Hand-held computer programs for preliminary helicopter design.

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Monterey, California. Naval Postgraduate School

http://hdl.handle.net/10945/20195
NAVAL POSTGRADUATE SCHOOL
Monterey, California

THESIS

HAND-HELD COMPUTER PROGRAMS FOR
PRELIMINARY HELICOPTER DESIGN

by

Paul John Fardink

October 1982

Thesis Advisor: Donald M. Layton

Approved for public release; distribution unlimited
**Hand-Held Computer Programs for Preliminary Helicopter Design**

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**Report Date:**

October 1982

**Number of Pages:**

179

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The second part consists of major subroutines. These subroutines compute profile power, induced power, climb power, parasite power, and total power; equivalent area and induced power for a tandem rotor; and data input and change.

The third part consists of the main programs. These programs compute the various power requirements for hovering flight, forward (straight and level) flight, vertical flight, and forward climbing flight; also tailrotor power, autorotative flight, and tandem rotor flight.
Hand-Held Computer Programs for
Preliminary Helicopter Design

by

Paul John Fardink
Major, United States Army
B.S., United States Military Academy, 1970

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN AERONAUTICAL ENGINEERING

from the

NAVAL POSTGRADUATE SCHOOL
October 1982
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I. INTRODUCTION

A. BACKGROUND

This project was undertaken to give the user of the HP-41 Programmable Calculator a series of programs that would give acceptable results during the preliminary phases of the helicopter design process. The HP-41 is a handheld programmable calculator designed and manufactured by the Hewlett-Packard Company of Corvallis, Oregon. This personal computing system easily fits into a coat pocket, thus being able to go anywhere. This, in turn, gives the preliminary design engineer a computational versatility and flexibility not previously experienced. To date, no known project of this magnitude has been attempted with a handheld calculator.

B. GOALS

The single goal of this project was to construct a series of self-prompting, alpha-numeric programs that could be used with acceptable results during the preliminary helicopter design process. In doing this, this project supplements the theory and computational processes as outlined by Professor Donald M. Layton in Aircraft Performance [Ref. 1]. An additional projected end use was for utilization by the Aeronautical Engineering students of the Naval Postgraduate School enrolled in the Helicopter Performance and Helicopter Design courses.
II. APPROACH TO THE PROBLEM

The basic line of approach used in this project was to construct calculator programs consisting mainly of subroutines. The subroutine is the key ingredient of this effort for the following reasons:

1. The use of subroutines greatly reduces the amount of required calculator program memory. Numerous main programs utilize the same basic equations and computational techniques even though the end results will be different. When these processes are organized into subroutine format, the numerous main programs can call and execute these common subroutines repeatedly, until the desired outputs are calculated for the particular flight conditions. For example, program "FORFLT" and program "VERFLT" are different in that program "FORFLT" will calculate the power requirements for forward (straight and level) flight while program "VERFLT" will calculate the power requirements for vertical flight. The results will be different, yet both main programs will call and execute fifteen identical subroutines where computational techniques are the same for both programs. The end result being that program memory, i.e. the number of calculator registers required, is optimized.

2. The use of subroutines greatly enhances the ease of program editing. Each individual subroutine calculates a
single specific function or variable, i.e. rotor disc area, rotor solidity, ground effect, density of the air, etc. Perhaps the user of these programs does not agree with the theory used for calculating ground effect or perhaps the user knows of a shorter technique that will greatly reduce the required amount of program memory for storage of the subroutine. The user need only edit that particular subroutine and no more. Confusion has been minimized, and there is no need for massive amounts of program editing.

These subroutines and this project utilize the basic aerodynamic theories of the helicopter, and it is not the intention of this project to teach this theory, nor is it the intention of this project to teach calculator programming operations. The user of these programs is assumed to have a basic knowledge of helicopter aerodynamics and it is further assumed that the user is proficient with the HP-41 programmable calculator.
III. THE SOLUTION

A. PROGRAM AND SUBROUTINE ORGANIZATION

The program and subroutine documentation used throughout this project exists in six sections. The nature of each of these sections is as follows:

1. Purpose

This section gives a brief description of the intended purpose of the program or subroutine. This section will often show a listing of the various program displays and outputs.

2. Equations

This section lists the various equations used within the program or subroutine. If the program or subroutine should call and execute another subroutine, this section will not list nor discuss the equations used by the "called" subroutine. This section will also list and describe the notation used in the equations listed. Whenever applicable, units are also listed as part of the notation description. The vast majority of the equations used in these programs come from Aircraft Performance [Ref. 1], NACA Report [1235] [Ref. 2], and Aerodynamics of V/STOL Flight [Ref. 3].

3. Flowchart

This section contains a flowchart which is an outline of the computational process utilized in the program or
subroutine. The standard HP-41 flowcharting symbols as outlined in the Hewlett-Packard Owner's Handbook and Programming Guide [Ref. 4] have been used:

- circles for beginning and ending a program or subroutine
- rectangles to represent the functional operations
- diamonds to represent the decision processes.

The rectangle was modified somewhat from the standard HP notation in order to visually represent a subroutine:

- modified rectangle to represent subroutine operation

4. Example Problems and User Instructions

This section represents a series of example problems that when executed by the user, will serve to familiarize the user with program operation, program displays, required calculator key strokes, program notation, program inputs, and program outputs. The example problems contain the design data of actual operational military helicopters which in turn serves to familiarize the user with these aircraft. A word of warning must be emphasized. The results or outputs
of these programs when compared with actual operational data are sometimes amazingly accurate, but at other times, they are not. Again, the theory used in computation uses numerous assumptions that do not take into account actual flight and operational conditions. Therefore, when executing power requirements, these programs should never be used in lieu of the appropriate manufacturer's performance charts or operator's manuals. Again, the purpose of these programs is to give the preliminary design engineer acceptable figures in the preliminary helicopter design process and not to supersede performance charts or operator's manuals.

5. **Programs and Subroutines Used**

This section lists all of the programs and subroutines used during the execution of the main program or subroutine. The user must insure that the listed programs and subroutines are in program memory before execution of the program is attempted otherwise the word "NONEXISTENT" will appear in the calculator display as the calculator searches for a subroutine or program that cannot be found in the calculator's program memory. As expected, the program cannot and obviously will not be executed.

6. **Program Listings**

This section contains a listing of the program lines of the program or subroutine. In some cases, as in Appendix B, both the program and its subroutine version are listed. The main programs listed in Appendix D will call and execute
many of the major subroutines listed in Appendix C as well as the minor subroutines listed in Appendix B.
IV. RESULTS

The results of this programming project are presented in Appendices B, C, and D. Appendix B contains many short programs and their subroutine form. These programs execute simple calculations such as solidity of the rotor system, rotor disc area, density of the air, etc. Appendix C contains major subroutines. These subroutines execute major calculations such as induced power, profile power, data input, tandem rotor equivalent area, etc. Appendix D contains the major programs for power required calculations. These main programs call and execute many of the minor subroutines found in Appendix B and many of the major subroutines found in Appendix C.

The validity of the output of these programs is excellent for the intended purpose of preliminary helicopter design calculations and estimations. As mentioned previously, the idealized theory used does make several assumptions and thus certain limitations are imposed upon the results. Some of the limitations are listed here:

1. Symmetric airfoils with zero twist are used throughout these programs. All actual helicopters have main rotor blades which utilize some degree of twist. This in turn will affect the overall lift generation and distribution.
2. The streamlining effects of the vertical fin on tail rotor power requirements in forward flight were not modeled and thus taken into account.

3. Compressibility effects on the advancing main rotor blade and stall effects on the retreating main rotor blade were not modeled and thus taken into account. Both of these effects will add to the overall horsepower requirements in forward flight computations.

4. The theory used did not take into account accessory losses such as hydraulic pumps, electrical generators, fuel pumps, heaters and air conditioners. Nor did the theory take into account drive train losses such as gear and transmission friction. All helicopter manufacturers will in some form incorporate these losses into their performance charts.

5. These programs do not take into account the main rotor downwash effects on the helicopter fuselage. This is a small horsepower requirement and was neglected here.

6. These programs do not take into account those real world operating conditions that have an overall effect on the performance of the helicopter. These conditions include, but are not limited to, engine erosion, dirty engine compressor blades, dirty and/or dented rotor blades. Again, these programs should not be substituted for performance charts and operator's manuals.
V. CONCLUSIONS AND RECOMMENDATIONS

The user of these programs should work through the example problems given in the various program and subroutine listings. In doing so, Table I, Appendix A, An Alphabetical Listing of All Calculator Displays and Their Intended Meaning, will become a valuable aid. Table II, Appendix A, Program and Subroutine Storage Requirements, will also become useful in that it readily assists the user in keeping track of the calculator memory required and remaining. And, if it becomes necessary, Table III, Appendix A, Storage Register Utilization, will assist the user in the program editing process in that it lists the program registers used and their contents; 32 program registers have been used. The user should insure that the calculator has been sized for \( \theta \) before attempting execution of the programs.
APPENDIX A

QUICK REFERENCE TABLES

The tables in this appendix will serve the user of this project as a source of quick reference. Table I is an alphabetical listing of all the possible calculator displays and their intended meanings. Table II lists all of the programs and subroutines and their respective storage requirements both in terms of registers required and bytes required. This table readily assists the user in keeping track of the calculator memory required and remaining. Table III lists the storage registers and their utilization. This table will assist the user in the program editing process.
### TABLE I

**AN ALPHABETICAL LISTING OF ALL CALCULATOR DISPLAYS AND THEIR INTENDED MEANINGS**

<table>
<thead>
<tr>
<th>Display</th>
<th>Explanation</th>
<th>Formula Notation</th>
</tr>
</thead>
<tbody>
<tr>
<td>AREA=</td>
<td>Answer: rotor disc area in ft²</td>
<td>$A_D$</td>
</tr>
<tr>
<td>a=?</td>
<td>Prompt: fraction of the radius where the taper starts on a tapered rotor blade (decimal value)</td>
<td>$a$</td>
</tr>
<tr>
<td>B=</td>
<td>Answer: tip loss factor (decimal value)</td>
<td>$B$</td>
</tr>
<tr>
<td>b=?</td>
<td>Prompt: number of blades in the rotor system</td>
<td>$b$</td>
</tr>
<tr>
<td>BOTH</td>
<td>indicates calculator is about to execute combination of vertical flight and horizontal flight (forward climbing flight)</td>
<td>-</td>
</tr>
<tr>
<td>C=?</td>
<td>Prompt: chord length of the rotor blade in ft</td>
<td>$C$</td>
</tr>
<tr>
<td>CdO=?</td>
<td>Prompt: average profile drag coefficient</td>
<td>$\overline{C_{d_0}}$</td>
</tr>
<tr>
<td>CE=</td>
<td>Answer: equivalent chord in ft</td>
<td>$C_e$</td>
</tr>
<tr>
<td>CHANGE?</td>
<td>Prompt: asks if the original input data now needs to be changed. 1 is Yes, 0 is No</td>
<td>-</td>
</tr>
<tr>
<td>C RV b R W</td>
<td>chord-rotational velocity-number of blades-radius-weight, press key on calculator keyboard directly beneath the variable in need of change</td>
<td>$C$, $\Omega$, $b$, $R$, $W$</td>
</tr>
<tr>
<td>CT=</td>
<td>Answer: coefficient of thrust</td>
<td>$C_T$</td>
</tr>
<tr>
<td>C0=?</td>
<td>Prompt: root chord in ft</td>
<td>$C_0$</td>
</tr>
<tr>
<td>Cl=?</td>
<td>Prompt: tip chord in ft</td>
<td>$C_t$</td>
</tr>
<tr>
<td>------</td>
<td>-------------------------</td>
<td>------</td>
</tr>
<tr>
<td>d=?</td>
<td>Prompt: distance between the rotor shafts of a tandem rotor helicopter in ft</td>
<td>$d$</td>
</tr>
<tr>
<td>DA=</td>
<td>Answer: density altitude in ft</td>
<td>$h_p$</td>
</tr>
<tr>
<td>DA=?</td>
<td>Prompt: density altitude in ft</td>
<td>$h_p$</td>
</tr>
<tr>
<td>$d$(HOR.GLIDE)=</td>
<td>Answer: horizontal distance travelled on the ground at the forward autorotative flight velocity for minimum rate of descent in ft</td>
<td>$d$</td>
</tr>
<tr>
<td>D.L.=</td>
<td>Answer: disc loading of the rotor system in lbs/ft$^2$</td>
<td>D.L.</td>
</tr>
<tr>
<td>D.N.=</td>
<td>Answer: density of the air $\frac{\text{lb-sec}^2}{\text{ft}^4}$ or $\frac{\text{slug}}{\text{ft}^3}$</td>
<td>$\rho$</td>
</tr>
<tr>
<td>F=</td>
<td>Answer: a non-dimensional coefficient used in autorotation calculations</td>
<td>$\bar{F}$</td>
</tr>
<tr>
<td>FOR ONLY?</td>
<td>Prompt: execute forward flight portion of program only? 1 is Yes, 0 is No</td>
<td>-</td>
</tr>
<tr>
<td>FOR $V=?$</td>
<td>Prompt: forward flight velocity in kts</td>
<td>$V_f$</td>
</tr>
<tr>
<td>F.P.A.(FF)=?</td>
<td>Prompt: equivalent flat plate area for forward flight calculations in ft$^2$</td>
<td>$f_f$</td>
</tr>
<tr>
<td>F.P.A.(VF)=?</td>
<td>Prompt: equivalent flat plate area for vertical flight calculations in ft$^2$</td>
<td>$f_v$</td>
</tr>
<tr>
<td>GE=0</td>
<td>Answer: ground effect on the induced power is equal to zero</td>
<td>-</td>
</tr>
<tr>
<td>GE=0,RATIO=1</td>
<td>Answer: ground effect on the induced power is equal to zero, therefore the ground effect ratio is equal to 1</td>
<td>-</td>
</tr>
<tr>
<td>H=?</td>
<td>Prompt: height of the rotor system above the ground in ft</td>
<td>h</td>
</tr>
<tr>
<td>HOVER?</td>
<td>Prompt: execute hovering flight portion of program only? 1 is Yes, 0 is No</td>
<td>-</td>
</tr>
<tr>
<td>LCM=?</td>
<td>Prompt: lift coefficient multiplier in drag coefficient terms</td>
<td>$K_1$</td>
</tr>
<tr>
<td>L(TAIL)=?</td>
<td>Prompt: tail length; distance from center of main rotor shaft to center of tailrotor shaft in ft</td>
<td>$\lambda_t$</td>
</tr>
<tr>
<td>M(TIP)=</td>
<td>Answer: Mach Number at the tip of the advancing rotor blade</td>
<td>$M_T$</td>
</tr>
<tr>
<td>PA=?</td>
<td>Prompt: pressure altitude in ft</td>
<td>$h_p$</td>
</tr>
<tr>
<td>PC=</td>
<td>Answer: climb power in horsepower</td>
<td>$P_c$</td>
</tr>
<tr>
<td>PI=</td>
<td>Answer: induced power in horsepower</td>
<td>$P_i$</td>
</tr>
<tr>
<td>PI(TL)=</td>
<td>Answer: induced power with tip losses in horsepower</td>
<td>$P_i(TL)$</td>
</tr>
<tr>
<td>PI(TL+GE)=</td>
<td>Answer: induced power with tip losses plus ground effect in horsepower</td>
<td>$P_i(TL+GE)$</td>
</tr>
<tr>
<td>PO=</td>
<td>Answer: profile power in horsepower</td>
<td>$P_o$</td>
</tr>
<tr>
<td>PO(TDM)=</td>
<td>Answer: profile power for a tandem rotor helicopter in horsepower</td>
<td>$P_o$</td>
</tr>
<tr>
<td>PP=</td>
<td>Answer: parasite power in horsepower</td>
<td>P</td>
</tr>
<tr>
<td>-----</td>
<td>------------------------------------</td>
<td>---</td>
</tr>
<tr>
<td>PT(ACFT)=</td>
<td>Answer: total power for the aircraft in horsepower</td>
<td>P_T</td>
</tr>
<tr>
<td>PT(MR)=</td>
<td>Answer: total power for the main rotor in horsepower</td>
<td>P_T</td>
</tr>
<tr>
<td>PT(TDM)=</td>
<td>Answer: total power for a tandem rotor helicopter in horsepower</td>
<td>P_T</td>
</tr>
<tr>
<td>PT(TR)=</td>
<td>Answer: total power for the tailrotor in horsepower</td>
<td>P_T</td>
</tr>
<tr>
<td>R=?</td>
<td>Prompt: radius of the rotor system in ft</td>
<td>R</td>
</tr>
<tr>
<td>RATIO=</td>
<td>Answer: ground effect ratio</td>
<td>-</td>
</tr>
<tr>
<td>REC=?</td>
<td>Prompt: is the rotor blade of rectangular planform? 1 is Yes, 0 is No</td>
<td>-</td>
</tr>
<tr>
<td>RV=?</td>
<td>Prompt: rotational velocity of the rotor system in radians/second</td>
<td>Ω</td>
</tr>
<tr>
<td>SOLID=</td>
<td>Answer: the solidity of the rotor system</td>
<td>σ_r</td>
</tr>
<tr>
<td>T=?</td>
<td>Prompt: ambient temperature in degrees celsius</td>
<td>T(°C)</td>
</tr>
<tr>
<td>TR DATA</td>
<td>the calculator is now ready to prompt for the tailrotor data input</td>
<td>-</td>
</tr>
<tr>
<td>U=</td>
<td>Answer: the advance ratio</td>
<td>μ</td>
</tr>
<tr>
<td>VERT ONLY?</td>
<td>Prompt: execute vertical flight portion of program only? 1 is Yes, 0 is No</td>
<td>-</td>
</tr>
<tr>
<td>VERT V=?</td>
<td>Prompt: vertical velocity in ft/min</td>
<td>V_v</td>
</tr>
</tbody>
</table>

