THESIS

POWERPLANT SELECTION FOR CONCEPTUAL HELICOPTER DESIGN

by

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Thesis Advisor: Donald M. Layton

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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.
Powerplant Selection for Conceptual Helicopter Design
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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).


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:

\[ \text{SHP} = \left[ \frac{6}{\sqrt{3}} \right] \text{(SHP)} \]  \hspace{1cm} (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]:

\[ \text{ESHP} = 1.03 \cdot \text{RSHP} + 0.1 \cdot (n-1) \cdot \text{RSHP} + 10 \]  \hspace{1cm} (2.2)

Where n is the number of engines used.
<table>
<thead>
<tr>
<th>Engine</th>
<th>20000 ft.</th>
<th>-12 F</th>
<th>4000 ft.</th>
<th>95 F</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>SHP Actual</td>
<td>SHP Analytical</td>
<td>% Difference</td>
<td>SHP Actual</td>
</tr>
<tr>
<td>A</td>
<td>214</td>
<td>208</td>
<td>3</td>
<td>325</td>
</tr>
<tr>
<td>B</td>
<td>369</td>
<td>350</td>
<td>5</td>
<td>583</td>
</tr>
<tr>
<td>C</td>
<td>914</td>
<td>772</td>
<td>15</td>
<td>1170</td>
</tr>
<tr>
<td>D</td>
<td>1000</td>
<td>891</td>
<td>11</td>
<td>1404</td>
</tr>
<tr>
<td>E</td>
<td>1378</td>
<td>1237</td>
<td>10</td>
<td>2055</td>
</tr>
<tr>
<td>F</td>
<td>2070</td>
<td>1682</td>
<td>19</td>
<td>3086</td>
</tr>
</tbody>
</table>

**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:

\[ W_{EI} = 0.0974(W_{ED})^{1.2} \]

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

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

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

Turboshaft Engine Data Base

<table>
<thead>
<tr>
<th>Engine</th>
<th>A/C</th>
<th>Dry Weight lbs.</th>
<th>Installed Weight lbs.</th>
<th>Military SHP @ SS1</th>
</tr>
</thead>
<tbody>
<tr>
<td>T63-A-5A</td>
<td>OH-6A</td>
<td>136.0</td>
<td>175.2</td>
<td>317</td>
</tr>
<tr>
<td>A11-250-C18</td>
<td>Th-57A</td>
<td>136.0</td>
<td>194.0</td>
<td>317</td>
</tr>
<tr>
<td>T63-A-720</td>
<td>OH-58C</td>
<td>158.0</td>
<td>218.0</td>
<td>420</td>
</tr>
<tr>
<td>T58-GE-8F</td>
<td>UH-2D</td>
<td>305.0</td>
<td>403.0</td>
<td>1350</td>
</tr>
<tr>
<td>T58-GE-5</td>
<td>S-67</td>
<td>335.0</td>
<td>471.0</td>
<td>1500</td>
</tr>
<tr>
<td>T58-GE-10</td>
<td>CH-47D</td>
<td>340.0</td>
<td>454.0</td>
<td>1400</td>
</tr>
<tr>
<td>T700-GE-700</td>
<td>YAH-63</td>
<td>423.0</td>
<td>547.0</td>
<td>1560</td>
</tr>
<tr>
<td>T700-GE-701</td>
<td>AH-64</td>
<td>427.0</td>
<td>587.0</td>
<td>1690</td>
</tr>
<tr>
<td>T58-GE-16</td>
<td>CH-46E</td>
<td>430.0</td>
<td>621.0</td>
<td>1870</td>
</tr>
<tr>
<td>T53-L-703</td>
<td>AH-1S</td>
<td>495.0</td>
<td>607.0</td>
<td>1485</td>
</tr>
<tr>
<td>T53-L13</td>
<td>UH-1H</td>
<td>540.0</td>
<td>683.0</td>
<td>1400</td>
</tr>
<tr>
<td>T55-L-7</td>
<td>CH-47A</td>
<td>580.0</td>
<td>671.0</td>
<td>2650</td>
</tr>
<tr>
<td>T64-GE-16</td>
<td>AH-56</td>
<td>700.0</td>
<td>969.0</td>
<td>3370</td>
</tr>
<tr>
<td>T400-CP400</td>
<td>UH-1N</td>
<td>701.0</td>
<td>910.0</td>
<td>1800</td>
</tr>
<tr>
<td>T400-CP400</td>
<td>AH-1J</td>
<td>701.0</td>
<td>908.0</td>
<td>1800</td>
</tr>
<tr>
<td>T64-GE-6</td>
<td>CH-53A</td>
<td>723.0</td>
<td>881.0</td>
<td>2850</td>
</tr>
<tr>
<td>T400-WV-402</td>
<td>AH-1T</td>
<td>733.0</td>
<td>936.0</td>
<td>1970</td>
</tr>
<tr>
<td>T55-L-11D</td>
<td>CH-47C</td>
<td>735.0</td>
<td>897.0</td>
<td>3750</td>
</tr>
<tr>
<td>T55-L712</td>
<td>CH-47D</td>
<td>760.0</td>
<td>925.0</td>
<td>3400</td>
</tr>
<tr>
<td>JTFD12A-4A</td>
<td>CH-54A</td>
<td>920.0</td>
<td>1093.0</td>
<td>4500</td>
</tr>
</tbody>
</table>

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:

\[ W_{EI} = 45 + 1.2W_{ED} \] (2.3)

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

I. SELECTION AND OPTIMIZATION

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

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

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

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

4. Variety of manufacturers [Ref. 7], [Ref. 17], [Ref. 18], and [Ref. 19].
Figure 2.1 Engine Dry Weight vs. Installed Weight
Essentially, an engine(s) which would fulfill a specific mission capability could have been selected by inspection almost at random from this list once power requirements were determined. However, it seemed much more realistic to optimize the selection in some way.

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

\[
\text{Fuel Wt.} = 0.05W_f <\text{NRP}> + W_f <\text{cruise}> \frac{\text{Range}_{\text{max}}}{V_{\text{cruise}}} \\
+ 0.25W_f <V_{\text{end}}> + 0.05W_f <\text{NRP}> \quad (2.4)
\]

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>
<thead>
<tr>
<th>Subject Area</th>
<th>Program Name</th>
<th>Registers</th>
<th>Subroutine Name</th>
<th>Registers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Engine fuel flow characteristics</td>
<td>FUELFL</td>
<td>56</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Mission fuel and engine weights</td>
<td>WEIGHT</td>
<td>30</td>
<td>FUELFL</td>
<td>56</td>
</tr>
<tr>
<td>Total helicopter power required</td>
<td>POWER</td>
<td>106</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Maximum endurance velocity</td>
<td>VE</td>
<td>22</td>
<td>POWER</td>
<td>106</td>
</tr>
<tr>
<td>Maximum range velocity</td>
<td>VMR</td>
<td>25</td>
<td>POWER</td>
<td>106</td>
</tr>
</tbody>
</table>
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.
LIST OF REFERENCES


3. Ibid., pp. 3-25.

4. Ibid., pp. 8-12.

5. Ibid., pp. 3-110.


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:

Static ESHP = SHP + \( F_n / 2.5 \)

Flight ESHP = 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:

\[
DI = \left( \frac{P_{\text{MEAN}} - P_{\text{LOW MEAN}}}{P_{\text{MEAN}}} \right)
\]

\[
DI = \left( \frac{T_{\text{MAX}} - T_{\text{MEAN}}}{T_{\text{MEAN}}} \right)
\]

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.

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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

<table>
<thead>
<tr>
<th>Engine</th>
<th>Dry Weight (lbs)</th>
<th>Standard Sea Level Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>SHP</td>
</tr>
<tr>
<td>A</td>
<td>158</td>
<td>M: 420</td>
</tr>
<tr>
<td>(T63-A-720)</td>
<td></td>
<td>N: 370</td>
</tr>
<tr>
<td></td>
<td></td>
<td>C: 278</td>
</tr>
<tr>
<td>B</td>
<td>268</td>
<td>M: 708</td>
</tr>
<tr>
<td>(LTS101-750A)</td>
<td></td>
<td>N: 659</td>
</tr>
<tr>
<td></td>
<td></td>
<td>C: 494</td>
</tr>
<tr>
<td>C</td>
<td>423</td>
<td>M: 1561</td>
</tr>
<tr>
<td>(T700-GE-700)</td>
<td></td>
<td>N: 1318</td>
</tr>
<tr>
<td></td>
<td></td>
<td>C: 989</td>
</tr>
<tr>
<td>D</td>
<td>709</td>
<td>M: 1800</td>
</tr>
<tr>
<td>(T400-CP-400)</td>
<td></td>
<td>N: 1530</td>
</tr>
<tr>
<td></td>
<td></td>
<td>C: 1148</td>
</tr>
<tr>
<td>E</td>
<td>580</td>
<td>M: 2500</td>
</tr>
<tr>
<td>(T55-L-7)</td>
<td></td>
<td>N: 2200</td>
</tr>
<tr>
<td></td>
<td></td>
<td>C: 1650</td>
</tr>
<tr>
<td>F</td>
<td>750</td>
<td>M: 3400</td>
</tr>
<tr>
<td>(T55-L-712)</td>
<td></td>
<td>N: 3000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>C: 2250</td>
</tr>
</tbody>
</table>

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:

\[ \text{ESHP} = \left( \frac{\delta}{\sqrt{\theta}} \right) \text{(ESHP)} \]

Where \( \delta = \frac{P}{P_{SSL}} \)

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

C. ENGINE INSTALLED WEIGHT

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

\[ W_{EI} = 45. + 1.2 \cdot W_{ED} \] (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).
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:  

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

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

\[ Wf_i = SFC_i \times SHP_i \]

\[ \hat{\beta} = \frac{Wf_M - Wf_N}{SHP_M - SHP_N} + \frac{Wf_M - Wf_C}{SHP_M - SHP_C} + \frac{Wf_N - Wf_C}{SHP_N - SHP_C} \div 3 \]

\[ \hat{\alpha} = \left| \hat{\beta} \left( SHP_M + SHP_N + SHP_C \right) - (Wf_M + Wf_N + Wf_C) \right| \div 3 \]

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

\[ \sqrt{\delta} = \sqrt{\frac{T}{T_{SSL}}} = \sqrt{\frac{T + 459.688}{518.688}} \]

\[ ZHI = \hat{\alpha}(\sqrt{\delta}) \]

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

\[ Wf = [PSHP + ESHP] \hat{\beta} \]

where:

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

SHP is shaft horsepower of the engine

Wf 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

\( \delta \) 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)

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

\( T \) is temperature in degrees F

\( ZHI \) is the zero horsepower increment at input conditions

\( n \) is the number of engines

\( PSHP \) is the zero velocity horsepower (Phantom SHP)

\( ESHP \) is the engine shaft horsepower required
3. Flowchart

Start

Prompt for Military SFC

Increase by 5% and store in R3

Prompt for Military SHP; store in R6

Prompt for Normal SFC

Increase by 5% and store in R3

Prompt for Normal SHP; store in R6

Prompt for Cruise SFC

Increase by 5% and store in R6

Prompt for Cruise SHP; store in R6

Compute $\phi$; store in R8

Display $\phi$

Compute $\&$; store in R9

Display $\&$

LBL 'OPCON'

LBL 'PRATIO'

Prompt for PA (ft); store in R10

Compute $\phi$

LBL 'TRATIO'

