP?"
25 PROMPT
26 1.6889
27 *
28 STO 44
29+LBL 01
30 RCL 46
31 ST+ 20
32 XEQ "PI"
33 RCL 41
34 +
35 RCL 20
```

```
36 1.6889
37 /
38 /
39 RCL 43
40 X>Y?
41 GTO 02
42 GTO 03
43+LBL 02
44 RCL Y
45 STO 43
46 RCL 20
47 STO 45
48 RCL 37
49 STO 42
50+LBL 03
51 RCL 44
52 RCL 20
53 X<Y?
54 GTO 01
55 CF 03
56 TONE 5
57 RCL 45
58 1.6889
59 /
60 FIX 0
61 "VMR="
62 ARCL X
63 AVIEW
64 STOP
65 RCL 42
66 "P<VMR>="
67 ARCL X
68 AVIEW
69 STOP
70 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:

<u>Main Rotor</u>	<u>Tail Rotor</u>	<u>Aircraft</u>
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]:

<u>Maximum continuous</u>	<u>Output Shaft</u>		<u>Output Torque</u>
<u>Power at:</u>	<u>SHP</u>	<u>RPM</u>	<u>(ft lb)</u>
Std Sea Level	1310	20,000	344

Solve for the torque conversion factor:

$$\begin{aligned} \text{Torque (ft lb)} &= \frac{\text{SHP} \cdot 550(\text{ft-lb/sec})(1/\text{hp}) \cdot 60}{20,000 \text{ rev/min}(2\pi \text{ rad/sec})} \\ &= .263 \text{ SHP} \end{aligned}$$

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

$$\text{Maximum Continuous Torque Available} = 88\%$$

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

$$2(344)/.88 = 792 \text{ ft-lb}$$

or

$$792/.263 = 2973 \text{ ESHP}$$

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

	<u>Analytical</u>	<u>Operator's Manual</u>	<u>% Error</u>
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
<u>4000 ft and 95 F</u>			
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

Standard Sea Level Conditions

	<u>Analytical</u>	<u>Operator's Manual</u>	<u>% Error</u>
Maximum Endurance Velocity (kts)	81	80	1
Maximum Range Velocity (kts)	140	142	1
<u>4000 ft and 95 F</u>			
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

Cruise Velocity = 110 kts

Temp = 95 F

Max Endurance Velocity:

Range = 275 nm

= 88 kts (actual)

= 90 kts (analytical)

Normal Rated Power (2 engines):

= 2620 ESHP

Mission Fuel Weight Profile Equation

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

Results

	Operator's		
	<u>Analytical</u>	<u>Manual</u>	<u>% Error</u>
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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