TABLE I
(continued)
<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
<th>Unit</th>
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</thead>
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<tr>
<td>VF(MIN.R.O.D.)=</td>
<td>Answer: forward autorotative flight velocity for minimum autorotative rate of descent in kts</td>
<td>$V_f$</td>
</tr>
<tr>
<td>VI=</td>
<td>Answer: induced velocity in ft/sec</td>
<td>$V_i$</td>
</tr>
<tr>
<td>VT=</td>
<td>Answer: velocity at the rotor tip in ft/sec</td>
<td>$V_T$</td>
</tr>
<tr>
<td>VV=</td>
<td>Answer: vertical autorotative velocity in a vertical autorotation in ft/min</td>
<td>$V_v$</td>
</tr>
<tr>
<td>VV(MIN.R.O.D.)=</td>
<td>Answer: vertical autorotative velocity (ft/min) at the forward autorotative flight velocity for minimum autorotative rate of descent</td>
<td>$V_v$</td>
</tr>
<tr>
<td>W=?</td>
<td>Prompt: weight of the helicopter in lbs</td>
<td>W</td>
</tr>
<tr>
<td>Subject Area</td>
<td>Name</td>
<td>Reg</td>
</tr>
<tr>
<td>----------------------</td>
<td>------</td>
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<tr>
<td>Density Altitude</td>
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<td>-</td>
</tr>
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<td>Density</td>
<td>&quot;DN&quot;</td>
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<td>Disc Area</td>
<td>&quot;AD&quot;</td>
<td>2</td>
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<td>Solidity</td>
<td>&quot;SD&quot;</td>
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<td>Tip Velocity</td>
<td>&quot;VT&quot;</td>
<td>2</td>
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<td>Induced Velocity</td>
<td>&quot;VI&quot;</td>
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<td>&quot;CT&quot;</td>
<td>3</td>
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<td>Tip Loss Factor</td>
<td>&quot;TL&quot;</td>
<td>3</td>
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<td>Equivalent Chord</td>
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<td>-</td>
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<td>&quot;GE&quot;</td>
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<td>&quot;VC&quot;</td>
<td>24</td>
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<tr>
<td>of Induced Velocity</td>
<td></td>
<td></td>
</tr>
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<td>Data Input</td>
<td>&quot;DATA&quot;</td>
<td>11</td>
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<tr>
<td>Change of Data</td>
<td>&quot;CG&quot;</td>
<td>17</td>
</tr>
<tr>
<td>Subject Area</td>
<td>Name</td>
<td>Reg</td>
</tr>
<tr>
<td>-------------</td>
<td>----------</td>
<td>-----</td>
</tr>
<tr>
<td>Profile Power</td>
<td>&quot;PO&quot;</td>
<td>9</td>
</tr>
<tr>
<td>Induced Power</td>
<td>&quot;PI&quot;</td>
<td>16</td>
</tr>
<tr>
<td>Climb Power</td>
<td>&quot;PC&quot;</td>
<td>5</td>
</tr>
<tr>
<td>Parasite Power</td>
<td>&quot;PP&quot;</td>
<td>6</td>
</tr>
<tr>
<td>Total Power</td>
<td>&quot;PT&quot;</td>
<td>5</td>
</tr>
<tr>
<td>Equivalent Area Tandem Rotor</td>
<td>&quot;AE&quot;</td>
<td>7</td>
</tr>
<tr>
<td>Induced Power Tandem Rotor</td>
<td>&quot;PIT&quot;</td>
<td>15</td>
</tr>
<tr>
<td>Appendix D</td>
<td>Hover</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Forward Flight</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Vertical Flight</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>All Flight Regimes</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Tailrotor</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Autorotation</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Tandem Rotor</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Checks</td>
<td>-</td>
</tr>
</tbody>
</table>
# TABLE III
## 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>$C_0$ - the root chord of the rotor blade (ft)</td>
</tr>
<tr>
<td>02</td>
<td>$C_1$ - the tip chord of the rotor blade (ft)</td>
</tr>
<tr>
<td>03</td>
<td>a - fraction of radius where the taper starts on a tapered rotor blade (decimal value)</td>
</tr>
<tr>
<td>04</td>
<td>$C$ or $C_e$ - the chord or equivalent chord length of the rotor blade (ft)</td>
</tr>
<tr>
<td>05</td>
<td>$R$ - the radius of the rotor system (ft)</td>
</tr>
<tr>
<td>06</td>
<td>$b$ - the number of blades in the rotor system</td>
</tr>
<tr>
<td>07</td>
<td>$\overline{C}_{d_0}$ - the average profile drag coefficient</td>
</tr>
<tr>
<td>08</td>
<td>$\Omega$ - the rotational velocity of the rotor system (radians/sec)</td>
</tr>
<tr>
<td>09</td>
<td>$h$ - rotor system height above the ground (ft)</td>
</tr>
<tr>
<td>10</td>
<td>$W$ - weight of the helicopter (lbs)</td>
</tr>
<tr>
<td>11</td>
<td>$\rho$ - density of the air $\frac{lb\cdot sec^2}{ft^3}$ or $\frac{slug}{ft^3}$</td>
</tr>
<tr>
<td>12</td>
<td>$A_D$ - rotor disc area (ft$^2$)</td>
</tr>
<tr>
<td>13</td>
<td>$V_T$ - velocity of the rotor tip (ft/sec)</td>
</tr>
<tr>
<td>14</td>
<td>$C_T$ - coefficient of thrust</td>
</tr>
<tr>
<td>15</td>
<td>$B$ - tip loss factor</td>
</tr>
<tr>
<td>16</td>
<td>$P_i(TL)$ - induced power with tip losses (horsepower)</td>
</tr>
<tr>
<td>17</td>
<td>$h/D$ - height ÷ diameter of rotor system used for ground effect calculations</td>
</tr>
<tr>
<td></td>
<td>( P_i(TL+GE) ) - induced power with tip losses plus ground effect (horsepower)</td>
</tr>
<tr>
<td>---</td>
<td>----------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>18</td>
<td>( \sigma_r ) - the solidity of the rotor system</td>
</tr>
<tr>
<td>19</td>
<td>( v_i ) - induced velocity (ft/sec)</td>
</tr>
<tr>
<td>20</td>
<td>( P_o ) - profile power (horsepower)</td>
</tr>
<tr>
<td>21</td>
<td>blank - used for computations</td>
</tr>
<tr>
<td>22</td>
<td>( V_v ) - vertical velocity (ft/sec)</td>
</tr>
<tr>
<td>23</td>
<td>( f_v ) - equivalent flat plate area for vertical flight calculations (ft²)</td>
</tr>
<tr>
<td>24</td>
<td>( V_f ) - forward velocity (ft/sec)</td>
</tr>
<tr>
<td>25</td>
<td>( f_f ) - equivalent flat plate area for forward flight calculations (ft²)</td>
</tr>
<tr>
<td>26</td>
<td>( V_{iT} ) - vertical component of the induced velocity through the rotor system for forward climbing flight (ft/sec)</td>
</tr>
<tr>
<td>27</td>
<td>( P_p ) - parasite power (horsepower)</td>
</tr>
<tr>
<td>28</td>
<td>( P_c ) - climb power (horsepower)</td>
</tr>
<tr>
<td>29</td>
<td>( P_T ) - total power (horsepower)</td>
</tr>
<tr>
<td>30</td>
<td>indirect storage register - used by all the main programs in conjunction with Subroutine &quot;CG&quot;</td>
</tr>
</tbody>
</table>

Note - Subroutine "CF", Subroutine "VC", and Program "TR" contain the only deviations from the above table in storage register utilization. This is done to optimize calculator storage requirements. The appropriate program or subroutine listing gives a complete explanation for the appropriate deviation. The calculator should be sized for 032.
APPENDIX B

MINOR PROGRAMS AND SUBROUTINES

This appendix consists of several short programs and their subroutine form. These programs compute density altitude, density, disc area, solidity, tip velocity, induced velocity, coefficient of thrust, tip loss factor, equivalent chord, and ground effect. The subroutines will be called and executed by the main programs in appendix D.
DENSITY ALTITUDE

1. PURPOSE

This program computes the density altitude, \( h_\rho \), in feet when given the pressure altitude, \( h_p \), in feet and the temperature in degrees celsius. The equation used for this program is based upon the standard atmosphere and described in NACA Report (1955) No. 1235 [Ref. 2]. This equation and thus this program is accurate to an altitude of 36,089 feet (isothermal level).

2. EQUATIONS

\[
\frac{(1 - K_1 h_p)^{5.2561}}{(1 - K_1 h_\rho)^{4.2561}} = \frac{T}{T_{ssl}} \tag{1}
\]

where:

- \( T \) is the ambient temperature (absolute)
- \( T_{ssl} \) is the standard sealevel temperature (absolute)
- \( h_p \) is the pressure altitude (feet)
- \( h_\rho \) is the density altitude (feet)
- \( K_1 \) is a constant equal to \( 6.375 \times 10^{-5} \)
3. FLOWCHART

4. EXAMPLE PROBLEMS AND USER INSTRUCTIONS

The altimeter of a UH-60A currently indicates a pressure altitude of 1600 feet and the O.A.T. (Outside Air Temperature) gauge indicates 24° Celsius. What is the density altitude?

Keystrokes:  
[XEQ] [ALPHA] DA [ALPHA] 
1600 [R/S] 
24 [R/S]  
Display: 
PA=?  
T=?  
DA=3,006.48

note - do not touch the calculator and proceed immediately to the next problem

The same UH-60A is now sitting on the deck of a ship. The altimeter indicates 0 feet and the O.A.T. gauge indicates 15°.
What is the density altitude?

Keystrokes: 

[R/S] [R/S]
0 [R/S]
15 [R/S]

Display: 

PA=?
T=?
DA=0.00

(standard day sea level conditions)

note - pushing the run stop [R/S] button twice will reposi-
tion the calculator to the top of the program

5. PROGRAMS & SUBROUTINES USED

"DA"

6. PROGRAM LISTINGS

```plaintext
01 LBL "DA"
02 "PA=?"
03 PROMPT
04 6.875 E-
05 *
06 CHS
07 1
08 +
09 5.2561
10 Y↑X
11 "T=?"
12 PROMPT
13 273.16
14 +
15 /
16 288.16
17 *
18 .23496
19 Y↑X
20 CHS
21 1
22 +
23 6.875 E-
24 /
25 FIX 2
26 "DA=
27 ARCL X
28 AVIEW
29 END
```
DENSITY

1. PURPOSE

This program/subroutine computes the density of the air at a given altitude. The equation used for this calculation is based upon the standard atmosphere and described in NACA Report No. 1235 [Ref. 2]. This equation and thus this program is accurate to an altitude of 36,089 feet (isothermal level). This program is therefore considered sufficient for all computations using density, $\rho$, here and in succeeding programs.

2. EQUATIONS

$$\rho = \rho_{SSL} \left[ 1 - (K_1)(h) \right]^{-2.561}$$  \hspace{1cm} (2)

where:

- $\rho_{SSL}$ is the density of the air at standard sea level conditions which is equal to $0.0023769 \left[ \frac{\text{lb} \cdot \text{sec}^2}{\text{ft}^2} \right]$ or $\left[ \frac{\text{slug}}{\text{ft}^2} \right]$.
- $K_1$ is a constant equal to $6.875 \times 10^{-6}$
- $h$ is the density altitude (ft)
- $\rho$ is the density of the air at level $h$

with the input of known values, the equation to be programmed now becomes:

$$\rho = 0.0023769 \left[ 1 - (6.875 \times 10^{-6})(h) \right]^{-2.561}$$  \hspace{1cm} (3)
3. FLOWCHART

![Flowchart Diagram]

Start

Execute Subroutine "DN";
Prompt for and input D.A.
while solving equation
for \( \rho \), and store answer
into \( R_{11} \)

Display answer

Stop

4. EXAMPLE PROBLEMS AND USER INSTRUCTIONS

Find the density, \( \rho \), at a density altitude, D.A., of 1000 feet.

Keystrokes: \[\text{[XEQ]} \ [\text{ALPHA}] \ \text{DENSITY} \ [\text{ALPHA}] \ 1000 \ [\text{R/S}]\]

Display: \[\text{D.A.=}? \quad \text{DN}=0.0023081\]

Note - do not touch the calculator and proceed immediately
to the next problem

Find the density, \( \rho \), at a density altitude, D.A., of 5283 feet.
Keystrokes:  
[R/S] [R/S]  
5,283 [R/S]  

Display:  
D.A.=?  
DN=0.0020306  

note - pushing the run stop [R/S] button twice will reposition the calculator to the top of the program  

Find the density, \( \rho \), at a density altitude, D.A., of 0 feet (sea level).  

Keystrokes:  
[R/S] [R/S]  
0 [R/S]  

Display:  
D.A.=?  
DN=0.0023769  
(standard day sea level conditions)  

5. PROGRAMS & SUBROUTINES USED  
"DENSITY"  
"DN"  

6. PROGRAM LISTINGS  

PROGRAM

01 *LBL "DENITY"  
02 XEQ "DN"  
03 FIX 7  
04 "DN="  
05 ARCL X  
06 AVIEW  
07 END  

SUBROUTINE

01 *LBL "DN"  
02 "D.A.=?"  
03 PROMPT  
04 6.375 E-06  
05 *  
06 CHS  
07 1  
08 +  
09 ENTER↑  
10 4.2561  
11 Y↑X  
12 .0023769  
13 *  
14 STO 11  
15 END
DISC AREA

1. PURPOSE

This program/subroutine calculates the disc area of a rotor system when given the radius. The disc area is the total area enscribed by the plane of the rotor without coning.