Prompt for T (F); store in R11

next page
4. Example Problem and User Instructions

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

<table>
<thead>
<tr>
<th>Engine Data</th>
<th>Operating conditions:</th>
</tr>
</thead>
<tbody>
<tr>
<td>SHP</td>
<td>SFC</td>
</tr>
<tr>
<td>Military</td>
<td>1561 .460</td>
</tr>
<tr>
<td>Normal</td>
<td>1310 .470</td>
</tr>
<tr>
<td>Cruise</td>
<td>989 .510</td>
</tr>
<tr>
<td>Two engines (N = 2)</td>
<td></td>
</tr>
<tr>
<td>a. Assume &quot;POWER&quot; will not be used:</td>
<td></td>
</tr>
<tr>
<td>RSHP = 500 hp</td>
<td></td>
</tr>
</tbody>
</table>

Keystrokes:                               Display:
(XEQ) (ALPHA) FUELFL (ALPHA)            SFC-M?
0.460 (R/S)                               SHP-M?
1561 (R/S)                                SFC-N?
0.470 (R/S)                               SHP-N?
1310 (R/S)                                SFC-C?
0.510 (R/S)                               SHP-C?
989 (R/S)                                 B = 0.3948
(R/S)                                     ALPHA = 135.32
(R/S)                                     PA=？
0 (R/S)                                   T(F)=？
59 (R/S)                                  ZHI = 135.32
(R/S)                                     N=？
2 (R/S)                                   PSHP = 685.46
(R/S)                                     POWER?
Now use "FF" to compute the fuel flow rate for the same engine at the same altitude and temperature but with:

\[ \text{RSHP} = 700 \text{ shp} \]

Keystrokes: 
\[ \text{Display:} \]
\[ \text{(XEQ) (ALPHA) FF (ALPHA)} \]
\[ \text{POWER?} \]
\[ 0 \text{ (R/S)} \]
\[ \text{RSHP=)?} \]
\[ 700 \text{ (R/S)} \]
\[ \text{WF = 586.91} \]

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

\[ \text{PA} = 4000 \text{ ft} \]
\[ \text{T} = 95 \text{ F} \]
\[ \text{RSHP} = 700 \text{ shp} \]

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

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:

\[ \text{VF} = 95 \text{ kts} \]
Keystrokes:  
(XEQ) (ALPHA) FUELFL (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

\[ VF = 120 \text{ kts} \]

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

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

\[ PA = 4000 \text{ ft} \]
\[ T = 95 \text{ F} \]
\[ VF = 120 \text{ kts} \]

Keystrokes: Display:
(XEQ) (ALPHA) OPCON (ALPHA) PA. FT.?
4000 (R/S) T<F>?
95 (R/S) ZHI = 120.86
(R/S) N=?
2 (R/S) PSHP = 612.20
(R/S) POWER?
1 (R/S) PA=?
4000 (R/S) T<F>=?
95 (R/S) VF=?
120 (R/S)          PT = 634.12
(R/S)              PT = 634.12
(R/S)              WF = 528.60

5. Programs and Subroutines Used
   "FUELFL"
   "OPCON"
   "PRATIO"
   "TRATIO"
   "FF"

6. Storage Register Utilization
   Table V shows specific storage register contents.
TABLE V

FUELFL Storage Register Utilization

<table>
<thead>
<tr>
<th>Storage Register</th>
<th>Stored Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>00</td>
<td>blank - used for computations</td>
</tr>
<tr>
<td>01</td>
<td>SFC&lt;sub&gt;M&lt;/sub&gt; - specific fuel consumption at military power at sea level (lb/hr/hp)</td>
</tr>
<tr>
<td>02</td>
<td>SHP&lt;sub&gt;M&lt;/sub&gt; - shaft horsepower output at military power at sea level (hp)</td>
</tr>
<tr>
<td>03</td>
<td>SFC&lt;sub&gt;N&lt;/sub&gt; - specific fuel consumption at normal power at sea level (lb/hr/hp)</td>
</tr>
<tr>
<td>04</td>
<td>SHP&lt;sub&gt;N&lt;/sub&gt; - shaft horsepower output at normal power at sea level (hp)</td>
</tr>
<tr>
<td>05</td>
<td>SFC&lt;sub&gt;C&lt;/sub&gt; - specific fuel consumption at cruise power at sea level (lb/hr/hp)</td>
</tr>
<tr>
<td>06</td>
<td>SHP&lt;sub&gt;C&lt;/sub&gt; - shaft horsepower output at cruise power at sea level (hp)</td>
</tr>
<tr>
<td>07</td>
<td>W&lt;sub&gt;f&lt;/sub&gt;&lt;sup&gt; M &lt;/sup&gt; - fuel flow rate at sea level military power with 5% increase (lb/hr)</td>
</tr>
<tr>
<td>08</td>
<td>W&lt;sub&gt;f&lt;/sub&gt;&lt;sup&gt; N &lt;/sup&gt; - fuel flow rate at sea level normal power with 5% increase (lb/hr)</td>
</tr>
<tr>
<td>09</td>
<td>W&lt;sub&gt;f&lt;/sub&gt;&lt;sup&gt; C &lt;/sup&gt; - fuel flow rate at sea level cruise power with 5% increase (lb/hr)</td>
</tr>
<tr>
<td>10-37</td>
<td>- used by program &quot;POWER&quot;</td>
</tr>
<tr>
<td>38</td>
<td>( \hat{\beta} ) - average slope of the fuel flow line</td>
</tr>
<tr>
<td>39</td>
<td>( \hat{\alpha} ) - average zero horsepower intercept at standard sea level conditions (lb/hr)</td>
</tr>
<tr>
<td>40</td>
<td>n - number of engines in the helicopter</td>
</tr>
<tr>
<td>41</td>
<td>PSHP - zero velocity shaft horsepower (phantom shp)</td>
</tr>
</tbody>
</table>

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

01 LBL "FUELFL"
02 "SFC-M?"
03 PROMPT
04 STO 01
05 .85
06 *
07 ST+ 01
08 "SHP-M?"
09 PROMPT
10 STO 02
11 "SFC-N?"
12 PROMPT
13 STO 03
14 .85
15 *
16 ST+ 03
17 "SHP-N?"
18 PROMPT
19 STO 04
20 "SFC-C?"
21 PROMPT
22 STO 05
23 .85
24 *
25 ST+ 05
26 "SHP-C?"
27 PROMPT
28 STO 06
29 RCL 01
30 RCL 02
31 *
32 STO 07
33 RCL 03
34 RCL 04
35 *
36 STO 08
37 RCL 05
38 RCL 06
39 *
40 STO 09
41 CLX
42 RCL 07
43 RCL 08
44 *
45 RCL 02
46 RCL 04
47 *
48 /
49 ABS
50 STO 38
181 ST+ 39
182 3
183 ST/ 39
184 RCL 39
185 CLA
186 "ALPHA="
187 ARCL X
188 AVIEW
189 STOP
190 K=0?
191 RCL 39
192 "FF"
193 FS? 03
194 GTO 02
195 "POWER?"
196 PROMPT
197 X:=@
118LBL "OPCON"
119 XEQ "DR"
120 GTO 02
121 PROMPT
122 .6754 E-6
123 CHS
124 PROMPT
125 6.3754 E-6
126 "RSHP=?"
127 1
128 ENTER+
129 5.256
130 Y+X
131 STO 02
132 "P.A. FT?"
133 PROMPT
134 5.8754 E-6
135 PROMPT
136 1
137 P.A.
138 RSHP?
139 STO 02
140 "PF?"
141 "PRATIO"
142 "P.F.?
143 6.3754 E-6
144 PROMPT
145 1
146 RCL 37
147 RCL 39
148 SQRT
149 RCL 41
150 STO 83
151 STO 39
152 STOP
153 CLX
154 "FF"
155 FS? 03
156 GTO 02
157 "POWER?"
158 PROMPT
159 X=0?
160 GTO 01
161 XEQ "DR"
162 GTO 02
163 XEQ "DR"
164 "RSHP= ?"
165 PROMPT
166 GTO 03
167 GTO 03
168 RCL 37
169 "RSHP= ?"
170 GTO 03
171 "RSHP= ?"
172 1
173 .1
174 * 175 1.03
176 + 177 * 178 RCL 40
179 RCL 40
180 RCL 41
181 + 182 RCL 38
183 = 184 CLA
185 "WF="
186 ARCL X
187 AVIEW
188 END
189 END
190 END
191 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)

50
WTT = Total weight of installed engine plus mission fuel (lb)

2. Equations

\[ W_{EI} = 45 + 1.2 \cdot W_{ED} \]

\[ W_{tf} = 0.05 W_f <NRP> + \frac{MAX \ RANGE}{V_{CRUISE}} (W_f <V_{CRUISE}> ) \]

\[ + 0.25 W_f <V_{END}> + 0.05 W_f <NRP> \]

\[ W_{tt} = W_{EI} + W_{tf} \]

\[ W_f = (PSHP + ESHP) \beta \]

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)

\( \beta \) is the slope of the fuel flow line for the engine
3. Flowchart

Start

Prompt for $W_{ce}$

Compute $W_{ce}$; store in $R_2$

Display $W_{ce}$

Prompt for Range

Prompt for cruise velocity (kts); store in $R_2$

Compute cruise time; store in $R_3$

Convert $V_{crus}$ in $R_2$ to ft/sec

Yes = 1

Is POWER used?

No = 0

Ieq 'POWER' at LBL 'DA'

Ieq 'OPCON'

Compute cruise fuel weight store in $R_3$

Prompt for $V_{end}$ (kts)

Convert $V_{end}$ to ft/sec; Store in $R_3$

Ieq 'Pi' to get $P_{end}$

Ieq 'FF' for max-end fuel flow rate

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52
Compute fuel weight for max-end flight segment; add to \( R_e \)

Compute fuel flow for normal rated power (NRP)

Compute fuel weight for <NRP> flight segment; add to \( R_e \); \( R_e \) now contains total fuel wt., \( W_t \)

Multiply \( W_t \) by \( N \); add to \( W_t \)

Compute \( W_t \)

Display \( W_t \)

Stop
4. Example Problem and User Instructions

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

**WED** = 400 lb

**Operating Conditions:**

**Range** = 350 nm

PA = 0

**V<crus>** = 100 kts; **P<crus>** = 531.87 shp

**T** = 59 F

**V<end>** = 58 kts; **P<end>** = 383.42 shp

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

a. Assume "POWER" will not be used:

Keystrokes: Display:

(XEQ) (ALPHA) WEIGHT (ALPHA) WED=?

400 (R/S) WEI = 525.0

(R/S) RANGE=?

350 (R/S) V<CRUS>=?

100 (R/S) POWER?

0 (R/S) P<CRUS>=?

531.87 (R/S) PA FT ?

0 (R/S) T(F) ?

59 (R/S) ZHI = 135.2

(R/S) N = ?