2. EQUATIONS

\[ A_D = \pi R^2 \]  \hspace{1cm} (4)

where:

- \( A_D \) is the Disc Area (\( \text{ft}^2 \))
- \( R \) is the rotor system radius (\( \text{ft} \))

3. FLOWCHART

![Flowchart](image)

Start

Prompt for and input \( R \) into \( R_{05} \)

Execute Subroutine "AD"; solves equation for \( A_D \) and stores answer into \( R_{12} \)

Display answer

Stop
4. EXAMPLE PROBLEMS AND USER INSTRUCTIONS

The rotor radius of the UH-60A Blackhawk is 26.83 feet. Find the Disc Area.


The rotor radius of the AH-1T SeaCobra is 24.00 feet. Find the Disc Area.

Keystrokes: [R/S] [R/S] 24.00 [R/S] Display: AREA=1,809.56

5. PROGRAMS AND SUBROUTINES USED

"AREA"
"AD"

6. PROGRAM LISTINGS

PROGRAM

01 LBL "ARE A"
02 "R=?”
03 PROMPT
04 STO 05
05 XEQ "AD"
06 FIX 2
07 "AREA=“
08 ARCL X
09 AVIEW
10 END

SUBROUTINE

01 LBL "AD"
02 RCL 05
03 X+2
04 PI
05 *
06 STO 12
07 END
1. PURPOSE
This program/subroutine computes solidity, \( \sigma_r \), the fraction of the disc area that is composed of blades, i.e. solid.

2. EQUATIONS

\[
\sigma_r = \frac{b \cdot c \cdot R}{\pi \cdot R^2} = \frac{b \cdot c}{\pi \cdot R}
\]  \( \text{(5)} \)

where:

- \( \sigma_r \) is the solidity of the rotor system
- \( b \) is the number of rotor blades in the rotor system
- \( R \) is the radius of the rotor system (ft)
- \( c \) is the chord length of the rotor blade (ft)

3. FLOWCHART

```
Start

Prompt for and input b into R0,6
c into R0,4
R into R1,5

Execute Subroutine "SD"; solves equation for \( \sigma_r \) and stores answer into R1,3

Display answer

Stop
```
4. SAMPLE PROBLEMS AND USER INSTRUCTIONS

Find the solidity, $\sigma_r$, of the aft rotor system on the CH-46E Sea Knight (note - the fore and aft rotor systems both have the same dimensions).

\[ R = 25.50 \text{ ft} \]
\[ c = 1.5625 \text{ ft} \]
\[ b = 3 \]

Keystrokes: \[\text{[XEQ]} \ [\text{ALPHA}] \ SOLID \ [\text{ALPHA}] \]
\[3 \text{ [R/S]}\]
\[1.5625 \text{ [R/S]}\]
\[25.50 \text{ [R/S]}\]

Display: \[b=\? \]
\[C=\? \]
\[R=\? \]
\[\text{SOLID}=0.05851 \]

Find the solidity, $\sigma_r$, of the main rotor system of the CH-54A Skycrane.

\[ R = 36.00 \text{ ft} \]
\[ c = 1.972 \text{ ft} \]
\[ b = 6 \]

Keystrokes: \[\text{[R/S]} \]
\[6 \text{ [R/S]}\]
\[1.972 \text{ [R/S]}\]
\[36.00 \text{ [R/S]}\]

Display: \[b=\? \]
\[C=\? \]
\[R=\? \]
\[\text{SOLID}=0.10462 \]

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5. PROGRAMS & SUBROUTINES USED

"SOLID"
"SD"

6. PROGRAM LISTINGS

<table>
<thead>
<tr>
<th>PROGRAM</th>
<th>SUBROUTINE</th>
</tr>
</thead>
<tbody>
<tr>
<td>01•LBL &quot;SOLID&quot;</td>
<td>01•LBL &quot;SD&quot;</td>
</tr>
<tr>
<td>02 &quot;b=?&quot;</td>
<td>02 RCL 06</td>
</tr>
<tr>
<td>03 PROMPT</td>
<td>03 RCL 04</td>
</tr>
<tr>
<td>04 STO 06</td>
<td>04 *</td>
</tr>
<tr>
<td>05 &quot;C=?&quot;</td>
<td>05 RCL 05</td>
</tr>
<tr>
<td>06 PROMPT</td>
<td>06 /</td>
</tr>
<tr>
<td>07 STO 04</td>
<td>07 PI</td>
</tr>
<tr>
<td>08 &quot;R=?&quot;</td>
<td>08 /</td>
</tr>
<tr>
<td>09 PROMPT</td>
<td>09 STO 19</td>
</tr>
<tr>
<td>10 STO 05</td>
<td>10 END</td>
</tr>
<tr>
<td>11 XEQ &quot;SD&quot;</td>
<td></td>
</tr>
</tbody>
</table>
TIP VELOCITY

1. PURPOSE

This program/subroutine computes the tip velocity of the rotor blade. The tip velocity, $V_T$, is the product of the rotational velocity, $\Omega$, and the rotor radius, $R$.

2. EQUATIONS

$$V_T = \Omega R$$

where:

- $V_T$ is the velocity of the rotor tip (ft/sec)
- $\Omega$ is the rotational velocity (radians/sec)
- $R$ is the rotor radius (ft)

3. FLOWCHART

Start

Prompt for and input $R$ into $R_{0,5}$

RV into $R_{0,8}$

Execute Subroutine "VT"; solves equation for $V_m$ and stores answer into $R_{1,3}$

Display answer

Stop
4. SAMPLE PROBLEMS AND USER INSTRUCTIONS

The rotor radius of a CH-53D Sea Stallion is 36.11 feet and the normal rotational velocity is 19.37 radians/sec. Find the tip velocity.

Keystrokes: Display:
[XEQ] [ALPHA] VTIP [ALPHA] R=?
36.11 [R/S] RV=?
19.37 [R/S] VT=699.45

The rotor radius of an AH-64 is 24.00 feet and the normal rotational velocity is 30.26 radians/sec. Find the tip velocity.

Keystrokes: Display:
[R/S] R=?
24 [R/S] RV=?
30.26 [R/S] VT=726.24

note - to convert RPM to radians/sec, divide by 9.55

5. PROGRAMS & SUBROUTINES USED

"VTIP"
"VT"
6. PROGRAM LISTINGS

PROGRAM

01 LBL "VTI
02 R=?
03 PROMPT
04 STO 05
05 RV=?
06 PROMPT
07 STO 08
08 XEQ "VT"
09 FIX 2
10 VT=
11 ARCL X
12 AVIEW
13 END

SUBROUTINE

01 LBL "VT"
02 RCL 08
03 RCL 05
04 *
05 STO 13
06 END
INDUCED VELOCITY

1. PURPOSE

This program/subroutine computes the induced velocity, \( v_\text{i} \), the total inflow velocity through the rotor system during hover.

2. EQUATIONS

\[
v_\text{i} = \left( \frac{T}{2\rho \cdot A_\text{D}} \right)^{\frac{1}{2}} \tag{7}
\]

where:

\( v_\text{i} \) is the induced velocity (ft/sec)
\( \rho \) is the density of the air \( \left[ \frac{\text{lb} \cdot \text{sec}^2}{\text{ft}^4} \right] \)
\( A_\text{D} \) is the rotor disc area (ft\(^2\))
\( T \) is the thrust which is equal to the weight, \( W \) (lbs)
3. FLOWCHART

Start

Prompt for and input W into R_{10},
R into R_{05}

Execute Subroutine "AD"

Execute Subroutine "DN"

Execute Subroutine "VI"; solves equation for v_i and stores answer into R_{20}

Display answer

Stop

4. EXAMPLE PROBLEMS AND USER INSTRUCTIONS

Find the induced velocity, v_i, of the main rotor system of a hovering SH-2F LAMPS under the following conditions:

DA = 0 (sea level)
W = 11,300 lb
R = 22.0 ft

note - insure that Subroutines "AD" and "DN" are in program memory

Keystrokes: [XEQ] [ALPHA] VIND [ALPHA]

Display: W=?
Find the induced velocity, $v_i$, of the main rotor system of a hovering CH-54A Skycrane under the following conditions:

- D.A. = 2000 ft
- R = 36 ft
- $W = 42,500$ (maximum gross weight)

Keystrokes:

[R/S]
42,500 [R/S]
36 [R/S]
2,000 [R/S]

Display:

W=?
R=?
D.A.=?
VI=48.26

5. PROGRAMS & SUBROUTINES USED

"VIND"
"VI"
"AD"
"DN"
COEFFICIENT OF THRUST

1. PURPOSE

This program/subroutine computes the coefficient of thrust for a given rotor system. The coefficient of thrust is a non-dimensional coefficient established to facilitate computations and comparisons. [Ref.1]

2. EQUATIONS

\[ C_T = \frac{T}{A_D \cdot \rho \cdot V_T^2} \]  

where:

- \( C_T \) is the coefficient of thrust (non-dimensional)
- \( A_D \) is the disc area (ft\(^2\))
- \( V_T \) is the tip velocity (ft/sec)
- \( \rho \) is the density of the air [\( \text{lb} \cdot \text{sec}^2 / \text{ft}^4 \)]
- \( T \) is the thrust which is equal to the weight, \( W \) (lb)
3. FLOWCHART

Start

Prompt for and input W into \( R_{10} \)
R into \( R_{03} \)
RV into \( R_{08} \)

Execute Subroutine "DN"

Execute Subroutine "AD"

Execute Subroutine "VT"

Execute Subroutine "CT"; solves equation for \( C_T \) and stores answer into \( R_{14} \)

Display answer

Stop

4. EXAMPLE PROBLEMS AND USER INSTRUCTIONS

Find the coefficient of thrust, \( C_T \), for a UH-1H Iroquois operating under the following conditions:

\[
N = 305 \text{ RPM} \quad \Omega = 31.94 \text{ radians/sec}
\]

D.A. = 1600 ft

\( W = 8400 \) lbs

\( R = 24.09 \) ft
Keystrokes:  
[XEQ] [ALPHA] CTHRUST [ALPHA]  
8,400 [R/S]  
24.09 [R/S]  
31.94 [R/S]  
1,600 [R/S]  

Display:  
W=?  
R=?  
RV=?  
D.A.=?  
CT=0.0034320  

Find the coefficient of thrust, $C_T$, for an OH-6A operating under the following conditions:  

$N = 470$ RPM $\rightarrow \Omega = 49.21$ radians/sec  
$D.A. = 4000$ ft  
$W = 2500$ lb  
$R = 13.165$ ft  

Keystrokes:  
[R/S]  
2,500  
13.165  
49.21  
4,000  

Display:  
W=?  
R=?  
RV=?  
D.A.=?  
CT=0.0051824  

5. PROGRAMS & SUBROUTINES USED  
"CTHRUST"  
"CT"  
"DN"  
"AD"  
"VT"
6. PROGRAM LISTINGS

PROGRAM

01 LBL "CTH
RUST"
02 "W=?"
03 PROMPT
04 STO 10
05 "R=?"
06 PROMPT
07 STO 05
08 "RV=?"
09 PROMPT
10 STO 08
11 XEQ "IN"
12 XEQ "AD"
13 XEQ "VT"
14 XEQ "CT"
15 FIX 7
16 "CT="
17 ARCL X
18 AVIEW
19 END

SUBROUTINE

01 LBL "CT"
02 RCL 10
03 RCL 11
04 /
05 RCL 12
06 /
07 RCL 13
08 X↑2
09 /
10 STO 14
11 END
TIP LOSS FACTOR

1. PURPOSE

This program/subroutine computes the tip loss factor, \( B \). Tip vortices, at the tip of the rotor blades, tend to despoil the pressure difference at the tips and thereby reduces the lift at the tips. The extent of these losses depends upon the rotor blade loadings, and number of blades. Numerous theories exist. The theory used in this subroutine is an approximation of the tip loss factor made by Prandtl and Betz. [Ref. 1] After the tip loss factor, \( B \), has been computed in the subroutine and returned to the main programs used later, the induced power will change in accordance with the following equation:

\[
P_i_{TL} = \frac{P_i}{B}
\]  \( (9) \)

where:

- \( P_i_{TL} \) is the induced power with tip losses
- \( P_i \) is the induced power
- \( B \) is the tip loss factor

2. EQUATIONS

\[
B = 1 - \frac{\sqrt{2C_m}}{b}
\]  \( (10) \)
where:

- $C_T$ is the coefficient of thrust
- $b$ is the number of rotor blades
- $B$ is the tip loss factor

3. FLOWCHART

![Flowchart Diagram]

Start

Prompt for and input $W$ into $R_{10}$
- $R$ into $R_{05}$
- $RV$ into $R_{08}$
- $b$ into $R_{06}$

- Execute Subroutine "DN"
- Execute Subroutine "AD"
- Execute Subroutine "VT"
- Execute Subroutine "CT"

- Execute Subroutine "TL"; solves equation for $B$ and stores answer into $R_{15}$

Display answer

Stop
4. EXAMPLE PROBLEMS AND USER INSTRUCTIONS

Find the tip loss factor, \( B \), for an OH-6A Cayuse operating under the following conditions:

\[
N = 470 \text{ RPM} \rightarrow \Omega = 49.21 \text{ radians/sec}
\]
\[
D.A. = 5,000 \text{ ft}
\]
\[
W = 2,150 \text{ lbs}
\]
\[
R = 13.165 \text{ ft}
\]
\[
b = 4
\]

Keystrokes:  

[XEQ] [ALPHA] TIPLOSS [ALPHA]  

Display:  

W=?

2150 [R/S]  

R=?

13.165 [R/S]  

RV=?

49.21 [R/S]  

b=?

4 [R/S]  

D.A.=?

5000 [R/S]  

B=0.9760

Find the tip loss factor, \( B \), for the same helicopter in the above problem, only this time use the maximum gross weight of \( W = 2550 \text{ lbs} \).

Keystrokes:  

[R/S]  

Display:  

W=?

2550 [R/S]  

R=?

13.165 [R/S]  

RV=?
5. PROGRAMS & SUBROUTINES USED

"TIPLOSS"
"TL"
"DN"
"AD"
"VT"
"CT"

6. PROGRAM LISTINGS

PROGRAM

01 LBL "TIPLOSS"
02 "W=?”
03 PROMPT
04 STO 10
05 "R=?”
06 PROMPT
07 STO 05
08 "RV=?”
09 PROMPT
10 STO 06
11 "J=?”
12 PROMPT
13 STO 06
14 XEQ "DN"
15 XEQ "AD"
16 XEQ "VT"
17 XEQ "CT"
18 XEQ "TL"
19 FIX 4
20 "B=?”
21 ARCL X
22 AVIEW
23 END

SUBROUTINE

01 LBL "TL"
02 RCL 14
03 2
04 *
05 SQRT
06 RCL 06
07 /
08 CHS
09 1
10 +
11 STO 15
12 END
1. PURPOSE

This program is also used as a subroutine by the main programs. This program computes the equivalent chord, C_e, for a tapered rotor blade. A tapered rotor blade (the chord at the tip less than the chord at the root) has less tip loss effect due to the smaller surface area over which the losses may occur; this is the primary reason for tapering the tips of the rotor blades. [Ref. 1]

2. EQUATIONS

The calculation for equivalent chord for thrust determinations has reduced to the following figure and equation:

\[ C_e = C_1 + \frac{1}{4} \left[ \frac{C_0 - C_1}{l - a} (1 - a^n) \right] \]  (11)

FIGURE 1
Tapered Rotor Blade
where:

\( C_e \) is the equivalent chord (ft)
\( C_0 \) is the root chord (ft)
\( C_1 \) is the tip chord (ft)
\( a \) is the fraction of radius where the taper starts (decimal value)

note - when \( a = 0 \), the blade has a linear taper from the root to the tip. When \( a = 1 \), the blade is completely rectangular, and \( C_e = C \)

3. FLOWCHART

![Flowchart Image](image-url)

Start

Prompt for and input
\( C_0 \) into \( R_{01} \)
\( C_1 \) into \( R_{02} \)
\( a \) into \( R_{03} \)

Solves equation for \( C_e \)

Display answer

Stop
4. EXAMPLE PROBLEMS AND USER INSTRUCTIONS

Find the equivalent chord, $C_e$, for a tapered rotor blade with the following dimensions:

- $C_0 = 1.6$ ft
- $C_1 = 0.8$ ft
- $a = 0.75$

Keystrokes: [XEQ] [ALPHA] ECHORD [ALPHA]  
Display:

1.6 [R/S]  
0.8 [R/S]  
.75 [R/S]

Find the equivalent chord, $C_e$, for a tapered rotor blade with the following dimensions:

- $C_0 = 1.0$ ft
- $C_1 = 0.9$ ft
- $a = 0.9$

Keystrokes:  
Display:

1 [R/S]  
.9 [R/S]  
.9 [R/S]

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5. PROGRAMS & SUBROUTINES USED

"ECHORD"

6. PROGRAM LISTINGS

PROGRAM

01 ©LBL "ECHORD"
02 "C0=?"
03 PROMPT
04 STO 01
05 "C1=?"
06 PROMPT
07 STO 02
08 "a=?"
09 PROMPT
10 STO 03
11 ©LBL "EC"
12 RCL 03
13 ENTER↑
14 4
15 Y↑X
16 CHS
17 1
18 +
19 RCL 01
20 ENTER↑
21 RCL 02
22 -
23 *
24 RCL 03
25 CHS
26 1
27 +
28 /
29 4
30 /
31 RCL 02
32 +
33 FIX 3
34 "CE="
35 ARCL X
36 AVIEW
37 STOP
38 END
1. PURPOSE

This program/subroutine computes the ground effect ratio \( \frac{P}{P_{OGE}} \), as a function of the ratio of the rotor system height above the ground to the diameter of the rotor system. [Ref. 1] FIGURE 2 is a graph which shows the ratio of power required to hover in-ground-effect to that required to hover out-of-ground-effect for the average helicopter. This curve was obtained as the best fit to considerable amounts of test data on both single and tandem rotor helicopters. [Ref. 3]

![Figure 2](image)

FIGURE 2
Ground Effect Curve [Ref. 3]

2. EQUATIONS

A curve fitting equation for the plot of FIGURE 2 results in the following equation:
G.E. RATIO = \[ \frac{P}{P_{OGE}} = \left[ -0.1276(h/D)^4 + 0.7080(h/D)^3 - 1.4569(h/D)^2 ight. \\
  \\
  \left. + 1.3432(h/D) + 0.5147 \right] \] \tag{12}

where:

- \( h \) is the height of the rotor system above the ground (ft)
- \( D \) is the diameter of the rotor system (ft)
- \( P \) is the power in-ground-effect
- \( P_{OGE} \) is the power out-of-ground effect

3. FLOWCHART

![Flowchart Diagram]

Start

Prompt for \( H \) and \( R \) while solving for \( (h/D) \) and store answer in \( R_i \)?

Yes

Display "GE=0,RATIO=1"

No

Execute Subroutine "GE"; solves equation for G.E.RATIO

Display answer

Stop
4. EXAMPLE PROBLEMS AND USER INSTRUCTIONS

The rotor radius of an SH-3H is 31.0 ft. It is currently hovering above the deck of the antisubmarine carrier Yorktown with the rotor system 24.33 ft above the deck (wheels 10 ft above the deck). What is the ground effect ratio?

Keystrokes: 

\begin{verbatim}
[SEQ] [ALPHA] GEFFECT [ALPHA] \\
24.33 \[R/S]\ \\
31 \[R/S]\ \\
\end{verbatim}

Display: 

\begin{verbatim}
H=\
R=\
RATIO=0.8572 \\
\end{verbatim}

The rotor radius of an AH-1S Cobra is 22.0 ft. It is moving into a holding position behind and just below the top of some tall cover with the rotor system 70.0 ft above the ground (skids 58.0 ft above the ground). What is the ground effect ratio?

Keystrokes: 

\begin{verbatim}
[R/S] \\
70 \[R/S]\ \\
22 \[R/S]\ \\
\end{verbatim}

Display: 

\begin{verbatim}
H=\
R=\
GE=0,RATIO=1 \\
\end{verbatim}

note - the Cobra is hovering out of ground effect

5. PROGRAMS & SUBROUTINES USED

"GEFFECT"
"GE"

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6. PROGRAM LISTINGS

PROGRAM

01 LBL "GEF"
FECT"
02 "H=?"
PROMPT
04 "R=?"
PROMPT
06 2
07 *
08 /
09 STO 17
10 1.55
11 -
12 X>0?
13 GTO 01
14 XEQ "GE"
15 FIX 4
16 "RATIO="
17 ARCL X
18 AVIEW
19 GTO 02
20 LBL 01
21 "GE=0,RA
TIO=1"
22 PROMPT
23 LBL 02
24 END

SUBROUTINE

01 LBL "GE"
02 RCL 17
03 1.3432
04 *
05 RCL 17
06 X^2
07 -1.4569
08 *
09 +
10 RCL 17
11 3
12 Y^X
13 .7080
14 *
15 +
16 RCL 17
17 4
18 Y^X
19 -.1276
20 *
21 +
22 .5147
23 +
24 END
APPENDIX C

MAJOR SUBROUTINES

This appendix consists of several major subroutines that are called and executed by the main programs of appendix D. These subroutines compute the vertical component of the induced velocity for forward climbing flight; prompt for data input; prompt for change of original data input; compute profile power, induced power, climb power, parasite power, and total power all for a single rotor helicopter; and compute the equivalent area and the induced power requirements for a tandem rotor helicopter.
COEFFICIENTS

1. PURPOSE

This is a Subroutine used by those main programs that deal with forward climbing flight computations. This Subroutine calculates and stores the coefficients of a fourth order equation which Subroutine "VC" will recall and use to solve for the one real root of this equation. This real root is the vertical component of the induced velocity, $v_i$, which when multiplied with the thrust, $T$, gives the product of induced power, $P_i$, for forward climbing flight.

2. EQUATIONS

\[ A(v_i)_T^4 + B(v_i)_T^3 + C(v_i)_T^2 + D(v_i)_T + E = 0 \]  \hspace{1cm} (13)

where:

\[ A = 1.0 \]

\[ B = 2V_v \]

\[ C = (V_f^2 + V_v^2) \]

\[ D = 0 \]

\[ E = -v_i^4 \]

$V_v$ is the vertical velocity (ft/sec)

$V_f$ is the forward velocity (ft/sec)

$v_i$ is the induced velocity at a hover (ft/sec)
3. FLOWCHART

Start

Prompt for and input R into R_{0,5}
W into R_{1,0}

Execute Subroutine "DN"

Execute Subroutine "AD"

Execute Subroutine "VI"

Solve equation for E and store answer into R_{1,0}

Solve equation for D and store answer into R_{1,1}

Solve equation for A and store answer into R_{1,4}

Solve equation for B and store answer into R_{1,3}

Solve equation for C and store answer into R_{1,2}

Stop

4. EXAMPLE PROBLEMS AND USER INSTRUCTIONS

This subroutine is immediately followed by Subroutine "VC" when used in the main programs. During its computation, Subroutine "VC" uses storage registers R_{0,0} through R_{1,9}.
It is therefore necessary to use Subroutine "DATA" at a latter time in the main program in order to get the input data properly stored into the correct memory registers. Because of this, some repetition of input data prompting will occur during main program usage.

5. PROGRAMS AND SUBROUTINES USED

"CF"
"DN"
"AD"
"VI"

6. PROGRAM LISTINGS

SUBROUTINE
01\*LBL "CF"
02 "R=?”
03 PROMPT
04 STO 05
05 "W=?”
06 PROMPT
07 STO 10
08 XEQ "DN"
09 XEQ "AD"
10 XEQ "VI"
11 4
12 Y\^X
13 CHS
14 STO 10
15 0
16 STO 11
17 1
18 STO 14
19 RCL 23
20 2
21 *
22 STO 13
23 2
24 /
25 X\^2
26 RCL 25
27 X\^2
28 +
29 STO 12
30 END

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VERTICAL COMPONENT OF INDUCED VELOCITY

1. PURPOSE

Subroutine "VC" is a subroutine used by those main programs that deal with forward climbing flight computations. It will immediately follow Subroutine "CF" in the main program listing because Subroutine "VC" recalls the coefficients of a fourth equation that Subroutine "CF" previously calculated. Subroutine "VC" uses the input of these coefficients to solve for the one real root of this fourth order equation. This real root is \( v_{iT} \), the vertical component of the induced velocity through the rotor system for forward climbing flight computations. Subroutine "VC" is a shortened version of Program "MHL". Program "MHL" was obtained from the Catalog of Contributed Programs HP-41C User's Library. [Ref. 5] When given a polynomial with real coefficients, Program "MHL" will use Maehly's Method, a modification of the well-known Newton's Method to find the real roots of the equation. In its original form, Program "MHL" has 131 program steps. This program was modified for use as Subroutine "VC" with 105 program steps.

2. EQUATIONS

See Subroutine "CF" for a complete description of the fourth order equation that Subroutine "VC" solves.

Neither the equations used in the iterative root solving process are shown, ncr is a flowchart for this process shown.
A complete description of this process is available from the HP-41C User's Library Catalog, Program Number 00660C. [Ref. 5]

3. FLOWCHART

none

4. EXAMPLE PROBLEMS AND USER INSTRUCTIONS

The user may wonder why Subroutine "CF" and Subroutine "VC" were not combined into one subroutine. Subroutine "VC" has previously appeared in several different forms. Each form has solved the fourth order polynomial using a different technique. Subroutine "VC" currently exists in the shortest form found; both in number of program steps and program running time. Perhaps the user of this subroutine is aware of an even shorter process and can thus modify this subroutine even farther. It is important to remember here that one of the primary reasons for the use of subroutines was for ease of program editing and modification.

5. PROGRAMS & SUBROUTINES USED

"VC"

6. PROGRAM LISTINGS

SUBROUTINE

<table>
<thead>
<tr>
<th>Line</th>
<th>Code</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>01</td>
<td>LBL</td>
<td>&quot;VC&quot;</td>
</tr>
<tr>
<td>02</td>
<td>FIX</td>
<td>2</td>
</tr>
<tr>
<td>03</td>
<td>SF</td>
<td>00</td>
</tr>
<tr>
<td>04</td>
<td>SF</td>
<td>01</td>
</tr>
<tr>
<td>05</td>
<td>CF</td>
<td>29</td>
</tr>
<tr>
<td>06</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>07</td>
<td>STO</td>
<td>00</td>
</tr>
<tr>
<td>08</td>
<td>10.01</td>
<td></td>
</tr>
<tr>
<td>09</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>STO</td>
<td>06</td>
</tr>
<tr>
<td>11</td>
<td>STO</td>
<td>08</td>
</tr>
<tr>
<td>12</td>
<td>RCL</td>
<td>00</td>
</tr>
<tr>
<td>13</td>
<td>.1</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>%</td>
<td></td>
</tr>
</tbody>
</table>

69
15 RCL Z
16 +
17 STO 07
18 CLX
19 STO 01
20 20
21 STO 02
22 FC?C 01
23 GTO 02
24 1 E-3
25 STO 04
26 LBL 02
27 RCL 02
28 XEQ "AB"
29 X=0?
30 GTO 05
31 RCL 02
32 XEQ "BA"
33 STO 05
34 FS? 00
35 GTO 04
36 RCL 07
37 STO 09
38 LBL 03
39 RCL 03
40 RCL 02
41 RCL IND
42 -
43 /
44 ST- 05
45 DSE 09
46 GTO 03
47 LBL 04
48 RCL 02
49 RCL 03
50 RCL 05
51 /
52 -
53 ENTER↑
54 X<> 02
55 -
56 RCL 02
57 /
58 ABS
59 RCL 04
60 X<Y?
DATA

1. PURPOSE

This is a subroutine used by all main programs for data input, and depending upon the looping involved, some programs will use this subroutine more than once. In some very few instances, not every item of data that the calculator prompts for is required for program execution. In these few instances, the EXAMPLE PROBLEMS AND USER INSTRUCTIONS sections are very explicit in the correct procedures to be taken for data input. The primary reason in the repetitive use of this subroutine is to save program steps and calculator memory. Alpha characters and operators, the main ingredient of this subroutine, are more costly in storage requirements (bytes) than the typical numerical operators that are used throughout these programs. [Ref. 4]

2. EQUATIONS

none
3. FLOWCHART

![Flowchart Diagram]

4. EXAMPLE PROBLEMS AND USER INSTRUCTIONS

No equations are used, but this subroutine prompts for the following input where:

- Promp for and input C
- Execute Subroutine "ECHORD"
- Prompt for and input R into R0, b into R0, \( C_{d_0} \) into R0, \( \Omega \) into R0, h into R0, W into R1,
- Execute Subroutine "DN"
- Stop
Display: Explanation:

REC? asks if the rotor blade is of rectangular planform
1 [R/S] if the answer is yes

C=? asks for the blade chord (ft)
0 [R/S] if the answer is no

C0=? asks for the root chord (ft)

Cl=? asks for the tip chord (ft)

a=? asks for the fraction of radius of the rectangular
portion of the blade (decimal value)

R=? asks for the rotor disc radius (ft)

b=? asks for the total number of individual blades
in the rotor system

CdO=? asks for the average profile drag coefficient, $C_{d_o}$

RV=? asks for the rotational velocity, $\Omega$ (radians/sec)

H=? asks for the rotor system height above the
ground, $h$ (ft)

W=? asks for the weight of the helicopter (lbs)

D.A.=? asks for the density altitude, $h_p$ (ft)

5. PROGRAMS & SUBROUTINES USED

"DATA"
"ECHORD"
"DN"
SUBROUTINE

01 LBL "DAT A"
02 "REC?"
03 PROMPT
04 X>0?
05 GTO 10
06 XEQ "ECH ORD"
07 GTO 11
08 LBL 10
09 "C=?"
10 PROMPT
11 LBL 11
12 STO 04
13 "R=?"
14 PROMPT
15 STO 05
16 "b=?"
17 PROMPT
18 STO 06
19 "CdO=?"
20 PROMPT
21 STO 07
22 "RV=?"
23 PROMPT
24 STO 08
25 "H=?"
26 PROMPT
27 STO 09
28 "w=?"
29 PROMPT
30 STO 10
31 XEQ "IN"
32 END
1. PURPOSE

This is a subroutine used by all main programs for expediting the change of input data. This subroutine is the last step in the main program listing before program termination. This subroutine allows for as many as five of the input variables to be quickly changed before returning to the top of the main program listing and initiating a new program operation. Upon examining the program listing for this subroutine, it will become quickly apparent to the user the ease of which this subroutine could be edited for other desired changes. Again, this is one of the purposes and obvious advantages of using subroutines throughout these programs.

2. EQUATIONS

none
3. FLOWCHART

Start

Clear Flag 04

Change Data?

Yes=1

Set Flag 04

Set Flag 27

No=0

Yes Is Flag 04 Set?

GO TO Indirect R₃₁*

Stop

DISPLAY:

C

RV

b

R

W

Yes=1

REC?

No=0

C=?