2 (R/S) PSHP = 685.46

(R/S) WF = 511.90

P<END>=?
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
(R/S) V<END>=?
58 (R/S) WF = 445.67
(R/S) 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

<table>
<thead>
<tr>
<th>Storage Register</th>
<th>Stored Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>01</td>
<td>( W_{tf} ) - total fuel weight for mission profile (lb)</td>
</tr>
<tr>
<td>02</td>
<td>( \delta ) - ratio of pressure to standard sea level pressure</td>
</tr>
<tr>
<td>03</td>
<td>( \sqrt{\delta} ) - square root of the ratio of absolute temperature to SSL absolute temperature</td>
</tr>
<tr>
<td>42</td>
<td>( W_{EI} ) - estimated engine installed weight (lb)</td>
</tr>
</tbody>
</table>

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 "WEIGHT?"
04 PROMPT
05 1.2
06 =
07 45
08 +
09 STO 42
10 "HEI="
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 "<CRUS>"
42 PROMPT
43 STO 37
44 XEQ "OPCON"
45 PSE
46 RCL 01
47 *
48 STO 01
49 "<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

FORTRAN ENGINE OPTIMIZER

This appendix contains an interactive computer program written to optimize the selection of a turboshaft engine for the preliminary design of a helicopter. The program is written in FORTRAN and implemented on the IBM 3033 computer. Optimization is accomplished by the selection of the 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.
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:

<table>
<thead>
<tr>
<th>Main Rotor</th>
<th>Tail Rotor</th>
<th>Aircraft</th>
</tr>
</thead>
<tbody>
<tr>
<td>C = 1.5 ft</td>
<td>C = 0.50 ft</td>
<td>L&lt;tail&gt; = 23.50 ft</td>
</tr>
<tr>
<td>R = 20.0 ft</td>
<td>R = 3.00 ft</td>
<td>W&lt;gross&gt; = 7,000 lbs</td>
</tr>
<tr>
<td>b = 4</td>
<td>b = 2</td>
<td>F.P.A.(FF) = 21.2</td>
</tr>
<tr>
<td>CdO = 0.01</td>
<td>CdO = 0.014</td>
<td>Vmax = 120 kts</td>
</tr>
<tr>
<td>RPM = 296</td>
<td>RPM = 1332</td>
<td></td>
</tr>
</tbody>
</table>

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 Nonims1

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 ---

<table>
<thead>
<tr>
<th></th>
<th>SHP</th>
<th>SFC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Military</td>
<td>1561</td>
<td>.46</td>
</tr>
<tr>
<td>Normal</td>
<td>1310</td>
<td>.47</td>
</tr>
<tr>
<td>Cruise</td>
<td>989</td>
<td>.51</td>
</tr>
</tbody>
</table>

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 ---

<table>
<thead>
<tr>
<th></th>
<th>SHP</th>
<th>SFC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Military</td>
<td>1561</td>
<td>.46</td>
</tr>
<tr>
<td>Normal</td>
<td>1310</td>
<td>.47</td>
</tr>
<tr>
<td>Cruise</td>
<td>1000</td>
<td>.55</td>
</tr>
</tbody>
</table>

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

62
Calculate slope of fuel flow line and the zero horsepower increment (SSL)

Call subroutine FUELSL

Output engine SSL data

Do if J = 1

Input PA and T

Calculate pressure and temperature ratios

Call PRATIO

Call TRATIO

End Do

Input number of engines to be used in the helicopter

Calculate zero horsepower intercept at operating conditions

Call ZHIALT

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

Call ZVHP

If J = 1

Input rotor power requirement

RSHP directly

Else

Velocity at which RSHP desired

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

Get RSHP from "HPWRPIP DATA"
Else use power required entered for engine 1
Calculate fuel flow rate at operating conditions
       Call FLOALT
Output fuel flow data
Give options for doing additional fuel flow calculations
       If desired, calculate fuel flow rate with different
       PA and T
       If desired, calculate fuel flow rate with a different
       engine
Calculate fuel weight for the mission profile
       If $J = 1$
           Input design maximum range
           Input design cruise velocity
Else use range and cruise velocity previously entered
Read cruise power required from "HPWRPIP DATA"
Calculate maximum endurance velocity and rotor power
required
       Call MAXEND
Calculate the zero horsepower intercept at the conditions
used for power required calculations
       Call PRATIO
       Call TRATIO
       Call ZHIALT
Calculate the zero velocity shaft horsepower (phantom
SHP)
       Call ZVSHP

64
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 --------

<table>
<thead>
<tr>
<th></th>
<th>SHP</th>
<th>SFC</th>
</tr>
</thead>
<tbody>
<tr>
<td>MILITARY</td>
<td>1561.00</td>
<td>0.4830</td>
</tr>
<tr>
<td>NORMAL</td>
<td>1310.00</td>
<td>0.4935</td>
</tr>
<tr>
<td>CRUISE</td>
<td>989.00</td>
<td>0.5355</td>
</tr>
</tbody>
</table>

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

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

PA: 4000.0 FT
TEMP: 95.0 F
ZHI: 120.86 LB/HR

PSHP: 612.21 SHP
RSHP: 385.70 SHP
FUEL FLOW RATE: 417.76 LB/HR

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

PA: 4000.0 FT
TEMP: 95.0 F
MAX RANGE: 350.00 NM
CRUISE VEL: 100 KTS
MAX END VEL: 65 KTS

CRUISE PWR REQD: 471.20 SHP
MAX END PWR REQD: 377.30 SHP

INSTALLED ENGINE WEIGHT <EA>: 552.60 LB
FUEL WEIGHT: 1826.80 LB
WEIGHT OF INSTALLED POWERPLANT 1 AND FUEL: 2932.00 LB
--------- ENGINE 2 DATA ---------

<table>
<thead>
<tr>
<th></th>
<th>SHP</th>
<th>SFC</th>
</tr>
</thead>
<tbody>
<tr>
<td>MILITARY</td>
<td>1561.00</td>
<td>0.4830</td>
</tr>
<tr>
<td>NORMAL</td>
<td>1310.00</td>
<td>0.4935</td>
</tr>
<tr>
<td>CRUISE</td>
<td>1000.00</td>
<td>0.5775</td>
</tr>
</tbody>
</table>

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
ZHI: 218.05 LB/HR

PShp: 1355.34 SHP
BShp: 385.70 SHP

FUEL FLOW RATE: 579.55 LB/HR

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

PA: 4000.0 FT  TEMP: 95.0 F

MAX RANGE: 350.00 NM
CRUISE VEL: 100 KIS  CRUISE PWR REQD: 471.20 SHP
MAX END VEL: 65 KIS  MAX END PWR REQD: 377.30 SHP

INSTALLED ENGINE WEIGHT <EA>: 495.00 LB
FUEL WEIGHT: 2409.25 LB
WEIGHT OF INSTALLED PCWEEPLANT 2 AND FUEL: 3399.25 LB

RECOMMEND ENGINE 1 BE SELECTED
HELO DESIGN ENGINE FUEL FLOW CHARACTERISTICS
AND ENGINE SELECTION OPTIMIZATION

THIS PROGRAM IS DESIGNED TO CALCULATE ENGINE
FUEL FLOW CHARACTERISTICS AND TO OPTIMIZE
THE SELECTION OF A POWERPLANT BASED UPON THE
INSTALLED ENGINE WEIGHT AND TOTAL FUEL WEIGHT
FOR THE DESIGN MISSION PROFILE FOR THE BASIC
DESIGN OF A HELICOPTER.

MAY 1, 1983

NOMENCLATURE

VARIABLES:

ALPHA AVG ZERO SHP FUEL FLOW
BETA SLOPE OF MF VS. SHP LINE
CM MAIN Rotor CHORD
CT TAIL Rotor CHORD
DELTA RATIO OF PRESSURE AT ALT. TO PRESSURE AT S.L.
DIFF DIFFERENCE BTWN PA FOR ENGINE AND PA FOR PWR REQ
DIFF1 DIFFERENCE BTWN TEMP FOR ENGINE AND TEMP FOR PWR REQ
DM MAIN Rotor COEF OF DRAG
DT TAIL Rotor COEF OF DRAG
FUELWT TOTAL WEIGHT OF FUEL FOR MISSION PROFILE
GW GROSS WEIGHT
LT LENGTH FRCP CG TO HUB OF TAIL Rotor
PAFT PRESSURE ALTITUDE IN FEET
PEND TOTAL POWER REQUIRED AT MAX ENDURANCE VELOCITY
PSHP PHANTOM SHAFT HORSE POWER
PWRC TOTAL POWER REQUIRED AT CRUISE VELOCITY
PWR TOTAL POWER REQUIRED
PWRM TOTAL POWER REQUIRED BY MAIN Rotor
PWTR TOTAL POWER REQUIRED BY TAIL Rotor
PWTRI INDUCED POWER
PWTRM INDUCED POWER, MAIN Rotor
PWTRT INDUCED POWER, TAIL Rotor
PWRO PROFIL POWER
PWROM PROFIL POWER, MAIN Rotor
PWROT PROFIL POWER, TAIL Rotor
**C**
PWRP  PARASITE POWER
**A**  480

**C**
RM  MAIN ROTOR RADIUS  **A**  490

**C**
RSHP REQUIRED FICT SHP  **A**  500

**C**
RSHPMX MAX RSHP  **A**  210

**C**
RT  TAIL ROTOR RADIUS  **A**  270

**C**
SFC SPECIFIC FUEL CONSUMPTION: LB/HR/SHP  **A**  530

**C**
SHP  ENGINE SHAFT HORSEPOWER  **A**  540

**C**
STRETA SQRT OF RATIO OF TEMP. AT ALT TO TEMP AT S.L.  **A**  550

**C**
SM  MAIN FICTR BEM  **A**  260

**C**
ST  TAIL ROTOR BEM  **A**  570

**C**
T  TEMP AT ALT. IN DEGREES FAHRENHEIT  **A**  580

**C**
VEND  MAX ENDURANCE VELOCITY  **A**  590

**C**
VFK  FORWARD VELOCITY OF THE AIRCRAFT, KNOTS  **A**  600

**C**
VHR  MAX RANGE VELOCITY  **A**  610

**C**
VR  INPUT VELOCITY  **A**  620

**C**
WEDRY  MANUFACTURER'S DRY ENGINE WEIGHT  **A**  630

**C**
WEI  ESTIMATED INSTALLED WEIGHT OF ONE ENGINE  **A**  640

**C**
WF  FUEL FLOW RATE AT KNOWN CONDITIONS  **A**  650

**C**
WFSL FUEL FLOW RATE AT SEA LEVEL  **A**  660

**C**
WFALT FUEL FLOW RATE AT ALT.  **A**  670

**C**
WFA  FUEL FLOW RATE AT NORMAL RATED POWER  **A**  680

**C**
WFB  FUEL FLOW RATE AT CRUISE POWER  **A**  690

**C**
WFC  FUEL FLOW RATE AT MAX ENDURANCE POWER  **A**  700

**C**
WTOT  TOTAL WEIGHT OF POWERPLANT AND FUEL WEIGHT  **A**  710

**C**
ZHI  ZERO SHP FUEL FLOW  **A**  720

**C**
ZHIX  ZERO SHP FUEL FLOW AT DESIRED ALT. AND TEMP.  **A**  730

**C**
**INT**  EGER S:

**C**
J  ENGINE NUMBER  **A**  750

**C**
LRSP  LOGICAL CONSTANT USED FOR INTERACTIVE RESPONSES  **A**  760

**C**
LRSP1 LOGICAL CONSTANT USED FOR INTERACTIVE RESPONSES  **A**  780

**C**
N  NUMBER OF ENGINES  **A**  790

**C**
NM  MAIN ROTOR BLADES  **A**  800

**C**
NUM  optimum engine selected  **A**  810

**C**
NORY  LOGICAL VARIABLE USED FOR INTERACTIVE RESPONSES  **A**  830

**C**
NT  TAIL ROTOR BLADES  **A**  840

**C**
VCRUS  SPECIFICATION CRUISE VELOCITY: KTS  **A**  850

**C**
VEND  MAXIMUM ENDURANCE VELOCITY: KTS  **A**  860

**C**
VINC  INCREMENT OF FORWARD SPEED FOR PRINT OUT  **A**  870

**C**
VMAX  MAXIMUM FORWARD VELOCITY OF THE AIRCRAFT  **A**  880

**C**
**C**
****
--- DECLARATIONS ---

REAL BETA, DELTA, FUEL, PSHP, VSHP, NA, PAPT, SFC, SHP, SHFI, SHTETA, WH, EDRE, WPA, WPB, WEC, WESI, WPAT, ALPHA, ZHI, SFC, SHF, WTOT(5), PWR, PWRM, PWRT, PWRI, PWRTM, PWRI, PWRO, PWROM, PWROT, PWRP, VP, VEND, DP3, PA, TP, FA, FT, SE, BL, CM, ST, RT, DT, CT, FEND

DIMENSION PWR(200), PWRT(200), PWRI(200), PWRTM(200), PWRO(200), PWROM(200), PWROT(200), PWRP(200), VFK(200)

INTEGER I, J, K, N, LRESPE, LRESP1, NORY, VCRUS, VINC, VMAX, VCNT, VMAX, NN, NT, 1VR

DATA LRESP/'Y', LRESP1/'Q'/

--- DEFINE FILES ---

CALL FOTCHM('FILEL1', 1, 'DISK', 'HPWRIP', 'A1')

WRITE(1, 350)

--- READ DATA FROM FILE HPWRIP DATA A ---

READ(4, 360) GH, PA, TF, FA, IT, VMAX, VINC
READ(4, 370) S1, TB, DB, CH, NN
READ(4, 370) ST, RT, CT, CT, NT
READ(4, 380) VCNT
DO 10 I = 1, VCNT
   K = I - 1
   READ(4, 390) K, VFK(I), PWR(I), PWRT(I), PWRI(I), PWRO(I), PWRTM(I), PWRI(I), PWRO(I), PWROM(I), PWROT(I)
10 CONTINUE

--- WRITE USER INSTRUCTIONS ---

CALL FOTCHM('CLRSCRM')
WRITE (6, 400)
WRITE (6, 410)
WRITE (6, 420)
READ(5, 430) NORY
IF (.NOT. (NORY .EQ. LRESP)) GO TO 340
CALL PRTCHS ('CLRSCRN')
WHITE (6,440)

C READ (5,450) NORY
C IF (.NOT. (NORY.EQ.LRES)) GO TO 340
C 20 CONTINUE
C
C------------------- PROMPT FOR ENGINE DATA -------------------
C
CALL PRTCHS ('CLRSCRN')
WHITE (6,460)
C READ (5,*) SFCI(1)
C CHECK TO INSURE SFC < 1.0; IF NOT TRY AGAIN
C IF (SFCI(1).LE.1.0) GO TO 40
WHITE (6,520)
GO TO 30
C 40 CONTINUE
C 50 CONTINUE
WHITE (6,470)
C READ (5,*) SHPI(1)
C CHECK TO INSURE SHP > 1.0; IF NOT TRY AGAIN
C IF (SHPI(1).GE.1.0) GO TO 60
WHITE (6,530)
GO TO 50
C 60 CONTINUE
C 70 CONTINUE
WHITE (6,480)
C READ (5,*) SFCI(2)
C CHECK TO INSURE SFC < 1.0; IF NOT TRY AGAIN
C IF (SFCI(2).LE.1.0) GO TO 80
WHITE (6,520)
GO TO 70
C 80 CONTINUE
C 90 CONTINUE
WHITE (6,490)
C READ (5,*) SHPI(2)
C CHECK TO INSURE SHF > 1.0; IF NOT TRY AGAIN
C IF (SHPI(2),GE.,1.0) GO TO 100
C WRITE (6,530)
C GO TO 90
100 CONTINUE
110 CONTINUE
C WRITE (6,500)
C READ (5,*) SFCI(3)
C CHECK TO INSURE SFC < 1.0; IF NOT TRY AGAIN
C IF (SFCI(3),LE.,1.0) GO TO 120
C WRITE (6,520)
C GO TO 110
120 CONTINUE
130 CONTINUE
C WRITE (6,510)
C READ (5,*) SHPI(3)
C CHECK TO INSURE SHF > 1.0; IF NOT TRY AGAIN
C IF (SHPI(3),GE.,1.0) GO TO 140
C WRITE (6,530)
C GO TO 130
140 CONTINUE
C WRITE (6,540)
C READ (5,*) WEDRY
C-------CALCULATE FUEL FLOW RATE AT GIVEN CONDITIONS-------
C CALL FUEISL (SHPI,SFCI,BETA,ALPHA)
C CALL FRTCHS ('CLRSCRN')
C WRITE (6,550) ETA
C WRITE (6,560) ALPHA
------------------PRINT ENGINE DATA------------------

WRITE HEADING

IF (J.GT.1) WRITE (8,570)
WRITE (8,580) J
WRITE (8,590) SHEP(1),SPCI(1)
WRITE (8,600) SHEP(2),SPCI(2)
WRITE (8,610) SHEP(3),SPCI(3)

WRITE (8,620) WEDRY,BETA,ALPHA

FOR SUBSEQUENT ENGINES USE THE SAME PRESSURE ALTITUDE AND
TEMPERATURE AS THOSE USED FOR ENGINE 1.

IF (.NOT. (J.EQ.1)) GO TO 160

------------------INPUT DESIRED CONDITIONS------------------

WRITE (6,630)
READ (5,640) NORY
IF (.NOT. (NORY.EQ.1)) GO TO 340
CALL PRTCMS ("CLRSCRN")

CONTINUE
WRITE (6,650)
READ (5,*) PAFT
WRITE (6,660)
READ (5,*) T

CONTINUE
CALCULATE PRESSURE RATIO, TEMP RATIO, AND ZERO SHP INCREDENT

CALL PRAIIO (PAFT,BELTA)
CALL TRATIO (T,STHETA)
CALL ZHIATI (ALPHA,DELTA,STHETA,ZHIX)

WRITE (6,670) PAFT,T,ZHIX
C---------- FROMT FOR NUMBER OF ENGINES AND CALCULATE PSHP----------
    CALL FRTCMS ('CLSCRN')
    WRITE (6,680)
C    READ (5,*), N
C    CALL ZVSHP (ZHIY,EETA,N,PSHP)
    WRITE (6,690) PSHP
C    170 CONTINUE
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. **
    IF (J.EQ.1) GO TO 200
    ELSE CALCULATE FUEL FLOW RATE FOR ENGINE J AT LAST ROTOR SHP
    REQUIRED ENTERED FOR ENGINE 1
C    CALL FLOALT (RSHPMX,EETA,N,PSHP,WFALT)
    WRITE (6,730)
    WRITE (6,740) PAP1,N,T,PSHP,ZHIY,RSHPMX,WFALT
C    CHECK PA AND T FOR POWER REQUIRED CALCULATIONS; PRINT A CAUTION
C    MESSAGE IF EITHER IS NOT THE SAME AS SPECIFIED BY THE USER FOR
C    FUEL FLOW CALCULATIONS.
C    DIFF=ABS(PA-PAFT)
    DIFF1=ABS(TP-T)
    IF (DIFF.LT.1.0) GC TO 180
    WRITE (6,750)
    WRITE (6,750)
    180 CONTINUE
    IF (DIFF1.LT.1.0) GO TO 190
    WRITE (6,760)
    WRITE (6,760)
    190 CONTINUE
C    GO TO 270
200 CONTINUE
C
C-------------- WRITE OPTICNS FOR CALCULATION OF FUEL FLOW RATE --------------
WRITE (6,700)
C
READ (5, *) N
IF (N.EQ. 3) GO TO 340
IF (N.EQ. 1) GO TO 210
WRITE (6,710)
READ (5, *) VR
RSHPMX=PSHR(VR+1)
GO TO 220
CONTINUE
WRITE (6,720)
READ (5, *) RSHEMX
CONTINUE