Execute Subroutine "ECHORD"

Store answer into R₀₄

Clear Flag 27

* Returns to and reruns the main program with new data
4. EXAMPLE PROBLEMS AND USER INSTRUCTIONS

No sample problem is given here because of the numerous examples that exist in the main programs. Note that when flag 27 is set, this automatically places the calculator into the [USER] mode. By pressing the key directly below the displayed variable in need of change, will next cause the calculator to prompt for the new data input. The new numeric value is then keyed in followed by [R/S]. The calculator will again prompt in the display for another change of data with: "CHANGE?". The user should remember that here as well as elsewhere in these programs, yes is 1 and no is 0. When all changes have been made and the answer no is received, the calculator will then return to the main program and begin execution with the new data. If on the initial time through, no changes are desired, and the answer no is given (notice from the flow chart that flag 04 has not been set), the main program will terminate operation.

5. PROGRAMS & SUBROUTINES USED

"CG"
"ECHORD"
6. PROGRAM LISTINGS

SUBROUTINE

01 *LBL "CG"
02 CF 04
03 *LBL 06
04 "CHANGE?"
05 PROMPT
06 X=0?
07 GTO 07
08 SF 04
09 SF 27
10 " C RV b R W"
11 PROMPT
12 *LBL A
13 "REC?"
14 PROMPT
15 X>0?
16 GTO 02
17 XEQ "ECH ORD"
18 GTO 03
19 *LBL 02
20 "C=?”
21 PROMPT
22 *LBL 03
23 STO 04
24 GTO 05
25 *LBL B
26 "RV=?"
27 PROMPT
28 STO 08
29 GTO 05
30 *LBL C
31 "b=?"
32 PROMPT
33 STO 06
34 GTO 05
35 *LBL D
36 "R=?"
37 PROMPT
38 STO 05
39 GTO 05
40 *LBL E
41 "W=?"
42 PROMPT
43 STO 10
44 *LBL 05
45 CF 27
46 GTO 06
47 *LBL 07
48 FS? 04
49 GTO IND
50 END
1. PURPOSE

This subroutine computes the profile power, \( P_0 \), required in terms of horsepower. Profile power is that power required to turn the rotor blades against their drag.

2. EQUATIONS

\[
P_{oh} = \frac{1}{8} \cdot \sigma_r \cdot \overline{Cd_o} \cdot \rho \cdot A_D \cdot V_T^3 \quad (14)
\]

\[
\mu = \frac{V_f}{V_T} \quad (15)
\]

\[
P_{of}/P_{oh} = (1 + 4.25\mu^2) \quad (16)
\]

where:

- \( P_{oh} \) is the profile power required to hover \( \text{[ft-lb/sec]} \)
- \( P_{of} \) is the profile power required in forward flight \( \text{[ft-lb/sec]} \)
- \( \overline{Cd_o} \) is the average profile drag coefficient
- \( A_D \) is the area of the rotor disc (\( \text{ft}^2 \))
- \( V_T \) is the tip velocity (\( \text{ft/sec} \))
- \( V_f \) is the forward velocity of the helicopter (\( \text{ft/sec} \))
- \( \sigma_r \) is the solidity of the rotor system
- \( \mu \) is the ratio of the rotor translational velocity to the velocity at the tip due to rotation
- \( \rho \) is the density of the air \( \text{[lb-sec}^2/\text{ft}^4]\)
3. FLOWCHART

Start

Recall \( V_T \) from \( R_{13} \)
A\_D from \( R_{12} \)
\( \rho \) from \( R_{11} \)
\( \overline{C_d} \) from \( R_{07} \)
\( \sigma \) from \( R_{19} \)
while solving equation for \( P_{oh} \) (hp)

Store answer into \( R_{21} \)

Recall \( V_f \) from \( R_{25} \)

Yes \( V_f = 0? \)  No

Recall \( P_{oh} \) from \( R_{21} \)
Recall \( V_T \) from \( R_{13} \)
while solving equations for \( \mu \), then for \( P_{of}/P_{oh} \)

Recall \( P_{oh} \) from \( R_{21} \)
while solving equation for \( P_{of} \)

Display answer and Store into \( R_{21} \)

Stop
4. EXAMPLE PROBLEMS AND USER INSTRUCTIONS

none

5. PROGRAMS & SUBROUTINES USED

"PO"

6. PROGRAM LISTINGS

SUBROUTINE

01 *LBL "PO"
02 RCL 13
03 3
04 Y↑X
05 RCL 12
06 *
07 RCL 11
08 *
09 RCL 07
10 *
11 RCL 19
12 *
13 4400
14 /
15 STO 21
16 RCL 25
17 X=0?
18 GTO 08
19 RCL 13
20 /
21 X↑2
22 4.25
23 *
24 1
25 +
26 RCL 21
27 *
28 GTO 09
29 *LBL 08
30 RCL 21
31 *LBL 09
32 "PO="
33 PROMPT
34 VIEW X
35 STOP
36 STO 21
37 END
INDUCED POWER

1. PURPOSE

This subroutine computes the induced power, \( P_i \), required in terms of horsepower. This subroutine deals only with hover and it takes into consideration both tip losses and ground effect. The induced power which produces a thrust equal to the weight (at hover) is equal to the product of the thrust and the inflow velocity. All of the main programs compute the inflow velocity peculiar to their flight conditions and will enter this subroutine at Label "PJ" or "TJ".

2. EQUATIONS

\[
P_i = T \cdot v = \frac{T \sqrt{T/2 \rho A_D}}{2 \rho A_D} = \frac{T^{1.5}}{\sqrt{2 \rho A_D}} \quad (17)
\]

\[
P_{iTL} = \frac{P_i}{B} \quad (9)
\]

\[
\text{G.E. RATIO} = \frac{P_i}{P_{iOGE}} \quad (12)
\]

where:

- \( T \) is the thrust which is equal to the weight, \( W \) (lb)
- \( v \) is the induced velocity (ft/sec)
- \( B \) is the tip loss factor
- \( \rho \) is the density of the air \( \left[ \frac{\text{lb-sec}^2}{\text{ft}^4} \right] \)
- \( A_D \) is the disc area (ft\(^2\))
\( P_i \) is the induced power \([\text{ft-lb/ sec}]\)

\( P_{iT} \) is the induced power with tip losses \([\text{ft-lb/ sec}]\)

\( P_{iOGE} \) is the induced power under out-of-ground-effect conditions \([\text{ft-lb/ sec}]\)

G.E. RATIO is the ground effect ratio

3. FLOWCHART

```
Start

Recall \( A_D \) from \( R_{12} \)
Recall \( \rho \) from \( R_{11} \)
Recall \( T \) from \( R_{10} \)
while solving
equation for \( P_{ih}(hp) \)

Display answer

Recall \( B \) from \( R_{15} \)
while solving
equation for \( P_{iT} \)

Display answer

Store answer into \( R_{15} \)

Recall \( h \) from \( R_{09} \)
Recall \( R \) from \( R_{05} \)
while solving
for \( h/D \)
```

next page→
Store answer into \( R_{17} \)

\[ \text{is} \quad \frac{h}{D} > 1.55? \]

Yes

Display "GE=0"

Recall \( P_{iTL} \) from \( R_{16} \)

No

Execute Subroutine "GE"

Recall \( P_{iTL} \) from \( R_{16} \) and solve for \( P_i(TL+GE) \) (hp)

Display answer

Store answer into \( R_{18} \)

Stop

4. EXAMPLE PROBLEMS AND USER INSTRUCTIONS

none

5. PROGRAMS AND SUBROUTINES USED

"PI"
"GE"
SUBROUTINE

01+LBL "PI"
02 RCL 10
03 1.5
04 Y↑X
05 RCL 11
06 RCL 12
07 *
08 2
09 *
10 SQRT
11 /
12 550
13 /
14+LBL "PJ"
15 "PI="
16 PROMPT
17 VIEW X
18 STOP
19 RCL 15
20 /
21+LBL "TJ"
22 "PI<TL>=

23 PROMPT
24 VIEW X
25 STOP
26 STO 16

27 RCL 09
28 2
29 /
30 RCL 05
31 /
32 STO 17
33 1.55
34 -
35 X>0?
36 GTO 12
37 XEQ "GE"
38 RCL 16
39 *
40 "PI<TL+G
E>="
41 PROMPT
42 VIEW X
43 STOP
44 GTO 13
45+LBL 12
46 "GE=0"
47 PROMPT
48 RCL 16
49+LBL 13
50 STO 18
51 END
1. PURPOSE

This subroutine computes the climb power, $P_c$, required in terms of horsepower.

2. EQUATIONS

$$P_c = T \cdot V_v$$

(18)

where:

- $P_c$ is climb power $[\text{ft-lb/s}]$
- $T$ is the thrust which is equal to the weight, $W$ (lb)
- $V_v$ is the vertical velocity (ft/sec)
3. FLOWCHART

Start

Recall $V_v$ from $R_{23}$

Yes is $V_v = 0$? No

Recall $W$ from $R_{10}$ while solving equation for $P_c$

Display answer

Store answer into $R_{24}$

Stop

4. EXAMPLE PROBLEMS AND USER INSTRUCTIONS

none

5. PROGRAMS & SUBROUTINES USED

"PC"
6. PROGRAM LISTINGS

SUBROUTINE

01 LBL "PC"
02 RCL 23
03 X=0?
04 GTO 02
05 RCL 10
06 *
07 550
08 /
09 "PC="
10 PROMPT
11 VIEW X
12 STOP
13 LBL 02
14 STO 29
15 END
1. PURPOSE

This subroutine computes the parasite power, $P_p$, required in terms of horsepower. As the helicopter proceeds from hover into forward flight, drag forces are created on the various components of the helicopter due to pressure drag and skin friction.

2. EQUATIONS

$$P_p = \frac{1}{2} \rho f_v V_v^3 + \frac{1}{2} \rho f_f V_f^3$$ (19)

where:

- $P_p$ is the parasite power $[\text{ft-lbf/sec}]$
- $f_v$ is the equivalent flat plate area for vertical flight ($\text{ft}^2$)
- $f_f$ is the equivalent flat plate area for forward flight ($\text{ft}^2$)
- $V_v$ is the vertical velocity ($\text{ft/sec}$)
- $V_f$ is the forward velocity ($\text{ft/sec}$)
- $\rho$ is the density of the air $[\text{lb/sec}^2/\text{ft}^4]$
3. FLOWCHART

Start

Recall $V_f$ from $R_{25}$
$f_f$ from $R_{26}$
$V_V$ from $R_{23}$
$f_V$ from $R_{24}$
$p$ from $R_{11}$

while solving equation for $P_p$ (hp)

Display answer

Store answer into $R_{28}$

Stop

4. EXAMPLE PROBLEMS AND USER INSTRUCTIONS

none

5. PROGRAMS & SUBROUTINES USED

"pp"
6. PROGRAM LISTINGS

SUBROUTINE

01 LBL "PP"
02 RCL 25
03 3
04 Y↑X
05 RCL 26
06 *
07 RCL 23
08 3
09 Y↑X
10 RCL 24
11 *
12 +
13 RCL 11
14 *
15 1100
16 /
17 "PP="
18 PROMPT
19 VIEW X
20 STOP
21 STO 28
22 END
TOTAL POWER

1. PURPOSE

This subroutine computes the total power, $P_T$, required for the main rotor in terms of horsepower.

2. EQUATIONS

$$P_T = P_i + P_o + P_c + P_p$$

where:

- $P_T$ is the total power required
- $P_i$ is the induced power required
- $P_o$ is the profile power required
- $P_c$ is the climb power required
- $P_p$ is the parasite power required
3. FLOWCHART

Start

Recall $P_i$ from $R_{18}$

$P_o$ from $R_{21}$

$P_p$ from $R_{23}$

$P_c$ from $R_{29}$

while solving equation for $P_T$ (hp)

Store answer into $R_{30}$

Display answer

Stop

4. EXAMPLE PROBLEMS AND USER INSTRUCTIONS

none

5. PROGRAMS & SUBROUTINES USED

"Pt"
6. PROGRAM LISTINGS

SUBROUTINE

01 LBL "PT"
02 RCL 18
03 RCL 21
04 +
05 RCL 28
06 +
07 RCL 29
08 +
09 STO 30
10 "PT<MR>=

11 PROMPT
12 VIEW X
13 STOP
14 END
1. PURPOSE

This subroutine computes the equivalent area, $A_e$, with tip losses of a tandem rotor helicopter in terms of square feet.

2. EQUATIONS

$$\text{overlap} = 1 - \frac{d}{D} \quad (21)$$

$$S_R = \frac{d}{R} \quad (22)$$

$$\gamma = \cos^{-1}(1 - \text{overlap}) \quad (23)$$

$$A_o = 2A_1 + 2A_2 = 2\pi R^2 \quad (24)$$
\[ A_e = 2A_1 + 2A_2 = A_0 \left( 1 - \frac{\gamma - \sin \gamma \cos \gamma}{\pi} \right) \]

where:

- \( S_R \) is the shaft spacing ratio
- \( A_0 \) is the total combined area of the two rotor discs (ft²)
- \( A_e \) is the equivalent area (ft²)
- \( \gamma \) is the wake skew angle (radians)
- \( R \) is the radius of the rotor system (ft)
- \( D \) is the diameter of the rotor system (ft)
- \( d \) is the distance between the rotor shafts (ft)
3. FLOWCHART

Start

Prompt for and input d,
Recall R from \( R_{05} \) while
solving equation for \( S_R \)

Store R into \( R_{00} \)

Recall B from \( R_{15} \) while
solving equation for \( \gamma \)

Store \( \gamma \) into \( R_{12} \)

Recall \( \gamma \) from \( R_{12} \)
\( R \) from \( R_{05} \)
\( B \) from \( R_{15} \)
while solving
equation for \( A_e \)

Store \( A_e \) into \( R_{12} \)

Stop

4. EXAMPLE PROBLEMS AND USER INSTRUCTIONS

none

5. PROGRAMS & SUBROUTINES USED

"AE"
6. PROGRAM>ListINGS

SUI3ROUTINE

01 LBL "AE"
02 "d=?"
03 PROMPT
04 RCL 05
05 /
06 STO 00
07 RCL 15
08 /
09 2
10 /
11 RAD
12 ACOS
13 STO 12
14 COS
15 RCL 12
16 SIN
17 *
18 CHS
19 RCL 12
20 +
21 PI
22 /
23 CHS
24 1
25 +
26 2
27 *
28 PI
29 *
30 RCL 05
31 RCL 15
32 *
33 x^2
34 *
35 STO 12
36 DEG
37 END
1. PURPOSE

This subroutine computes the induced power required for a tandem rotor helicopter in terms of horsepower. This subroutine will compute both the induced power at a hover, $P_{ih}$, and the induced power in forward flight, $P_{if}$.

2. EQUATIONS

$$P_{ih} = \frac{T^{1.5}}{\sqrt{2 \cdot \rho \cdot A_e}} \cdot K$$

(26)

$$K = 1.46 - 0.253S_R$$

(27)

$$P_{if} = P_{ih} \cdot K_u$$

(28)

$$K_u = 1 + \frac{d_f}{2}$$

(29)

$$S_R = \frac{d}{R}$$

(22)

$$\gamma = \tan^{-1}\left(\frac{1.5 \cdot T_f}{2 \cdot \rho \cdot A_f \cdot V_f^2}\right)$$

(30)

$$d_f = \frac{\sqrt{1 + S_R^2} + S_R \cdot \cos \gamma}{\sqrt{1 + S_R^2} \cdot (1 + S_R^2 \cdot \sin^2 \gamma)}$$

(31)

where:

$P_{ih}$ is the induced power at a hover [ft-lbf/sec]
\( P_{if} \) is the induced power in forward flight \([\text{ft-lb}_f/\text{sec}]\)

\( A_e \) is the effective area \((\text{ft}^2)\)

\( A_f \) is the area of the forward rotor disc \((\text{ft}^2)\)

\( d_f \) is the induced power correction factor

\( K_u \) is the forward flight correction factor

\( S_R \) is the rotor shaft spacing ratio

\( T_f \) is the thrust of the forward rotor which is usually equal to \( \frac{1}{2} W \), the weight \((\text{lb}_f)\)

\( V_f \) is the forward velocity \((\text{ft/sec})\)

\( K \) is the ratio of the induced power at a hover for a single rotor helicopter as compared to a tandem

\( d \) is the distance between the rotor shafts \((\text{ft})\)

\( R \) is the radius of the rotor system \((\text{ft})\)

\( T \) is the thrust which is equal to the weight, \( W \) \((\text{lb}_f)\)

\( \gamma \) is the wake skewing angle

\( \rho \) is the density of the air \([\frac{\text{lb-sec}^2}{\text{ft}^4}]\)

3. FLOWCHART

```
Start

Recall \( W \) from \( R_{10} \)

\( A_e \) from \( R_{12} \)

\( \rho \) from \( R_{11} \)

\( S_R \) from \( R_{00} \)

while solving equation for \( P_{ih} \) (hp)

next page+
```
Store answer into $R_{16}$

Recall $V_f$ from $R_{25}$

Yes

is $V_f = 0$?

No

Recall $P_{ih}$ from $R_{16}$

Recall $W$ from $R_{10}$, $\rho$ from $R_{11}$

Execute Subroutine "AD"

Recall $V_f$ from $R_{25}$ while solving equation for $\gamma$

Store answer into $R_{22}$

Recall $S_R$, $\gamma$, $P_{ih}$ from $R_{16}$

while solving equations for $d_f, K_u$ and finally $P_{ih} (hp)$

Execute Subroutine "TJ"*

Stop

*enters Subroutine "PI" at label "TJ"
4. EXAMPLE PROBLEMS AND USER INSTRUCTIONS

none

5. PROGRAMS & SUBROUTINES USED

"PIT"
"AD"
"PI" at label "TJ"

6. PROGRAM LISTINGS

SUBROUTINE

01 LBL "PIT"
02 RCL 10
03 1.5
04 Y↑X
05 RCL 12
06 RCL 11
07 *
08 2
09 *
10 SQRT
11 / 12 550
13 / 14 RCL 00
15 -.253
16 *
17 1.46
18 + 19 *
20 STO 16
21 RCL 25
22 X=0?
23 GTO 01
24 RCL 10
25 .375
26 *
27 RCL 11
28 /
29 XEQ "AD"
30 /
31 RCL 25
32 X↑2
33 /
34 ATAN
35 STO 22
36 SIN
37 X↑2
38 RCL 00
39 X↑2
40 *
41 1
42 +
43 RCL 00
44 X↑2
45 1
46 +
47 SQRT
48 STO 19
49 *
50 1/X
51 RCL 22
52 COS
53 RCL 00
54 *
55 RCL 19
56 +
57 *
58 2
59 /
60 1
61 +
62 RCL 16
63 *
64 GTO 02
65 LBL 01
66 RCL 16
67 LBL 02
68 XEQ "TJ"
69 END
APPENDIX D

MAIN PROGRAMS

This appendix consists of the main programs of this programming effort. The major ingredients of these programs are the subroutines found in the preceding two appendices. These main programs compute the various power requirements for hovering flight, forward (straight and level) flight, vertical flight, and forward climbing flight all for a single rotor helicopter; also tailrotor power requirements; autorotative flight; tandem rotor hovering and forward flight power requirements; and finally a short program to check several of the critical flight parameters.
1. PURPOSE

This main program computes the various power requirements in terms of horsepower for hovering flight. The various calculated power requirements are displayed as follows:

Display:                     Explanation:
PI=            induced power
PI(TL)=       induced power with tip losses
PI(TL+GE)=    induced power with tip losses plus ground effect
PO=            profile power
PT(MR)=       total power for the main rotor

2. EQUATIONS

No equations are found in the actual program itself. Consult the various subroutine listings for the equations used.
3. FLOWCHART

Start

- Clear all Storage Registers
- Alpha Store H1 into R31
- Execute Subroutine "DATA"
- Execute Subroutine "AD"
- Execute Subroutine "VT"
- Execute Subroutine "CT"
- Execute Subroutine "TL"
- Execute Subroutine "PI"
- Execute Subroutine "SD"
- Execute Subroutine "PO"
- Execute Subroutine "PT"
- Execute Subroutine "CG"

Stop
4. EXAMPLE PROBLEMS AND USER INSTRUCTIONS

Find the hover power requirements for an OH-58C, Kiowa, under the following conditions:

\[
\begin{align*}
C &= 1.086 \text{ ft} & \Omega &= 354 \text{ RPM} \pm 37.068 \text{ rads/sec} \\
R &= 17.7 \text{ ft} & h &= 25 \text{ ft} \\
b &= 2 & D.A. &= 1,000 \text{ ft} \\
W &= 3,000 \text{ lbs} & \bar{C}_d &= 0.008
\end{align*}
\]

Keystrokes:

[XEQ] [ALPHA] HOVER [ALPHA] [REC?]

(Rectangular Blade? 1 is Yes, 0 is No)

1 [R/S] C=?
1.086 [R/S] R=?
17.7 [R/S] b=?
2 [R/S] \bar{C}_d=?
.008 [R/S] RV=?
37.068 [R/S] H=?
25 [R/S] W=?
3,000 [R/S] D.A.=?
1,000 [R/S] PI=
[R/S] 140.16
[R/S] PI(TL)=
[R/S] 145.87
[R/S] PI(TL+GE)=
[R/S] 139.21
[R/S] PO=

106
It is desired at this point to increase the weight of this helicopter to 3,200 lbs (maximum gross weight). To observe what effect this change will have on the hover power requirements, press the key on the calculator keyboard directly beneath the variable in need of change. In this case the [LN] key is directly beneath the W in the display:

\[
\]

(Any Further Changes? 1 is Yes, 0 is No)
Now, using the same OH-58C at the new weight of 3,200 lbs find the hover power requirements with the rotor system height above the ground, h, equal to 60 ft.

Keystrokes:

[Display:
REC?
C=?
R=?
b=?
CdO=?
RV=?
H=?
W=?
D.A.=?
PI=
154.41
PI(TL)=
160.92
GE=0

(Ground effect is now equal to zero, the helicopter is hovering out of ground effect.)

[PO]=
45.57
PT(MR)=
206.48
5. PROGRAMS & SUBROUTINES USED

"AD"      "ECHORD"      "PT"
"CG"      "GE"         "SD"
"CT"      "HOVER"      "TL"
"DATA"    "PI"         "VT"
"DN"      "PO"

6. PROGRAM LISTINGS

PROGRAM
01 LBL "HOVER"
02 CLRG
03 "H1"
04 ASTO 31
05 XEQ "DATA"
06 LBL "H1"
07 XEQ "AD"
08 XEQ "VT"
09 XEQ "CT"
10 XEQ "TL"
11 XEQ "PI"
12 XEQ "SD"
13 XEQ "PO"
14 XEQ "PT"
15 XEQ "CG"
16 END
FORWARD FLIGHT

1. PURPOSE

This main program computes the various power requirements in terms of horsepower for forward (straight and level) flight. If the forward flight velocity, \( V_f \), is entered as zero, this program will also calculate the various hover power requirements. The various calculated power requirements are displayed as follows:

Display: Explanation:

\( \Pi = \) induced power

\( \Pi(TL) = \) induced power with tip losses

\( \Pi(TL+GE) = \) induced power with tip losses plus ground effect

\( \Pi_0 = \) profile power

\( \Pi_p = \) parasite power

\( \Pi_t(MR) = \) total power for the main rotor

2. EQUATIONS

\[
V_f \text{ (ft/sec)} = V_f \text{ (kts)} \cdot (1.68894)
\]

\[
P_i = T \cdot v_i T = T \left\{ - \frac{V_f^2}{v_i^2} + \sqrt{\left(\frac{V_f^2}{2v_i^2}\right)^2 + 1} \right\} \cdot v_i
\]
where:

\[ T \]  is the thrust which is equal to the weight, \( W \) (lb)

\[ V_f \]  is the forward velocity (ft/sec)

\[ v_i \]  is the induced velocity at a hover (ft/sec)

\[ P_i \]  is the induced power required \[ \frac{\text{ft-lbf}}{\text{sec}} \]

\[ v_{iT} \]  is the thrust component of the induced velocity vector (ft/sec)

No other equations are found in the actual program itself. Consult the various subroutine listings for the equations used.
3. FLOWCHART

Start

Clear all Storage Registers

Alpha Store F2 into R31

Prompt for and convert \( V_f \) from (kts) to (ft/sec) Store into \( R_{25} \)

Prompt for and input \( f_f \) into \( R_{26} \)

Execute Subroutine "DATA"

Execute Subroutine "AD"

Execute Subroutine "VT"

Execute Subroutine "CT"

Execute Subroutine "TL"

Execute Subroutine "VI"

Recall \( V_f \) from \( R_{25} \)
Recall \( V_i \) from \( R_{29} \)
Recall \( W_i \) from \( R_{10} \)

while solving equations for \( v_i T \) and then \( P_i (hp) \)

Execute Subroutine "PJ"*

Execute Subroutine "SD"

Execute Subroutine "PO"

Execute Subroutine "PP"

Execute Subroutine "PT"

Execute Subroutine "CG"

Stop

*enters Subroutine "PI" at label "PJ"
4. EXAMPLE PROBLEMS AND USER INSTRUCTIONS

Find the forward (straight and level) flight power requirements for an OH-6A, Cayuse, under the following conditions:

\[ C = 0.57 \text{ ft} \]
\[ R = 13.165 \text{ ft} \]
\[ b = 4 \]
\[ W = 2,250 \text{ lbs} \]
\[ h = 100 \text{ ft} \]

\[ \Omega = 470 \text{ RPM} \rightarrow 49.215 \text{ rads/sec} \]
\[ \overline{C_d}_o = 0.009 \]
\[ \text{D.A.} = 500 \text{ ft} \]
\[ V_f = 90 \text{ kts} \]
\[ f_f = 5.0 \text{ ft}^2 \]

Keystrokes:

[XEQ] [ALPHA] FORFLT [ALPHA]
90 [R/S]
5 [R/S]

(Rectangular Blade? 1 is Yes, 0 is No)

1 [R/S]
.57 [R/S]
13.165 [R/S]
4 [R/S]
.009 [R/S]
49.215 [R/S]
100 [R/S]
2,250 [R/S]
500 [R/S]

[R/S]
[R/S]
[R/S]

Display:

FOR V=?
F.P.A.(FF)=?
REC?

C=?
R=?
b=?
CdO=？
RV=？
H=？
W=？
D.A.=?
PI=

23.72
PI(TL)=

24.28

113
GE=0
PO=
48.27
PP=
37.39
PT(MR)=
109.94

CHANGE?

(Change Data? 1 is Yes, 0 is No)

1 [R/S]

It is desired at this point to decrease the rotor radius from 13.165 ft to 12.665 ft. To observe what effect this change will have on the forward flight horsepower requirements, press the key on the calculator keyboard directly beneath the variable in need of change. In this case the [LOG] key is directly beneath the R in the display:

[LOG] R=?
12.665 [R/S]

CHANGE?

(Any Further Changes? 1 is Yes, 0 is No)

0 [R/S]

PI=
25.63
PI(TL)=
26.28
GE=0
PO=
41.97
Find the hovering flight power requirements for the same OH-6A under the original conditions with the only difference being $V_f = 0$.

Keystrokes:

```
[ R/S ]                   pp = 37.39
[ R/S ]                   pt(mr) = 105.64
[ R/S ]                   change? 0.00
0 [ R/S ]
```

Display:

```
for v=?
    f.p.a.(ff) =?
    rec?
    c =?
    r =?
    b =?
    cdo =?
    rv =?
    h =?
    w =?
    d.a. =?
    pi = 121.50
    pi(tl) = 124.35
```
note - When program "HOVER" is executed for this case, the outputs are identical. Examination of equation 33 with \( V_f = 0 \), readily explains the reason for the identical results.

5. PROGRAMS & SUBROUTINES USED

```
"AD"     "FORFLT"     "SD"
"CG"     "GE"        "TL"
"CT"     "PI" at label "PJ"   "VI"
"DATA"   "PO"        "VT"
"DN"     "PP"        "VT"
"ECHORD" "PT"
```

6. PROGRAM LISTINGS

```
PROGRAM
01 LBL "FOR
FLT"
02 CLRG
03 "F2"
04 ASTO 31
05 "FOR V=0
06 PROMPT
07 \( 1.68894 \)
08 *
09 STO 25
10 "F.P.A.<
FF>=?"
11 PROMPT
12 STO 26
```
13 XEQ "DAT A"
14 LBL "F2"
15 XEQ "AD"
16 XEQ "VT"
17 XEQ "CT"
18 XEQ "TL"
19 XEQ "VI"
20 RCL 25
21 RCL 20
22 /
23 X↑2
24 2
25 /
26 STO 00
27 X↑2
28 1
29 +
30 SQRT
31 RCL 00
32 -
33 SQRT
34 RCL 20
35 *
36 RCL 10
37 *
38 550
39 /
40 XEQ "PJ"
41 XEQ "SD"
42 XEQ "PD"
43 XEQ "PP"
44 XEQ "PT"
45 XEQ "CG"
46 END
1. PURPOSE

This main program computes the various power requirements in terms of horsepower for vertical flight (vertical ascent). If the vertical velocity, \( V_v \), is entered as zero, this program will also calculate the various hover power requirements. The various calculated power requirements are displayed as follows:

Display:

\[
\begin{align*}
\text{PI} &= \text{induced power} \\
\text{PI}(TL) &= \text{induced power with tip losses} \\
\text{PI}(TL+GE) &= \text{induced power with tip losses plus ground effect} \\
\text{PO} &= \text{profile power} \\
\text{PP} &= \text{parasite power} \\
\text{PC} &= \text{climb power} \\
\text{PT(MR)} &= \text{total power for the main rotor}
\end{align*}
\]

Explanation:

2. EQUATIONS

\[
V_v \text{ (ft/sec) } = V_v \text{ (ft/min) } \cdot 60
\]  \hspace{1cm} (34)

\[
v_v = -\frac{V_v}{2} + \sqrt{(V_v/2)^2 + \frac{v_i^2}{v_h^2}}
\]  \hspace{1cm} (35)

\[
P_{ic} = T \cdot v_v
\]  \hspace{1cm} (36)
where:

- $T$ is the thrust which is equal to the weight, $W$ (lb$_f$)
- $v_v$ is the induced velocity due to pumping in a vertical climb (ft/sec)
- $V_v$ is the steady rate of climb velocity (ft/sec)
- $v_{ih}$ is the induced velocity at a hover (ft/sec)
- $P_{ic}$ is the induced power required to climb $\left[\frac{ft-lb_f}{sec}\right]$ 

No other equations are found in the actual program itself. Consult the various subroutine listings for the equations used.
3. FLOWCHART

Start

Clear all Storage Registers

Alpha Store Vl into R31

Prompt for and convert V, from (ft/min) to (ft/sec) Store into R23

Prompt for and input fV into R24

Execute Subroutine "DATA"

Execute Subroutine "AD"

Execute Subroutine "VT"

Execute Subroutine "CT"

Execute Subroutine "TL"

Execute Subroutine "VI"

Recall Vv from R23, Vl from R20, W from R13 while solving equation for vV and then PiC (hp)

Execute Subroutine "PJ"*

Execute Subroutine "SD"

Execute Subroutine "PO"

Execute Subroutine "PP"

Execute Subroutine "PC"

Execute Subroutine "PT"

Execute Subroutine "CG"