C------------------ CALCULATE FUEL FLOW RATE -------------------------------
CALL FLOALT (RSHEMX,BETA,N,PSHE,WFALT)
C
CALL PRTCMS ('CLRSCREEN')
C
C------------------ PRINT FUEL FLOW DATA ---------------------------------
WRITE (6,730)
WRITE (6,730)
WRITE (6,740) FAPT,N,T,PSHP,ZHIX,RSHPMX,WFALT
WRITE (6,740) FAPT,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.
DIFF=ABS (PA-PAPT)
DIFF1=ABS (TP-T)
IF (DIFF.LT.1.0) GO TO 230
WRITE (6,750)
WRITE (6,750)
CONTINUE
IF (DIFF1.LT.1.0) GO TO 240
WRITE (6,760)
WRITE (6,760)
CONTINUE
WRITE (6,770)
CONTINUE
C------ WRITE OPTIONS FOR DOING ADDITIONAL FUEL FLOW CALCULATIONS ------
C
READ (5,780) NCRY
C
IF (.NOT. (NORY.EQ.1RESP)) GO TO 250
GO TO 150
CONTINUE
IF (NORY.EQ.1RESP1) GO TO 340
C
WRITE (6,790)
C
READ (5,800) NORY
C
IF (.NOT. (NORY.EQ.1RESP)) GO TO 260
GC TO 170
CONTINUE
IF (NORY.EQ.1RESP1) GO TO 340
C
CONTINUE
C
FOR SUBSEQUENT ENGINE COMPARISONS, USE THE DESIGN MISSION PROFILE
C
IF (.NOT. (J.EQ.1)) GC TO 280
C
C------- CALCULATE FUEL WEIGHT FOR MISSION PROFILE -------
C-------
WRITE (6,810)
C
READ (5,820) NORY
C
IF (NORY.EQ.1RESP1) GO TO 340
IF (.NOT. (NORY.EQ.1RESP)) GO TO 290
C
---- PROMPT FOR RANGE AND CRUISE VELOCITY ----
C
WRITE (6,830)
C
READ (5,*) RANGE
C
WRITE (6,840)
C
READ (5,*) WCRUS
C
C---- CALCULATE V-MAX ENDURANCE AND BSHP FOR V-MAX ENDURANCE ----
C       CALL MAXEND (PUR,VRK,VCURS,VMAX,PURC,PEND,VEND)
C 280  CONTINUE
C
C---- CALCULATE TOTAL WEIGHT OF ENGINE AND FUEL-------------------
C---- CALCULATE ZERO HORSEPOWER INCREMENT ------------------------
C---- AT CONDITIONS USED FOR POWER REQUIRED CALCULATIONS----------
C----
C       CALL PRATIO (PA,DELTA)
C       CALL TRATIO (TF,STHETA)
C       CALL ZTHALT (ALPHA,DELTA,STHETA,ZHIX)
C
C---- CALCULATE ZERO VELOCITY HORSEPOWER (PHANTOM SHAFT HORSEPOWER)----
C       CALL ZVSHP (ZHIX,EETA,W,PSHP)
C
C---- CALCULATE FUEL FLOW RATES ---------------------------------
C       WFA=(FLOAT(N)*SHEI(2)+PSHP)*EETA
C       CALL FLOATS (PURC,BETA,N,PSHP,WFA)
C       CALL FLOATS (PEND,EETA,N,PSHP,WFC)
C
C---- CALCULATE TOTAL FUEL WEIGHT---------------------------------
C       CALL FUELWT (RNGE,VCURS,WFA,WFE,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) FA,TF,RNGE,VCURS,PWRC,VEND,PEND
C       WRITE (8,850) FA,TF,RNGE,VCURS,PWRC,VEND,PEND
C       WRITE (6,860) WEI,FUELWT,J,WTCT(J)
C       WRITE (8,860) WEI,FUELWT,J,WTCT(J)
C 290  CONTINUE
C----------------- GIVE OPTION TO TRY ANOTHER ENGINE -----------------
  WRITE (6,870)
  C
  READ (5,880) NCBY
  C
  IF (.NOT. (NORY.EQ.LRESP)) GO TO 300
  J=J+1
  C
  RETURN ABOVE TO INPUT NEW ENGINE DATA
  300
  GO TO 20
  CONTINUE
  IF (NORY.EQ.LRESP) GO TO 340
  C
  C---------------- DETERMINE OPTIMUM ENGINE SELECTION ----------------
  IF (.NOT. (J.GT.1)) GO TO 330
  MINWT=WTOT (I)
  NUM=1
  DO 320 I=2,J
    IF (.NOT. (WTOT (I).LT.WTOT (I-1))) GO TO 310
    MINWT=WTCT (I)
    NUM=I
  310
  CONTINUE
  320
  CONTINUE
  C
  WRITE (6,890) NUM
  C
  WRITE (6,890) NUM
  C
  330
  CONTINUE
  C
  340
  CONTINUE
  C
  STOP
  350
  FORMAT (1X,48H********** ENGINE FUEL FLOW AND OPTIMIZATION *,11H  
  1**********/)//
  360
  370
  380
  FORMAT (I4)
  390
  FORMAT (1H,I5,F4.4,F10.7.1)
  400
  FORMAT (1/5X,52H THIS PROGRAM COMPUTES FUEL FLOW AND FUEL WEIGHT 
  1A.17H USING USER INPUT. / 39H VALUES OF ENGINE PERFORMANCE CHARAC 
  2R.32HISTICS FOR A SELECTED TURBOHAFT / 21H ENGINE. THE PROGRAM 
  32HUSES POWER REQUIRED DATA FOR A PRELIMINARY / 12H HELICOPTER 
  33H DESIGN PREVIOUSLY CALCULATED AND STORED IN DATA FILE /1X,59HFPWB 
  5IP. THIS DATA FILE MUST BE RESTORING ON THE USERS DISK /1F,43HIF P 
  6UEL 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
  A500
  A5010
  A5020
  A5030
  A5040
  A5050
  A5060
  A5070
  A5080
  A5090
  A5100
  A5110
  A5120
  A5130
  A5140
410 FORMAT ('/5X,44HTHE PROGRAM HAS FOUR COMPUTATIONAL SEGMENTS: /2X,34
1H1. CALCULATION OF ENGINE FUEL FLOW, 45H CHARACTERISTICS USING INPUT
2T VALUES OF ENGINE, /2X, 58H SPECIFIC FUEL CONSUMPTION AND SHAFT
3HORSEPOWER AVAILABLE AT THREE /2X, 15H POWER SETTINGS, /2X, 21H2,
4H CALCULATION OF THE /4H FUEL FLOW RATE AT A SPECIFIED VALUE OF REQ
5UINED, /2X 5H ROTO. 19HR SHAFT HORSEPOWER, /2X 35H3. CALCULATION OF
6H THE ESTIMATED ENG. 39H INSTALLED WEIGHT AND THE TOTAL FUEL, /2X,1
7H WEIGHT FOR A DES 20H HIGHER MISSION PROFILE, /2X 35H4. CALCULATION OF
8H ESTIMATED ENGINE, 35H INSTALLED WEIGHT AND THE TOTAL FUEL, /2X, 20H
9H WEIGHT FOR UP TO FIVE 39H ENGINES. THE ENGINE WITH THE MINIMUM RES
10UULTING FUEL 4H AND /2X, 49H POWERPLANT WEIGHT IS THEN RECOMMENDED AS
11H OPTIMUM, 26H WHICH USE IN THE HELICOPTER. /5X, 29H PROGRAM OUTPUT IS
12H WRITTEN BOTH TO THE TERMINAL AND TO FILE - FUELPO, /2X, 10H LIST
13H ING, 50H WHICH IS CREATED BY THE PROGRAM ON THE USER DISK.
14H FORMAT (1H, 51H THOUGHOUT THE PROGRAM, ENTER ONE OF THE FOLLOWING
15H RESPONSES TO CONTINUE PROGRAM EXECUTION : /1X, 6HY: YES, /1X
16H 5H: NO, /1X, 7H: QUIT, /1X, 32H NOW ENTER Y TO CONTINUE OR Q TO 
17H.5300
18H FORMAT (A1)
19H FORMAT (1H, 48H THIS SEGMENT OF THE PROGRAM CALCULATES THE FUEL /1
20H 60H FLOW CHARACTERISTICS FOR A TURBO-SHAFT ENGINE OPERATING IN THE
21H 2/1X, 29H ATMOSPHERE - BELOW 36000 FT: /1X, 32H REQUIRED INPUT DATA I
22H 3S: /IX 55H (1) SHP AND SFC AT NORMAL MILITARY AND CRUISE POWER
23H 4T /IX, 41H (2) DESIRED PRESSURE ALTITUDE IN FEET, /2X, 41H (3) DE
24H SURED TEMPERATURE IN DEGREES F, /IX, 33H (4) ENGINE DRY WEIGHT I
25H 6N LBS. /IX, 11H ENTER Y TO, 21H CONTINUE OR Q TO QUIT)
26H FORMAT (A1)
27H FORMAT (1H, 36H ENTER SFC FOR MILITARY POWER SETTING)
28H FORMAT (1H, 36H ENTER SFC FOR CRUISE POWER SETTING)
29H FORMAT (1H, 36H ENTER SFC FOR NORMAL POWER SETTING)
30H FORMAT (1H, 34H ENTER SHP FOR NORMAL POWER SETTING)
31H FORMAT (1H, 34H ENTER SHP FOR CRUISE POWER SETTING)
32H FORMAT (1H, 34H ENTER SHP FOR MILITARY POWER SETTING)
33H FORMAT (//1X, 42H ENTER AGAIN, SFC SHOULD BE LESS THAN 1.0/)
34H FORMAT (//1X, 42H ENTER AGAIN, SHP SHOULD BE GREATER THAN 1.0/)
35H FORMAT (1H, 23H ENTER ENGINE DRY WEIGHT)
36H FORMAT (1X, 10H BETAN=, /F8.5/)
37H FORMAT (1X, 8H ALPHAG=, /F8.4, 4H SHP//)
38H FORMAT (1H)
39H FORMAT (1X, /23H ------------------ ENGINE,11, 22H DATA ------------------
40H 1---//, 16X, 3SHP, 15X, 3SPC/)
41H FORMAT (2X, 14H MILITARY, /F8.2, 10X, /F8.4/)
42H FORMAT (2X, 14H NORMAL, /F8.2, 10X, /F8.4/)
43H FORMAT (2X, 18H CRUISE, /F8.2, 10X, /F8.4/)
44H FORMAT (2X, 12H DRY WEIGHT, /F8.1, 6H LBS., /2X, 6H BETAN=, /F8.4, /2X, 1H
45H 1A, 6H ALPHAG, /F8.2, 6H LBS/HR///)
46H A5150
47H A5160
48H A5170
49H A5180
50H A5190
51H A5200
52H A5210
53H A5220
54H A5230
55H A5240
56H A5250
57H A5260
58H A5270
59H A5280
60H A5290
61H A5300
62H A5310
63H A5320
64H A5330
65H A5340
66H A5350
67H A5360
68H A5370
69H A5380
70H A5390
71H A5400
72H A5410
73H A5420
74H A5430
75H A5440
76H A5450
77H A5460
78H A5470
79H A5480
80H A5490
81H A5500
82H A5510
83H A5520
84H A5530
85H A5540
86H A5550
87H A5560
88H A5570
89H A5580
90H A5590
91H A5600
630 FORMAT (/'X,45HTHE PROGRAM CAN NOW CALCULATE THE ZERO SHAFT-/X,145HORSEPOWER INCREMENT AT ANY DESIRED PRESSURE /X,41HALTITUDE AT 2ND TEMPERATURE UP TO 36,000 FT./X,46HENTER .274Y TO CONTINUE OR 30 TO QUIT.)
A5610
640 FORMAT (A)
A5620
650 FORMAT (/'X, 31HENTER PRESSURE ALTITUDE IN FEET/)
A5630
660 FORMAT (/'X, 31HENTER TEMPERATURE IN DEGREES F.)
A5640
670 FORMAT (/'X, 41HTHE ZERO SHP INCREMENT FOR THIS ENGINE AT //5X, 7HP 1. A. = /X, P0.2, 4H FT.//5X, 7HTEMP = /X, P0.2, //5X, 3HRS , P10.2, 6HP LB/HR/2)
A5650
680 FORMAT (/'X, 45HTHE PROGRAM CAN NOW CALCULATE THE PHANTOM HORSEPOWER FOR THESE./51H C 2ND CONDITIONS ENTER THE NUMBER OF ENGINES BEING USED://)
A5660
690 FORMAT (/'X, 45HTHE PROGRAM WILL READ THE APPROPRIATE POWER FROM DATA FILE//2X, 8HPWRTPPF...//2X, 14HNOTE THIS Pilot...//2X, 8HPWRTPPF...//2X, 14HNOTE THIS Pilot...
A5670
A5680
700 FORMAT (/'X, 45HTE PROGRAM CAN NOW CALCULATE THE FUEL FLOW RATE FOR 1/59H THIS POWER PLANT AT ANY DESIRED VALUE OF ROTOR SHAFT HORSE./
A5690
251H POWER REQUIRED//51HP. THE USER HAS THREE OPTIONS: //2X, 2H1. 2 //A5700
31H INPUT RSHP DIRECTLY. //2X, 32H2. INPUT THE VELOCITY AT WHICH T. 19 //A5710
4THRS RSHP IS DESIRED. //2X, 34HTE PROGRAM WILL READ THE APPROPRIATE, 25H 5ATE POWER FROM DATA FILE//2X, 8HPWRTPPF...//2X, 14HNOTE THIS Pilot...//2X, 8HPWRTPPF...//2X, 14HNOTE THIS Pilot...
A5720
A5730
710 FORMAT (/'X, 45HFORWARD VELOCITY IN KNOTS.)
A5740
720 FORMAT (/'X, 38HENTER MOTOR SHAFT HORSEPOWER REQUIRED.)
A5750
730 FORMAT (/'X, 30H------ FUEL FLOW RATE ------/)
A5760
A5770
750 FORMAT (/'X, 45HCUTION: ALTITUDE FOR ENGINE FUEL FLOW RATE IS //X, 36HAS THE ALTITUDE AT WHICH POWER REQUIRES 18HRED W 2AS CALCULATED/)
A5780
A5790
760 FORMAT (/'X, 45HCUTION: TEMPERATURE FOR ENGINE FUEL FLOW RATE I, 1 4HS NOT THE SAME. //X, 31HAS THE ALTITUDE AT WHICH POWER, 23HREQUIRES 2D WAS CALCULATED/)
A5800
A5810
770 FORMAT (/'X, 53HDO YOU WANT TO TRY THE SAME ENGINE AT NEW CONDITIONS //X, 5X, 3HNN, OR Q)
A5820
A5830
780 FORMAT (A1)
A5840
790 FORMAT (/'X, 40HDO YOU WANT TO TRY THE SAME ENGINE AT A,28HDIFFERENT //X, 5X, 8HNN, OR Q)
A5850
A5860
800 FORMAT (A1)
A5870
810 FORMAT (/'X, 44HTHE MISSION PROFILE SPECIFIED FOR THE DESIGN, 26H OF 1A BASIC HELICOPTER IS: //X, 3X, 35H2. TIME TO FLY THE MAXIMUM RANGE AT 17H CRUISE VELOC 3ITY. //X, 34H3. 5 MINUTES @ NORMAL RATED POWER./, 5X, 43H4, 15 MINUTE 45 @ MAXIMUM ENDURANCE VELOCITY. ///, 2X, 46HD0 YOU WANT TO CALCULATE 5THE TOTAL FUEL WEIGHT, 35H FOR THE SPECIFIED MISSION PROFILE?. //X, 5X, 68HY NN, OR Q)
A5880
A5890
820 FORMAT (A1)
A5900
**FORMAT (2X,49HENTER SPECIFIED MAXIMUM RANGE IN NAUTICAL MILES.//) A6080**