Stop

*enters Subroutine "PI" at label "PJ"
4. EXAMPLE PROBLEMS AND USER INSTRUCTIONS

Find the vertical flight power requirements for an SH-3H, Sea King, under the following flight conditions:

\[ C = 1.52 \text{ ft} \quad \bar{C}_{d_o} = .0095 \]
\[ R = 31 \text{ ft} \quad D.A. = 100 \text{ ft} \]
\[ b = 5 \quad V_v = 1,000 \text{ ft/sec} \]
\[ W = 18,000 \text{ lbs} \quad f_v = 360 \text{ ft}^2 \]
\[ h = 100 \text{ ft} \quad \Omega = 203 \text{ RPM} + 21.257 \text{ rads/sec} \]

Keystrokes:

\[
\begin{align*}
[XEQ] & \quad [\text{ALPHA}] \ \text{VERFLT} \ [\text{ALPHA}] \\
1,000 & \ [R/S] \\
360 & \ [R/S] \\
\text{(Rectangular Blade? 1 is Yes, 0 is No)} \\
1 & \ [R/S] \\
1.52 & \ [R/S] \\
31 & \ [R/S] \\
5 & \ [R/S] \\
.0095 & \ [R/S] \\
21.257 & \ [R/S] \\
100 & \ [R/S] \\
18,000 & \ [R/S] \\
100 & \ [R/S] \\
\text{[R/S]} & \\
\text{[R/S]} & \\
\text{[R/S]} & \\
\end{align*}
\]

Display:

\[
\begin{align*}
\text{VERT } V=? \\
\text{F.P.A.} \ (VF)=? \\
\text{REC?} \\
\text{C=}? \\
\text{R=}? \\
\text{b=}? \\
\text{CdO=}? \\
\text{RV=}? \\
\text{H=}? \\
\text{W=}? \\
\text{D.A.=}? \\
\text{PI=} \\
\text{919.60} \\
\text{PI(TL)}= \\
\text{939.83} \\
\end{align*}
\]
GE = 0

P0 = 344.97

PP = 3.59

PC = 545.45

PT(MR) = 1,833.84

(Change Data? 1 is Yes, 0 is No)

1 [R/S]

C RV b R W

It is desired at this point to taper the rotor blades. The new main rotor blade dimensions are:

\[ C_0 = 1.52 \]
\[ C_1 = 0.76 \]
\[ a = 0.90 \]

To observe what effect this change will have on the vertical flight power requirements, press the key on the calculator keyboard directly beneath the variable in need of change. In this case the [Σ+] key is directly beneath the C in the display:

[Σ+] REC?

0 [R/S] C0=?

1.52 [R/S] Cl=?

.76 [R/S] a=?
.9 [R/S]

CE=1.413

(The new Equivalent Chord is 1.413 ft)

[R/S]

CHANGE?

(Any Further Changes? 1 is Yes, 0 is No)

0 [R/S]

PI=

[R/S]

919.595

[R/S]

PI(TL) =

939.828

[R/S]

GE = 0

[R/S]

PO =

320.776

[R/S]

PP =

3.591

[R/S]

PC =

545.455

[R/S]

PT(MR) =

1,809.649

[R/S]

CHANGE?

0.000

Find the hovering flight power requirements for the same
SH-3H under the original conditions with the only difference
being \( V_v = 0 \).

Keystrokes: Display:

[R/S]

VERT \( V = ? \)

0 [R/S]

F.P.A.(VF) = ?
360 [R/S] REC?
1 [R/S] C=?
1.52 [R/S] R=?
31 [R/S] b=?
5 [R/S] CdO=?
.0095 [R/S] RV=?
21.257 [R/S] H=?
100 [R/S] W=?
18,000 [R/S] D.A.=?
100 [R/S] PI=
[R/S] 1,160.712
[R/S] PI(TL) =
[R/S] 1,186.250
[R/S] GE=0
[R/S] PO =
[R/S] 344.966
[R/S] PP =
[R/S] 0.000
[R/S] PT(MR) =
[R/S] 1,531.217
[R/S] CHANGE?
0 [R/S] 0.000

note - When program "HOVER" is executed for this case, the outputs are identical. Examination of equations 35 and 36 with $V_v = 0$, readily explains the reason for the identical results.
5. PROGRAMS & SUBROUTINES USED

"AD" "GE" "SD"
"CG" "PC" "TL"
"CT" "PI" at label "PJ" "VERFLT"
"DATA" "PO" "VI"
"DN" "PP" "VT"
"ECHORD" "PT"

6. PROGRAM LISTINGS

PROGRAM
01+LBL "VER
FLT"
02 CLRG
03 "V1"
04 ASTO 31
05 "VERT V=
06 PROMPT
07 60
08 /
09 STO 23
10 "F.P.A.<
VF>=?"
11 PROMPT
12 STO 24
13 XEQ "DAT
A"
14+LBL "V1"
15 XEQ "AD"
16 XEQ "VT"
17 XEQ "CT"
18 XEQ "TL"
19 XEQ "VI"
20 RCL 23
21 2

22 /
23 RCL 20
24 /
25 STO 00
26 X^2
27 1
28 +
29 SQRT
30 RCL 00
31 -
32 RCL 20
33 *
34 RCL 10
35 *
36 550
37 /
38 XEQ "PJ"
39 XEQ "SD"
40 XEQ "PO"
41 XEQ "PP"
42 XEQ "PC"
43 XEQ "PT"
44 XEQ "PT"
45 END
1. PURPOSE

This main program computes the various power requirements in terms of horsepower for forward climbing flight. If the vertical velocity, \( V_v \), is entered as zero, this program will compute the various power requirements for forward (straight and level) flight. If the forward velocity, \( V_f \), is entered as zero, this program will compute the various power requirements for vertical flight. If both the vertical velocity, \( V_v \), and the forward velocity, \( V_f \), are entered as zero, this program will compute the various power requirements for hovering flight. The various calculated power requirements are displayed as follows:

Display: 

\[
\begin{align*}
\text{PI} &= \text{induced power} \\
\text{PI(TL)} &= \text{induced power with tip losses} \\
\text{PI(TL+GE)} &= \text{induced power with tip losses plus ground effect} \\
\text{PO} &= \text{profile power} \\
\text{PP} &= \text{parasite power} \\
\text{PC} &= \text{climb power} \\
\text{PT(MR)} &= \text{total power for the main rotor}
\end{align*}
\]

Explanation:

2. EQUATIONS

\[ V_f \text{ (ft/sec)} = V_f \text{ (kts)} \cdot (1.68894) \] (32)
\[ P_i = T \cdot v_{iT} \]  \hspace{1cm} (33)

\[ V_v (\text{ft/sec}) = V_v (\text{ft/min}) \cdot 60 \]  \hspace{1cm} (34)

where:

- \( T \) is the thrust which is equal to the weight, \( W \) (lb_f)
- \( P_i \) is the induced power \( \frac{\text{ft-lb}_f}{\text{sec}} \)
- \( V_v \) is the vertical velocity (ft/sec)
- \( V_f \) is the forward velocity (ft/sec)
- \( v_{iT} \) is the vertical component of the induced velocity (ft/sec)

No other equations are found in the actual program itself. Consult the various subroutine listings for the equations used.
3. FLOWCHART

Start

Clear all Storage Registers

Alpha Store Fl into \( R_{31} \)

Set Flag 01

Yes=1

Vertical Flight Only?

No=0

Forward Flight Only?

Yes=1

Clear Flag 01

Display "BOTH"

Prompt for and convert \( \dot{V}_f \) from (ft/min) to (ft/sec), Store in \( R_{23} \)

Prompt for and input \( f_V \) into \( R_{24} \)

Yes

is Flag 01 Set?

No

Prompt for and convert \( \dot{V}_f \) from (kts) to (ft/sec) Store into \( R_{25} \)

Prompt for and input \( f_f \) into \( R_{26} \)

next page +
Clear Flag 01

Execute Subroutine "CF"

Execute Subroutine "VC"

Execute Subroutine "DATA"

Execute Subroutine "AD"

Execute Subroutine "VT"

Execute Subroutine "CT"

Execute Subroutine "TL"

Recall \( v_{i_T} \) from \( R_{27} \)

Recall \( W \) from \( R_{19} \)

while solving equation for \( P_1 \) (hp)

Execute Subroutine "PJ"*

Execute Subroutine "SD"

Execute Subroutine "PO"

Execute Subroutine "PP"

Execute Subroutine "PC"

Execute Subroutine "PT"

Execute Subroutine "CG"

Stop

*enters Subroutine "PI" at label "PJ"
4. EXAMPLE PROBLEMS AND USER INSTRUCTIONS

Find the forward climbing flight power requirements for a UH-60A, Blackhawk, under the following conditions:

\[
\begin{align*}
C &= 1.73 \text{ ft} \\
R &= 26.835 \text{ ft} \\
b &= 4 \\
W &= 18,250 \text{ lbs} \\
h &= 200 \text{ ft} \\
D.A. &= 650 \text{ ft}
\end{align*}
\]

\[
\begin{align*}
\Omega &= 258 \text{ RPM} \times 27.02 \text{ rads/sec} \\
\bar{c_d} &= .008 \\
V_v &= 500 \text{ ft/sec} \\
V_f &= 60 \text{ kts} \\
f_v &= 308 \text{ ft}^2 \\
f_f &= 25.69 \text{ ft}^2
\end{align*}
\]

Keystrokes:  

Display:

[XEQ] [ALPHA] FLIGHT [ALPHA]  
VERT ONLY?

(Execute Vertical Flight Only? 1 is Yes, 0 is No)

0 [R/S]  
FOR ONLY?

(Execute Forward Flight Only? 1 is Yes, 0 is No)

0 [R/S]  
BOTH

(The calculator is ready to do the combination of both, i.e. forward climbing flight)

[R/S]  
VERT V=?

500 [R/S]  
F.P.A.(VF)=?

308 [R/S]  
FOR V=?

60 [R/S]  
F.P.A.(FF)=?

25.69 [R/S]  
R=?

26.835 [R/S]  
W=?

18,250 [R/S]  
D.A.=?
(Rectangular Blade? 1 is Yes, 0 is No)

1 [R/S]  C= ?
1.73 [R/S]  R= ?
26.835 [R/S]  b= ?
4 [R/S]  CdO= ?
.008 [R/S]  RV= ?
27.02 [R/S]  H= ?
200 [R/S]  W= ?
18,250 [R/S]  D.A.= ?

650 [R/S]  PI= 
[R/S]  549.98
[R/S]  PI (TL) = 
[R/S]  566.21
[R/S]  GE=0
[R/S]  PO= 
[R/S]  325.07
[R/S]  PP= 
[R/S]  57.05
[R/S]  PC= 
[R/S]  276.52
[R/S]  PT (MR) = 
[R/S]  1224.85
[R/S]  CHANGE?
0 [R/S]  0.00
Find the vertical flight power requirements for the same UH-60A under the same conditions with the only exception being that the forward flight velocity, \( V_f \), is now equal to zero.

Keystrokes:  
\[ \text{Display:} \]

\[ \begin{align*}
\text{[R/S]} & \quad \text{VERT ONLY?} \\
1 \quad \text{[R/S]} & \quad \text{VERT V=} \ ? \\
500 \quad \text{[R/S]} & \quad \text{F.P.A.}(V_{F})= \ ? \\
308 \quad \text{[R/S]} & \quad R= \ ? \\
26.835 \quad \text{[R/S]} & \quad W= \ ? \\
18,250 \quad \text{[R/S]} & \quad D.A.= \ ? \\
650 \quad \text{[R/S]} & \quad \text{REC}？ \\
1 \quad \text{[R/S]} & \quad C= \ ? \\
1.73 \quad \text{[R/S]} & \quad R= \ ? \\
26.835 \quad \text{[R/S]} & \quad b= \ ? \\
4 \quad \text{[R/S]} & \quad C_dO= \ ? \\
.008 \quad \text{[R/S]} & \quad RV= \ ? \\
27.02 \quad \text{[R/S]} & \quad H= \ ? \\
200 \quad \text{[R/S]} & \quad W= \ ? \\
18,250 \quad \text{[R/S]} & \quad D.A.= \ ? \\
650 \quad \text{[R/S]} & \quad PI= 1248.63 \\
[R/S] & \quad PI(TL)= 1285.50 \\
[R/S] & \quad GE=0 \\
[R/S] & \quad PO= \\
\end{align*} \]
note - When program "VERFLT" is executed for this case, the outputs are identical. Examination of subroutine "CF" and subroutine "VC" with $V_f = 0$, explains the reason for the identical results. Find the forward (straight and level) flight power requirements for the same UH-60 under the original conditions with the only exception being that the vertical velocity, $V_v$, is now equal to zero.

Keystrokes:          Display:
[R/S]                 VERT ONLY?
[R/S]                 FOR ONLY?
0 [R/S]               FOR $V=$?
1 [R/S]               F.P.A.(FF)=?
60 [R/S]              R=?
25.69 [R/S]           W=?
18,250 [R/S]
650 [R/S]
[R/S]
[R/S]
[R/S]
[R/S]
[R/S]
[R/S]
[R/S]
0 [R/S]

D.A. =
PI =
558.69
PI(TL) =
575.18
GE = 0
PO =
325.07
PP =
56.68
PT(MR) =
956.93
CHANGE?
0.00

note - When program "FORFLT" is executed for this case, the outputs are identical. Examination of subroutine "CF" and subroutine "VC" with \( V_Y = 0 \), explains the reason for the identical results.

Find the hovering flight power requirements for the same UH-60 under the original conditions with the only exceptions being that both the vertical velocity, \( V_Y \), and the forward velocity, \( V_f' \), are equal to zero.

Keystrokes: Display:
[R/S] VERT ONLY?
note - When program "HOVER" is executed for this case, the outputs are identical. Examination of subroutine "CF" and subroutine "VC" with \( V_f = 0 \), and \( V_v = 0 \), explains the reason for the identical results.

The user of program "FLIGHT" might wonder at this time as to why it is even necessary to have programs "HOVER", "FORFLT", and "VERFLT" when it has now become obvious that program "FLIGHT" will do all three cases. Three reasons exist to substantiate the existence of these other three programs. First, program "FLIGHT" is a long program and, as such, requires 31 more program registers than any of the other three. Second, program "FLIGHT" has a longer running time than any of the other three. Subroutine "VC" alone will take an average of 30 seconds of execution time. And third, program "FLIGHT" involves some double prompting for the same input. The reasons for this were explained in subroutines "DATA" and "CF". This procedure optimizes the use of data registers, but also increases the execution time.
Therefore, if the user's only desire is to execute pure hover, or forward flight, or vertical flight computations, then one of these other programs should be used. Both calculator memory space and calculator execution time will be significantly reduced.