**FORMAT (//2X,42HENTER SPECIFIED CRUISE VELOCITY IN KNOTS.) A6090**

**FORMAT (//2X,51H------- MISSION PROFILE CONDITIONS -------) A6100**

1. //2X HPA: 8X, F6.0, 3H FT 8X //2X, 1H MAX RA
2. //2X HGT: 1H, F8.2, 3H NM //2X, 1H CRUISE VEL: 1X, 14, 4H KTS //2X, 1H CRUISE P
3. //2X TEND: 2X, F8.2, 4H SHP //2X, 1H CRUISE END VEL: 1X, 13, 4H KTS //2X, 1H CRUISE P

**FORMAT (2X,39HINSTALLED ENGINE WEIGHT <EA>: F8.2, 3H LB //2X, 4H FUEL 1L, 9H WEIGHT: F8.2, 3H LB //2X, 29HWEIGHT OF INSTALLED POWERPLN, 2HT 2.11, 1H AND FUEL: F10.2, 3H IB) A6160**

**FORMAT (2X,38HD0 YOU WANT TO COMPARE ANOTHER ENGINE?, //, 5X, 6HY OR 1H) A6180**

**FORMAT (A1) A6200**

**END A6220**

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**SUBROUTINES**

**SUBROUTINE FUEL SI: CALCULATES SLOPE OF FUELPFLOW LINE AND THE**

**SSI ZERO HORSEPOWER INCREMENT.**

**subroutine fuel si (she, sfc, beta, alpha) c**

**real shp (3), sfc (3), wf (3), zhi (3), beta, alpha, beta1, beta2, beta3**

**do 10 i=1,3**

**sfc (i)=sfc (i)+.05*sfc (i)**

**wf (i)=shp (i)*sfc (i)**

**continue 10**

**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)))**
50 CONTINUE
IF (.NOT. (SHP (2) .EQ. SHP (3))) GO TO 60
BETA3=0.0
J=J-1
GO TO 70
CONTINUE
BETA3=ABS ((WF (2) - WF (3)) / (SHP (2) - SHP (3)))
70 CONTINUE
IF (.NOT. (FLOAT (J).LT.0.0)) GO TO 80
BETA=0.0
GO TO 90
80 CONTINUE
BETA=(BETA1+BETA2+BETA3)/FLOAT (J)
90 CONTINUE
C
DO 100 I=1,3
ZHI (I)=WF (I)-(BETA*SEH (I))
100 CONTINUE
ALPHA=(ZHI (1)+ZHI (2)+ZHI (3))/3.
C
RETURN
END
C-- SUBROUTINE PRATIO: CALCULATES RATIO OF PRESSURE AT ALTITUDE
C TO THE PRESSURE AT SEA LEVEL.
C--
C SUBROUTINE PRATIO (PAFT,DELTA)
C REAL PAFT,DELTA
C
IF (.NOT. (PAFT.EQ.0.0)) GO TO 10
DELTA=1.0
GO TO 20
10 CONTINUE
DELTA=(1.0-(6.8754E-06*PAFT))**5.256
C
RETURN
END
C-- SUBROUTINE TRATIO: CALCULATES RATIO OF TEMPERATURE AT OPERATING
C CONDITIONS TO SSL TEMPERATURE.
C--
C SUBROUTINE TRATIO (T,STHETA)
C REAL T,STHETA
C  
C  STHETA=SQR((-T + 459.688)/518.688)
C
C  RETURN
C  END
C
C  SUBROUTINE ZHIAIT:  CALCULATES THE ZERO HORSEPOWER INCREMENT AT
C  OPERATING CONDITIONS.
C
C  SUBROUTINE ZHIAIT (ALPHA,DELTA,STHETA,ZHIX)
C  REAL ALPHA,DELTA,STHETA,ZHIX
C  ZHIX=ALPHA*DELTA*STHETA
C  RETURN
C  END
C
C  SUBROUTINE ZVSHP:  CALCULATES THE ZERO VELOCITY HORSEPOWER (PHANTOM
C  SHAFT HORSEPOWER) AT OPERATING CONDITIONS.
C
C  SUBROUTINE ZVSHP (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 FLOALT:  CALCULATES THE FUEL FLOW RATE AT OPERATING
C  CONDITIONS FOR A GIVEN TOTAL ROTOR SHAFT
C  HORSEPOWER REQUIRED BY THE AIRCRAFT.
C
C  SUBROUTINE FLOALT (RSHPMX,BETA,N,PSHP,WFALT)
C  REAL BETA,ESHP,PSHP,RSHPMX,WFALT
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
   WALT= (PSHP + ESHP)*BETA
C
   RETURN
   END
C-- SUBROUTINE FUELWT: CALCULATES THE TOTAL FUEL WEIGHT FOR THE
C    SPECIFIED MISSION PROFILE.
C--
C  SUBROUTINE FUELWT (RNGE, VCRUS, WFA, WFB, WFC, FUELWT)
C  REAL RNGE, WFA, WFB, WFC, FUELWT
C  INTEGER N, VCRUS
C  FUELWT = 1.0*WFA + WFB + RNGE/5.0 + .25*WFC
C  RETURN
C  END
C-- SUBROUTINE ENGWT: CALCULATES THE ESTIMATED INSTALLED WEIGHT OF
C    AN ENGINE USING DRY WEIGHT AS PARAMETER.
C--
C  SUBROUTINE ENGWT (WEDRY, WEI)
C  WEI = 45.0 + 1.2*WEDRY
C  RETURN
C  END
C-- SUBROUTINE MAXEND: CALCULATES V-MAX ENDURANCE AND RSHP FOR
C    V-MAX ENDURANCE
C--
C  SUBROUTINE MAXEND (PWR, VFK, VCRUS, VMAX, PWRC, PEND, VEND)
C  REAL PWR (200), VFK (200), PWRC, PEND
C  INTEGER 1, VCRUS, VMAX, VEND
C  I = VCRUS
C  PWRC = PWR (I+1)
VEND=VFK (2)
PEND=PWR (2)
DO 20 I=2,VMAX
IF (.NOT. (PWR (I):.EQ. PWR (I-1))) GO TO 20
IF (.NOT. (PWR (I):.EQ. PWR (I+1))) GO TO 10
10 C
RETURN
END
APPENDIX E

HELIICOPTER 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: \[ PT = \] Explanation: 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:

\[
A_D = \frac{\pi R^2}{4}
\]

\[
\sigma = \frac{bc}{\pi R}
\]

\[
V_T = \Omega R
\]

\[
C_T = \frac{T}{A_D \rho V_T^2}
\]
\[ B = 1 - \frac{\sqrt{2C_T}}{b} \]

\[ v_i = \left[ \frac{T}{2\rho A_D} \right]^{\frac{1}{2}} \quad v_{if} = \frac{-v_i^2}{2v_i} + \left[ \frac{V_f^2}{2v_i^2} + 1 \right]^{\frac{1}{2}} v_i \]

\[ P_{TL}^2 = \frac{T V_{if}}{B} \]

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

b. Main rotor only:

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

\[ P_{MR}^T = P_{MR}^i + P_{MR}^0 + P_p \]

\[ T_{MR} = W \]

c. Tail rotor only:

\[ T_{tr} = \frac{P_{TR}}{\Omega_{MR} \Omega_{TR}} \]

d. Operating conditions:

\[ h_o = \frac{1 - \left[ \frac{T_{SSL}}{T} \right]^{1-K_1 h_p \frac{5.2561}{23496}}}{K_1} \]

\[ \rho = \rho_{SSL} \left[ 1 - (K_1 h_C) \right]^{4.2561} \]

e. Total Power:

\[ P_T = P_{MR} + P_{TR} + P_{tr} \]

where:

- \( A_D \) is the disk area (ft)
- \( R \) is the rotor radius (ft)
- \( \sigma \) 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)
$\Omega$ 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)
$\rho$ is the air density (slugs/ft)
B is the tiploss factor
$vi$ is the induced velocity (ft/sec)
$V_{if}$ is the induced velocity in forward flight (ft/sec)
$V_f$ is the forward velocity (ft/sec)
$Pi_{TL}$ is the induced power required with tip loss (hp)
$Po$ is the profile power required (hp)
$\overline{CdO}$ is the profile drag coefficient
$Pp$ is the parasite power required (hp)
$f_f$ is the equivalent flat plate area in forward flight (ft)
$P_{T_{MR}}$ is the total power required by the main rotor (hp)
$T_{MR}$ is the thrust of the main rotor (lb)
$W$ is the gross weight (lb)
$l_{tr}$ is the distance between tail rotor hub and main rotor mast (ft)
$h_p$ is the density altitude (ft)
$T$ is temperature (absolute)
$T_{SSL}$ is the standard sea level temperature (absolute)
$K_1$ is a constant $= 6.875 \times 10^{-8}$
$h_p$ is pressure altitude (ft)
\( \rho_{SSL} \) is standard sea level density of air (slugs/ft)

\( P_T \) is the total power required (hp)
3. Flowchart

Start

Prompt for and input Helo Data
Store in \( R_{17} \)

- LBL 'AREA'

Compute \( A_{mr} \); store in \( R_{20} \)

Compute \( A_{tr} \); store in \( R_{24} \)

- LBL 'SD'

Compute \( \sigma_{mr} \); store in \( R_{29} \)

Compute \( \sigma_{tr} \); store in \( R_{29} \)

- LBL 'VT'

Compute \( V_{r_{mr}} \); store in \( R_{27} \)

Compute \( V_{r_{tr}} \); store in \( R_{28} \)

- LBL 'DA'

Prompt for \( PA \) (ft); store in \( R_{10} \)

Prompt for \( T \) (F); store in \( R_{10} \)

Compute \( D_{A} \); store in \( R_{21} \)

- LBL 'DEN'

Compute air density; store in \( R_{22} \)

- LBL 'CT'

Yes

Is \( \text{Flag 02} \) set?

- Compute \( C_{r_{tr}} \); store in \( R_{20} \)

No

- Compute \( C_{r_{mr}} \); store in \( R_{20} \)
LBL 'TL'

Yes

Is Flag 02 Set?

Compute B <tr>
store in R24

Set ?

No

Compute B <mr>
store in R35

LBL 'VI'

Yes

Is Flag 02 Set?

Compute VI<tr>
store in R32

Set ?

No

Compute VI<mr>
store in R31

LBL 'PI'

Yes

Is Flag 02 Set?

No

Is Flag 03 Set?

Yes

No

Prompt for V6
Convert to ft/sec;
store in R20

Recall V from R20

Is Flag 02 Set?

Yes

Recall VI<tr> from R32

No

Is Flag 02 Clear?

Yes

next page

next page

next page
Recall VI<\text{mr}> from Rm

Compute VI<\text{mr}>; store in Reg
OR
Compute VI<\text{tr}>; store in Reg

Is Flag 02 set?

Yes

Recall Thrust<\text{tr}> from Rm

Is Flag 02 Clear?

Yes

Recall W from Rm

Compute Pi<\text{mr}>; store in Reg
OR
Compute Pi<\text{tr}>; store in Reg

next page

Is Flag 02 set?

Yes

Recall V_t<\text{tr}> from Rm

Is Flag J2 Clear?

No

next page

next page

next page

next page

next page
Recall \( W^{<ar>} \) from \( R^{w} \)

Compute \( W^{<ar>} \) or
Compute \( W^{<tr>} \)

Is Flag 02 set?

Yes

Recall \( A^{<ar>} \) from \( R^{a} \)

Is Flag 02 Clear?

Yes

Recall \( A^{<ar>} \) from \( R^{a} \)

Multiply by \( g \) from \( R^{g} \)

Is Flag 02 set?

Yes

Recall \( C^{<tr>} \) from \( R^{c} \)

Is Flag 02 Clear?

No

next page

next page

next page
Recall Cdo<mr> from R<sb>

Is Flag 02 set?

Yes

Recall σ<tr> from R<sb>

Is Flag 02 Clear?

Yes

Recall σ<mr> from R<sb>

Compute P<sb><mr> using V<sb><mr>

Compute P<sb><tr> using V<sb><tr>

Is Flag 02 Clear?

Yes

Store P<sb><mr> in R<sb>

Store P<sb><tr> in R<sb>

Is Flag 02 set?

Yes

Clear Flag 02

Compute A/C P<sb>; store in R<sb>
Recall $P_r$ from $R_w$.
Recall $P_r$ from $R_w$.
Recall $P_r$ from $R_w$.

Compute $P_r$: store in $R_w$.

"THRUST"

Compute Thrust $<tr>$; store in $R_s$.

Set Flag 02.

Ieq 'CT'.

"PT".

Recall $P_r$ from $R_s$.
Recall $P_r$ from $R_s$.
Recall $P_r$ from $R_s$.
Recall $P_r$ from $R_s$.

Compute $P_r$: store in $R_s$.

Is Flag 03 set?

Yes

No

Display $P_r$.

Stop.
4. Example Problem and User Instructions

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

<table>
<thead>
<tr>
<th>Main Rotor</th>
<th>Tail Rotor</th>
<th>Aircraft</th>
</tr>
</thead>
<tbody>
<tr>
<td>C = 1.50 ft</td>
<td>C = 0.50 ft</td>
<td>L\text{&lt;tail&gt;} = 23.50 ft</td>
</tr>
<tr>
<td>R = 20.0 ft</td>
<td>R = 3.00 ft</td>
<td>W\text{&lt;gross&gt;} = 7,000 lbs</td>
</tr>
<tr>
<td>b = 4</td>
<td>b = 2</td>
<td>F.P.A.(FF) = 21.2</td>
</tr>
<tr>
<td>CdO = 0.01</td>
<td>CdO = 0.014</td>
<td>VF = 0 kts (hover)</td>
</tr>
<tr>
<td>RV = 31 rad/sec</td>
<td>RV = 139.5 rad/sec</td>
<td></td>
</tr>
</tbody>
</table>

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)
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 heli-
copter 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

<table>
<thead>
<tr>
<th>Storage Register</th>
<th>Stored Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>00</td>
<td>$C_{MR}$ - main rotor chord (ft)</td>
</tr>
<tr>
<td>01</td>
<td>$R_{MR}$ - main rotor radius (ft)</td>
</tr>
<tr>
<td>02</td>
<td>$\Omega_{MR}$ - rotational velocity of the main rotor (radians/sec)</td>
</tr>
<tr>
<td>03</td>
<td>$C_{tr}$ - tail rotor chord (ft)</td>
</tr>
<tr>
<td>04</td>
<td>$R_{tr}$ - tail rotor radius (ft)</td>
</tr>
<tr>
<td>05</td>
<td>$P_{iMR}$ - main rotor induced power with tip losses (hp)</td>
</tr>
<tr>
<td>06</td>
<td>$P_{oMR}$ - main rotor profile power (hp)</td>
</tr>
<tr>
<td>07</td>
<td>$P_{p}$ - parasite power (hp)</td>
</tr>
<tr>
<td>08</td>
<td>$P_{i\text{tr}}$ - tail rotor induced power with tip losses (hp)</td>
</tr>
<tr>
<td>09</td>
<td>$P_{o\text{tr}}$ - tail rotor profile power (hp)</td>
</tr>
<tr>
<td>10</td>
<td>$b_{MR}$ - the number of main rotor blades</td>
</tr>
<tr>
<td>11</td>
<td>$W$ - the weight of the helicopter</td>
</tr>
<tr>
<td>12</td>
<td>$\overline{C}_{do\text{MR}}$ - the average profile drag coefficient for the main rotor</td>
</tr>
<tr>
<td>13</td>
<td>$f_{f}$ - the equivalent flat plate area for forward flight calculations (ft)</td>
</tr>
<tr>
<td>14</td>
<td>$b_{tr}$ - the number of tail rotor blades</td>
</tr>
<tr>
<td>15</td>
<td>$\overline{C}_{do\text{tr}}$ - the average profile drag coefficient for the tail rotor</td>
</tr>
<tr>
<td>16</td>
<td>$l_{tr}$ - the length of the tail, from main rotor hub to the tail rotor hub (ft)</td>
</tr>
<tr>
<td>17</td>
<td>$\Omega_{tr}$ - rotational velocity of the tail rotor (radians/sec)</td>
</tr>
<tr>
<td>18</td>
<td>$T$ - outside air temperature in degrees F</td>
</tr>
<tr>
<td>19</td>
<td>$h_{p}$ - pressure altitude (ft)</td>
</tr>
</tbody>
</table>
### TABLE VIII

POWER Storage Register Utilization: 20-37

<table>
<thead>
<tr>
<th>Storage Register</th>
<th>Stored Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>$V_f$ - forward velocity (ft/sec)</td>
</tr>
<tr>
<td>21</td>
<td>$h_p$ - density altitude (ft)</td>
</tr>
<tr>
<td>22</td>
<td>$\rho$ - air density (slugs/ft)</td>
</tr>
<tr>
<td>23</td>
<td>$A_{D_{MR}}$ - the main rotor disk area (ft)</td>
</tr>
<tr>
<td>24</td>
<td>$A_{D_{tr}}$ - the tail rotor disk area (ft)</td>
</tr>
<tr>
<td>27</td>
<td>$V_{T_{MR}}$ - velocity of the main rotor tip (ft/sec)</td>
</tr>
<tr>
<td>28</td>
<td>$V_{T_{tr}}$ - velocity of the tail rotor tip (ft/sec)</td>
</tr>
<tr>
<td>29</td>
<td>$C_{T_{MR}}$ - the coefficient of thrust for the main rotor</td>
</tr>
<tr>
<td>30</td>
<td>$C_{T_{tr}}$ - the coefficient of thrust for the tail rotor</td>
</tr>
<tr>
<td>31</td>
<td>$V_{i_{MR}}$ - induced velocity of the main rotor (ft/sec)</td>
</tr>
<tr>
<td>32</td>
<td>$V_{i_{tr}}$ - induced velocity of the tail rotor (ft/sec)</td>
</tr>
<tr>
<td>33</td>
<td>$B_{MR}$ - the tip loss factor for the main rotor</td>
</tr>
<tr>
<td>34</td>
<td>$B_{tr}$ - the tip loss factor for the tail rotor</td>
</tr>
<tr>
<td>35</td>
<td>$P_{T_{MR}}$ - the total power required for the main rotor (hp)</td>
</tr>
<tr>
<td>36</td>
<td>$T_{tr}$ - thrust required for the tail rotor (ft-lb/sec)</td>
</tr>
<tr>
<td>37</td>
<td>$P_{T}$ - total power required for the helicopter (hp)</td>
</tr>
</tbody>
</table>
7. Program Listings

01 LBL "POWER"
02 "HELLO DATA"
03 AVIEW
04 STOP
05 "m=?"
06 PROMPT
07 STO 11
08 "Ry<Mr>=?"
09 PROMPT
10 STO 17
11 "b<Mr>=?"
12 PROMPT
13 STO 18
14 "C<Mr>=?"
15 PROMPT
16 STO 00
17 "Cdo<Mr>=?"
18 PROMPT
19 STO 12
20 "R<Mr>=?"
21 PROMPT
22 STO 01
23 "F.R<(FF)'>?"
24 PROMPT
25 STO 13
26 "Ry<TR>=?"
27 PROMPT
28 STO 02
29 "b<TR>=?"
30 PROMPT
31 STO 14
32 "C<TR>=?"
33 PROMPT
34 STO 03
35 "Cdo<TR>=?"
36 PROMPT
37 STO 15
38 "R<TR>=?"
39 PROMPT
40 STO 04
41 "L<TAIL>=?"
42 PROMPT
43 STO 16
44 LBL "AREA"
45 RCL 01
46 XY2
47 PI
48 * 98 "T(F)=?"
49 STO 23
50 CLX

51 RCL 04
52 X^2
53 PI
54 *
55 STO 24
56 CLX
57 LBL "SD"
58 RCL 10
59 RCL 00
60 *
61 RCL 01
62 /
63 PI
64 /
65 STO 25
66 CLX
67 RCL 14
68 RCL 03
69 *
70 RCL 04
71 /
72 PI
73 /
74 STO 26
75 CLX
76 LBL "VT"
77 RCL 01
78 RCL 17
79 *
80 STO 27
81 CLX
82 RCL 04
83 RCL 02
84 *
85 STO 29
86 CLX
87 LBL "BA"
88 "PR>A?"
89 PROMPT
90 STO 19
91 6.875 E-06
92 *
93 CHS
94 1
95 *
96 5.2561
97 Y^X
98 "T(F)=?"
99 PROMPT
100 STO 18

181 32
182 -
183 .5555
184 *
185 273.16
186 +
187 /
188 298.16
189 *
190 .23496
191 Y^X
192 CHS
193 1
194 *
195 6.875 E-06
196 /
197 STO 21
198 LBL "DEN"
199 RCL 21
200 6.875 E-06
201 *
202 STO 22
203 STO 23
204 STO 24
205 STO 25
206 CLX
207 RCL 15
208 RCL 06
209 RCL 21
210 RCL 06
211 /
212 RCL 22
213 RCL 06
214 /
215 RCL 23
216 /
217 RCL 06
218 /
219 RCL 24
220 /
221 RCL 06
222 /
223 RCL 25
224 /
225 ENTER^
300+LBL "PP"
301 RCL 28
302 3
303 Y+X
304 RCL 13
305 *
306 RCL 22
307 *=
308 1100
309 /
310 STO 07
311+LBL "PT(NR)"
312 RCL 05
313 RCL 06
314 +
315 RCL 07
316 +
317 STO 35
318+LBL "THRU"
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
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:

<table>
<thead>
<tr>
<th>Display</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>V&lt;end&gt;=</td>
<td>Maximum Endurance Velocity</td>
</tr>
<tr>
<td>P&lt;V end&gt;=</td>
<td>Total power required at V&lt;end&gt;</td>
</tr>
</tbody>
</table>
2. Equations

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

where: \( V_f \) is forward velocity
3. Flowchart

Start

Set flag 03

Prompt for V-start; store in R48
R48 is now Vf for P

Convert V-start to ft/sec; Store in R50

Xeq 'POWER' at LBL 'DA'

Store P for V-start in R48
R48 is now P

Prompt for velocity increment; convert to ft/sec
and store in R46

Prompt for V-stop; convert to ft/sec
and store in R44

Increment velocity in R40

Xeq 'POWER' at 'PI'

New P now in R37

Recall P from R48

Recall P from R37

Yes

Is X <= Y?

No

Store X in R48
R48 is new P

Recall Vf from R50

Store in R50

next page

next page
Recall V-Stop from B44
Recall W from B40

Yes

Is \( x \leq y \) ?

No

Clear Flag 03

Xeq Tone

Display V<end>

Display P<end>

Stop
4. Example Problem and User Instructions

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

\( V_{\text{max}} = 120 \text{kts} \)

\( PA = 0 \text{ ft} \)

\( T = 59 \text{ F} \)

a. 10 kt increment from 0 to \( V_{\text{max}} \).

Keystrokes: 

\[
(\text{XEQ}) \ (\text{ALPHA}) \ VE \ (\text{ALPHA}) \\
0 \ (\text{R/S}) \\
0 \ (\text{R/S}) \\
59 \ (\text{R/S}) \\
10 \ (\text{R/S}) \\
120 \ (\text{R/S}) \\
(\text{R/S})
\]

Display:

\[
V_{-\text{START}}? \\
PA = ? \\
T_{<F>} = ? \\
\text{INCR} = ? \\
V_{-\text{STOP}} = ? \\
V_{<\text{end}} = 60 \\
(\text{R/S}) \\
P_{<\text{end}} = 384
\]

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

Keystrokes: 

\[
(\text{XEQ}) \ (\text{ALPHA}) \ VE \ (\text{ALPHA}) \\
55 \ (\text{R/S}) \\
0 \ (\text{R/S}) \\
59 \ (\text{R/S}) \\
1 \ (\text{R/S}) \\
65 \ (\text{R/S}) \\
(\text{R/S})
\]

Display:

\[
V_{-\text{START}}? \\
PA = ? \\
T_{<F>} = ? \\
\text{INCR} = ? \\
V_{-\text{STOP}} = ? \\
V_{<\text{end}} = 58 \\
(\text{R/S}) \\
P_{<V \text{ end}} = 383
\]
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

<table>
<thead>
<tr>
<th>Storage Register</th>
<th>Stored Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>00-41</td>
<td>- used by &quot;POWER&quot;</td>
</tr>
<tr>
<td>42</td>
<td>- used by &quot;WEIGHT&quot;</td>
</tr>
<tr>
<td>43</td>
<td>$P_{MIN}$ - the minimum calculated total power required (hp)</td>
</tr>
<tr>
<td>44</td>
<td>$V_B$ - the upper bound velocity selected for the iteration (ft/sec)</td>
</tr>
<tr>
<td>45</td>
<td>$V_{MP}$ - the velocity at minimum total power required (ft/sec)</td>
</tr>
<tr>
<td>46</td>
<td>$V_{INC}$ - the velocity increment selected (ft/sec)</td>
</tr>
</tbody>
</table>
7. Program Listings

```
91 LBL "VE"
02 SF 03
03 "V-START?"*
04 PROMPT
05 STO 45
06 1.6889
07 =
08 STO 26
09 XEQ "50"
10 STO 47
11 "INC +"
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+ 26
24 XEQ "P*"
25 RCL 43
26 RCL 57
27 X=Y?
28 GTO 13
29 GTO 14
30 LBL 17
31 STO 43
32 CLX
33 RCL 26
34 1.6889*
35 /
36 STO 45
37 LBL 14
38 RCL 44
39 RCL 26
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 47
51 "R<END>-
52 ARCL X
53 AVIEW
54 END
```

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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:

<table>
<thead>
<tr>
<th>Display</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>VMR</td>
<td>Maximum Range Velocity</td>
</tr>
<tr>
<td>P(&lt;\text{Vmr}&gt;)</td>
<td>Total power required at VMR</td>
</tr>
</tbody>
</table>

2. Equations

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

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)
- \(\text{PSHP}\) is the zero velocity shaft horsepower (phantom SHP) for the powerplant used at a specified pressure altitude and temperature (hp)
3. Flowchart

Start

Set flag 03

Prompt for PSHP; store in R41

Prompt for V-start; store in R28
R28 is now V for minimum slope: \((P_r + PSHP) / V_r\)

Convert V-start to ft/sec; Store in R26

Xeq 'POWER' at LBL 'DA'

Store \(P_r\) for V-start in R22
R22 is now \(P_r\) for minimum slope: \((P_r + PSHP) / V_r\)

Add PSHP to \(P_r\) and divide by V-start; store in R33
R33 is now minimum slope: \((P_r + PSHP) / V_r\)

Prompt for velocity increment; convert to ft/sec
and store in R20

Prompt for V-stop; convert to ft/sec
and store in R44

Increment velocity in R20

Xeq 'POWER' at 'PI'
New \(P_r\) now in R37

Compute new slope: \((P_r + PSHP) / V_r\)

Recall minimum slope from R33

next page next page

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Yes
\( \text{Is } x > y? \)

- Recall \( Y \); Store in \( R_{45} \)
  \( R_{45} \) is new min slope
- Recall \( V_L \) from \( R_{25} \)
  Store in \( R_{45} \)
  \( R_{45} \) is \( V_L \) for min slope

Recall \( V_{\text{Stop}} \) from \( R_{45} \)
Recall \( V_{\text{S}} \) from \( R_{25} \)

Yes
\( \text{Is } x \leq y? \)
No

- Clear Flag 03
- Xeq Tone
- Display \( V_{\text{mr}} \)
- Display \( P-V_{\text{mr}} \)
- Stop
4. Example Problem and User Instructions

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

PSHP = 310 SHP
V<end> = 58 kts
V<max> = 120 kts
PA = 0 ft
T = 59 F

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

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

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

Keystrokes: Display:
(XEQ) (ALPHA) VMR (ALPHA) PSHP = ?
310 (R/S) V-START = ?
103 (R/S) PA = ?
0 (R/S) T<F> = ?
59 (R/S) INCR = ?
1 (R/S) \hspace{2cm} V-STOP = ?

113 (R/S) \hspace{2cm} Vmr = 108

(R/S) \hspace{2cm} 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

<table>
<thead>
<tr>
<th>Storage Register</th>
<th>Stored Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>00-37</td>
<td>- used by &quot;POWER&quot;</td>
</tr>
<tr>
<td>42</td>
<td>( P_{MS} ) - power required at minimum ratio of power to velocity (hp)</td>
</tr>
<tr>
<td>43</td>
<td>( P/V_f ) - the minimum calculated ratio of power to velocity</td>
</tr>
<tr>
<td>44</td>
<td>( V_B ) - the upper bound velocity selected for the iteration (ft/sec)</td>
</tr>
<tr>
<td>45</td>
<td>( VMR ) - the velocity at the minimum ratio of power to velocity (ft/sec)</td>
</tr>
<tr>
<td>46</td>
<td>( V_{INC} ) - the velocity increment selected (ft/sec)</td>
</tr>
</tbody>
</table>
7. Program Listings

01 LBL "VMR"
02 SF 03
03 "PUSH?"
04 PROMPT
05 STO 41
06 "V-START?"
07 PROMPT
08 STO 45
09 1.68889
10 * 
11 STO 20 
12 XEQ "DR"
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 *PVHR)=="
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:

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

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]:

<table>
<thead>
<tr>
<th>Maximum continuous Power at:</th>
<th>Output Shaft SHP</th>
<th>RPM</th>
<th>Output Torque (ft lb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stnd Sea Level</td>
<td>1310</td>
<td>20,000</td>
<td>344</td>
</tr>
</tbody>
</table>

Solve for the torque conversion factor:

\[
\text{Torque (ft lb)} = \frac{\text{SHP} \cdot 550 (\text{ft-lb/sec}) (1/\text{hp}) \cdot 60}{20,000 \text{ rev/min}(2\pi \text{ rad/sec})} = 0.263 \text{ SHP}
\]

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

- Maximum Continuous Torque Available = 88%

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

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

or

\[
792/0.263 = 2973 \text{ ESHP}
\]

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

<table>
<thead>
<tr>
<th></th>
<th>Analytical</th>
<th>Operator's Manual</th>
<th>% Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hover OGE</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ESHP</td>
<td>2399</td>
<td>2676</td>
<td>10</td>
</tr>
<tr>
<td>$W_f$ (lb/hr)</td>
<td>1218</td>
<td>1263</td>
<td>4</td>
</tr>
<tr>
<td>50 knots</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ESHP</td>
<td>1413</td>
<td>1635</td>
<td>14</td>
</tr>
<tr>
<td>$W_f$ (lb/hr)</td>
<td>829</td>
<td>895</td>
<td>7</td>
</tr>
<tr>
<td>100 knots</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ESHP</td>
<td>1276</td>
<td>1487</td>
<td>14</td>
</tr>
<tr>
<td>$W_f$ (lb/hr)</td>
<td>775</td>
<td>845</td>
<td>8</td>
</tr>
<tr>
<td>130 knots</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ESHP</td>
<td>1593</td>
<td>1903</td>
<td>16</td>
</tr>
<tr>
<td>$W_f$ (lb/hr)</td>
<td>900</td>
<td>975</td>
<td>8</td>
</tr>
</tbody>
</table>

#### 4000 ft and 95 F

<table>
<thead>
<tr>
<th></th>
<th>Analytical</th>
<th>Operator's Manual</th>
<th>% Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hover OGE</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ESHP</td>
<td>2575</td>
<td>3122*</td>
<td>18</td>
</tr>
<tr>
<td>$W_f$ (lb/hr)</td>
<td>1259</td>
<td>1400*</td>
<td>10</td>
</tr>
<tr>
<td>50 knots</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ESHP</td>
<td>1551</td>
<td>1932</td>
<td>20</td>
</tr>
<tr>
<td>$W_f$ (lb/hr)</td>
<td>854</td>
<td>970</td>
<td>12</td>
</tr>
<tr>
<td>100 knots</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ESHP</td>
<td>1245</td>
<td>1605</td>
<td>22</td>
</tr>
<tr>
<td>$W_f$ (lb/hr)</td>
<td>733</td>
<td>850</td>
<td>14</td>
</tr>
<tr>
<td>130 knots</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ESHP</td>
<td>1452</td>
<td>2021</td>
<td>28</td>
</tr>
<tr>
<td>$W_f$ (lb/hr)</td>
<td>815</td>
<td>1010</td>
<td>19</td>
</tr>
</tbody>
</table>

*Approximate; exceeds maximum continuous power available.
TABLE XII

Analytical vs. Actual Max Endurance and Range Velocities

<table>
<thead>
<tr>
<th>Condition</th>
<th>Analytical</th>
<th>Operator's Manual</th>
<th>% Error</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Maximum Endurance</strong></td>
<td>81</td>
<td>80</td>
<td>1</td>
</tr>
<tr>
<td>Velocity (kts)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Maximum Range</strong></td>
<td>140</td>
<td>142</td>
<td>1</td>
</tr>
<tr>
<td>Velocity (kts)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>4000 ft and 95 F</strong></td>
<td>90</td>
<td>88</td>
<td>2</td>
</tr>
<tr>
<td><strong>Maximum Endurance</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Velocity (kts)</td>
<td>149</td>
<td>129*</td>
<td>16</td>
</tr>
<tr>
<td><strong>Maximum Range</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Velocity (kts)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*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):

\[ = 2620 \text{ ESHP} \]

Mission Fuel Weight Profile Equation

\[
\text{Fuel Weight} = 0.05W_f <\text{NRP}> + W_f <\text{cruise}> \times \text{Range}/V<\text{cruise}>
+ 0.25W_f <V<\text{end}>> + 0.05W_f <\text{NRP}>
\]

Results

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

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

<table>
<thead>
<tr>
<th>No.</th>
<th>Copies</th>
<th>Name and Details</th>
</tr>
</thead>
</table>
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    |        | Cameron Station  
    |        | Alexandria, Virginia 22314 |
| 2.  | 2      | Library, Code 0142  
    |        | Naval Postgraduate School  
    |        | Monterey, CA 93940 |
| 3.  | 1      | Department Chairman, Code 67  
    |        | Department of Aeronautics  
    |        | Naval Postgraduate School  
    |        | Monterey, CA 93940 |
| 4.  | 5      | Professor Donald M. Layton, Code 67-Ln  
    |        | Department of Aeronautics  
    |        | Naval Postgraduate School  
    |        | Monterey, CA 93940 |
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    |        | U.S. Army Aviation Safety Center  
    |        | Fort Rucker, AL 36362 |
| 7.  | 1      | CPT Stephen G. Kee  
    |        | 1041 Edgefield Road  
    |        | Shreveport, LA 71118 |