5. PROGRAMS & SUBROUTINES USED

"AD" "DN" "PI" at label "PJ" "TL"
"CF" "ECHORD" "PO" "VC"
"CG" "FLIGHT" "PP" "VI"
"CT" "GE" "PT" "VT"
"DATA" "PC" "SD"

6. PROGRAM LISTINGS

PROGRAM

\begin{verbatim}
01 LBL "FLIGHT"
02 CLRG
03 "F1"
04 ASTO 31
05 SF 01
06 "VERT ON LY?"
07 PROMPT
08 X>0?
09 GTO 04
10 "FOR ONL Y?"
11 PROMPT
12 X>0?
13 GTO 05
14 CF 01
15 "BOTH"
16 PROMPT
17 LBL 04
18 "VERT V=
19 PROMPT
20 60
21 /
22 STO 23
23 "F.P.A.<VF>=?"
24 PROMPT
25 STO 24
26 FS? 01
27 GTO 06
28 LBL 05
29 "FOR V=?"
30 PROMPT
31 1.66894
32 *
33 STO 25
34 "F.P.A.<FF>=?"
35 PROMPT
36 STO 26
37 LBL 06
38 CF 01
39 XEQ "CF"
40 XEQ "VC"
41 XEQ "DATA"
\end{verbatim}
42 LBL "F1"
43 XEQ "AD"
44 XEQ "VT"
45 XEQ "CT"
46 XEQ "TL"
47 RCL 27
48 RCL 10
49 *
50 550
51 /
52 XEQ "PJ"
53 XEQ "SD"
54 XEQ "PO"
55 XEQ "PP"
56 XEQ "PC"
57 XEQ "PT"
58 XEQ "CG"
59 END
1. PURPOSE

This main program computes the various tailrotor power requirements in terms of horsepower under all types of flight conditions. The tailrotor program must be executed immediately following the execution of any of the main rotor programs such as "HOVER", "FORFLT", "VERFLT", or "FLIGHT". The tailrotor program recalls and uses much of the information that the previously executed program has put into storage. By doing this, the tailrotor program is shortened. There is no need for regurgitation of input data and calculations for the main rotor, which is the starting point for all tailrotor computations. The various calculated power requirements are displayed as follows:

Display: Explanation:

\( P_I = \) induced power for the tailrotor

\( P_I(TL) = \) induced power with tip losses for the tailrotor

\( P_O = \) profile power for the tailrotor

\( P_T(TR) = \) total power for the tailrotor

\( P_T(MR) = \) total power for the main rotor

\( P_T(ACFT) = \) total power for the aircraft

2. EQUATIONS

\[
P_i^{(tr)} = T^{(tr)} \cdot v_i^{(tr)}
\]  (37)
\[ T_{\text{tr}} = \frac{P_{\text{mr}}/\Omega_{\text{mr}}}{\lambda_{\text{tr}}} \]

\[ v_{i_f}^{\text{tr}} = \left\{ -\frac{V_f^2}{2} + \left[\left(\frac{V_f}{2}\right)^2 + \frac{P_f^2}{(2A_D_{\text{tr}}\lambda_{\text{tr}}\Omega_{\text{mr}}\rho)^2} \right]^{1/2} \right\}^{1/2} \]

\[ v_i^{\text{tr}} = \frac{p_{\text{h}}(\text{mr})}{(2A_D_{\text{tr}}\lambda_{\text{tr}}\Omega_{\text{mr}}\rho)} \]

\[ P_{i_f}^{\text{tr}} = T_{\text{tr}} \cdot v_{i_f}^{\text{tr}} \]

\[ P_{\text{of}}^{\text{tr}} = \frac{1}{8}C_{\text{d}_0}(\text{tr}) \rho A_D^{\text{tr}} T_{\text{tr}}^3 \left( 1 + 4.3\left(\frac{V_f}{V_{T\text{mr}}}\right)^2 \right) \]

where:

\[ v_{i_f}^{\text{tr}} \]

is the induced velocity of the tailrotor in forward flight (ft/sec)

\[ P_{i_f}^{\text{tr}} \]

is the induced power required by tailrotor in forward flight [ft-lb_f/sec]

\[ P_{\text{of}}^{\text{tr}} \]

is the profile power required by the tailrotor in forward flight [ft-lb_f/sec]

\[ C_{\text{d}_0}(\text{tr}) \]

is the average profile drag coefficient of the tailrotor

\[ P_{\text{h}}(\text{mr}) \]

is the total power required by the main rotor in hover [ft-lb_f/sec]

\[ A_D^{\text{tr}} \]

is the disc area of the tailrotor (ft^2)
\( V_{T\text{(tr)}} \) is the tip velocity of the tailrotor (ft/sec)
\( V_{T\text{(mr)}} \) is the tip velocity of the main rotor (ft/sec)
\( v_i\text{(tr)} \) is the induced velocity of the tailrotor at a hover (ft/sec)
\( P_i\text{(tr)} \) is the induced power required by the tail-rotor at a hover \( \frac{\text{ft-lbf}}{\text{sec}} \)
\( T_{\text{(tr)}} \) is the required thrust for the tailrotor (lb
\( \Omega_{\text{(mr)}} \) is the rotational velocity of the main rotor system (radians/sec)
\( \sigma_{\text{(tr)}} \) is the solidity of the tailrotor
\( P_{\text{(mr)}} \) is the total power required by the main rotor \( \frac{\text{ft-lbf}}{\text{sec}} \)
\( l_{\text{tr}} \) is the tail length, the distance from the center of the main rotor system to the center of the tailrotor system (ft)
\( P_\text{f} \) is the total power required by the main rotor in forward flight \( \frac{\text{ft-lbf}}{\text{sec}} \)
\( V_\text{f} \) is the forward velocity of the helicopter (ft/sec)
\( \rho \) is the density of the air \( \frac{\text{lb-sec}^2}{\text{ft}^4} \)
3. FLOWCHART

Start

- Alpha Store T2 into R_{3,1}
- Recall \( \Omega (mr) \) from \( R_{0,8} \) and Store into \( R_{2,3} \)
- Recall \( V_T(mr) \) from \( R_{1,3} \) and Store into \( R_{2,6} \)
- Execute Subroutine "DATA" to input TR data
- Prompt for and input \( r_{2,2} \) into \( R_{2,4} \)
- Recall \( P_T(mr) \) from \( R_{3,0} \), \( \Omega (mr) \) from \( R_{2,3} \) while solving equation for \( T_{tr} \)
- Store Answer into \( R_{1,0} \)
- Execute Subroutine "AD"
- Execute Subroutine "VT"
- Execute Subroutine "TL"
- Execute Subroutine "SD"
- Execute Subroutine "VI"
Recall $V_f$ from $R_{25}$

Yes

is

$V_f > 0$?

No

Recall $T(tr)$ from $R_{10}$

while solving

equation for

$P_{ih}(tr)$ (hp)

Display Answer "PI(TL)="

Execute Subroutine "PO"

Recall $T(tr)$ from $R_{10}$

$v_i(tr)$ from $R_{20}$

while solving

equation for

$P_{ih}(tr)$ (hp)

Execute Subroutine "PJ"*

Recall $p$ from $R_{11}$

$A_D(tr)$ from $R_{12}$

$(tr)$ from $R_{24}$

$\Omega (mr)$ from $R_{23}$

$P_T(mr)$ from $R_{30}$

$V_f$ from $R_{25}$

$T(tr)$ from $R_{10}$

while solving

equation for

$P_{i_f}(tr)$ (hp)

Display Answer "PI="

Recall $B$ from $R_{15}$

while solving

equation for $P_{iTL}$

Display Answer "PI(TL)="

Store Answer into $R_{19}$

Recall $V_f$ from $R_{25}$

$V_T(mr)$ from $R_{26}$

$V_T(tr)$ from $R_{13}$

$A_D(tr)$ from $R_{12}$

$p$ from $R_{11}$

$\bar{C}_{D_0}$ from $R_{07}$

$\sigma(tr)$ from $R_{19}$

while solving

equation for

$P_{o_f}(tr)$ (hp)
4. EXAMPLE PROBLEMS AND USER INSTRUCTIONS

Find the tailrotor power requirements for an SH-3H, Sea King, conducting a "LAMPS" mission while hovering above the surface of the ocean under the following flight conditions:

\[ W = 18,650 \text{ lbs} \]
\[ h = 54 \text{ ft} \]
\[ D.A. = 0 \text{ ft} \]
\[ \lambda_{tr} = 36.6 \text{ ft} \]

**Main Rotor Data:**

- \( C = 1.52 \text{ ft} \)
- \( R = 31 \text{ ft} \)
- \( b = 5 \)
- \( \overline{C_d} = 0.0095 \)
- \( \Omega = 203 \text{ RPM} + 21.26 \text{ rads/sec} \)

**Tail Rotor Data:**

- \( C = 0.61 \text{ ft} \)
- \( R = 5.3 \text{ ft} \)
- \( b = 5 \)
- \( \overline{C_d} = 0.0105 \)
- \( \Omega = 1243 \text{ RPM} + 130.16 \text{ rads/sec} \)

**Keystrokes:**

1. \([\text{XEQ}]\) \([\text{ALPHA}]\) \(\text{HOVER}\) \([\text{ALPHA}]\)
2. \(1 \text{ [R/S]}\)
3. \(1.52 \text{ [R/S]}\)
4. \(31 \text{ [R/S]}\)
5. \(5 \text{ [R/S]}\)
6. \(0.0095 \text{ [R/S]}\)
7. \(21.26 \text{ [R/S]}\)
8. \(54 \text{ [R/S]}\)
9. \(18,650 \text{ [R/S]}\)
10. \(0 \text{ [R/S]}\)
11. \(\text{[R/S]}\)
12. \(\text{[R/S]}\)
13. \(\text{[R/S]}\)
14. \(\text{[R/S]}\)

**Display:**

- \( \text{REC?} \)
- \( \text{C=}？ \)
- \( \text{R=}？ \)
- \( \text{b=}？ \)
- \( \text{CdO=}？ \)
- \( \text{RV=}？ \)
- \( \text{H=}？ \)
- \( \text{W=}？ \)
- \( \text{D.A.=}？ \)
- \( \text{PI=} \)
- \( 1222.36 \)
- \( \text{PI(TL)}= \)
- \( 1249.70 \)
- \( \text{PI(TL+GE)}= \)
- \( 1216.90 \)
Subroutine "DATA" is about to be executed. This prompt tells the user that the tail rotor data should now be entered.

Subroutine "DATA" is about to be executed. This prompt tells the user that the tail rotor data should now be entered.
It is desired at this point to increase the length of the tail, $l_{tr}$, from 36.6 to 41.6 feet. To observe what effect this change will have on the tailrotor power requirements flag 04 must be set to return to the main program where it then becomes possible to change $l_{tr}$. The flowchart for subroutine "CG" depicts this process. In order to initiate this procedure, pick a variable and input its original value. In this example, $b$ is used:

$\sqrt{x}$

5 [R/S]
0 [R/S]
41.6 [R/S]
[R/S]
[R/S]
[R/S]
[R/S]
[R/S]
The same SH-3H is now returning to ship with $V_f = 100$ kts, $h = 500$ft, and $f_f = 31.27$ ft$^2$. Find the tailrotor power required.

Keystrokes:

[XEQ] [ALPHA] FORFLT [ALPHA]

Display:

FOR $V=?$

$100 \ [R/S]$  \ F.P.A. (FF)?

$31.27 \ [R/S]$  \ REC?  \ $1 \ [R/S]$

$1.52 \ [R/S]$

$31 \ [R/S]$

$5 \ [R/S]$

$.0095 \ [R/S]$  \ CdO=?

$21.26 \ [R/S]$

$500 \ [R/S]$  \ RV=?

$18,650 \ [R/S]$

$0 \ [R/S]$  \ D.A.=?

$0.00$  \ PI=

148
260.63
PI(TL)=
266.46
GE=0
PO=
442.73
PP=
325.53
PT(MR)=
1034.71
CHANGE?
0.00

TR DATA
REC?
C=?.61
R=5.3
b=5
CdO=0.0105
RV=130.16
H=500
W=18,650
D.A.=50
L(TAIL)=36.6
PI=
13.90
PI(TL)=
note - the CHANGE? process can be executed as many times as the user may desire, but the whole of program "TR" can only be executed once. By examining the flowchart for this program, it can be seen that several main rotor data elements are moved about in the storage registers. This is done to conserve program memory. Therefore, it becomes necessary to go back and execute one of the other main rotor programs before again attempting to execute program "TR" in its entirety.

5. PROGRAMS & SUBROUTINES USED

"AD"   "ECHORD"   "TL"
"CG"   "GE"   "TR"
"CT"   "PI" at label "PJ"   "VI"
"DATA"   "PO"   "VT"
"DN"   "SD"
6. PROGRAM LISTINGS

PROGRAM

01 LBL "TR"
02 "T2"
03 ASTO 31
04 RCL 03
05 STO 23
06 RCL 13
07 STO 26
08 "TR DATA"
09 PROMPT
10 XEQ "DAT A"
11 1000
12 STO 09
13 LBL "T2"
14 "L<TAIL>
15 =?"
16 PROMPT
17 STO 24
18 RCL 30
19 550
20 RCL 23
21 /  
22 RCL 24
23 / 
24 STO 10
25 XEQ "AD"
26 XEQ "VT"
27 XEQ "CT"
28 XEQ "TL"
29 XEQ "SD"
30 XEQ "VI"
31 RCL 25
32 X>0?
33 GTO 01
34 RCL 10
35 RCL 20
36 * 
37 550
38 /  
39 XEQ "PJ"
40 XEQ "PD"
41 GTO 02
42 LBL 01
43 RCL 11
44 2
45 *  
46 RCL 12
47 * 
48 RCL 24
49 * 
50 RCL 23
51 * 
52 X↑2
53 1/X
54 RCL 30
55 550
56 * 
57 X↑2
58 * 
59 RCL 25
60 X↑2
61 2
62 /
63 STO 00
64 X↑2
65 + 
66 SQRT
67 RCL 00
68 -  
69 SQRT
70 RCL 10
71 *  
72 550
73 /  
74 "PI=
75 PROMPT
76 VIEW X
77 STOP
78 RCL 15
79 /  
80 "PI<TL>=
81 PROMPT
82 VIEW X
83 STOP
84 STO 18
85 RCL 25
86 RCL 26
87 /  
88 X↑2
89 RCL 26
90 X↑2
\[ 91 \times 4.3 \frac{3}{9} \]

\[ 94 \text{RCL 13} \times 2 \]

\[ 96 \div 97 + 98 + \text{RCL 13} \]

\[ 100 \times 3 \]

\[ 101 \text{Y}^2 \times \text{RCL 12} \]

\[ 103 \times \text{RCL 11} \]

\[ 105 \times \text{RCL 07} \]

\[ 107 \times \text{RCL 19} \]

\[ 109 \times \]

\[ 110 \times 4400 \]

\[ 111 \div \]

\[ 112 \times \]

\[ 113 \text{"PO="} \]

\[ 114 \text{PROMPT} \]

\[ 115 \text{VIEW X} \]

\[ 116 \text{STOP} \]

\[ 117 \text{STO 21} \]

\[ 118 \text{LBL 02} \]

\[ 119 \text{RCL 18} \]

\[ 120 \text{RCL 21} \]

\[ 121 + \]

\[ 122 \text{"PT<TR>="} \]

\[ 123 \text{PROMPT} \]

\[ 124 \text{VIEW X} \]

\[ 125 \text{STOP} \]

\[ 126 \text{RCL 30} \]

\[ 127 \text{"PT<MR>="} \]

\[ 128 \text{PROMPT} \]

\[ 129 \text{VIEW X} \]

\[ 130 \text{STOP} \]

\[ 131 + \]

\[ 132 \text{"PT<ACFT} \]

\[ 133 \text{PROMPT} \]

\[ 134 \text{VIEW X} \]

\[ 135 \text{STOP} \]

\[ 136 \text{XEQ "CG"} \]

\[ 137 \text{END} \]
AUTOROTATION

1. PURPOSE

This main program computes several values for a single rotor helicopter in vertical and forward flight autorotation. The computed values are displayed as follows:

Display: Explanation:

\( \bar{V}_v \) = vertical velocity in a vertical autorotation (ft/min)

\( V_{F(MIN.R.O.D.)} = \) forward autorotative flight velocity for minimum autorotative rate of descent (kts)

\( V_{V(MIN.R.O.D.)} = \) vertical autorotative velocity (ft/min) at the forward autorotative flight velocity for minimum autorotative rate of descent

\( d(HOR.GLIDE) = \) horizontal distance travelled on the ground at the forward autorotative flight velocity for minimum rate of descent (ft)

2. EQUATIONS

\[ \bar{C}_L = \left( \frac{3K_2}{K_1} \right)^{\frac{1}{2}} \]  \hspace{1cm} (43)

\[ \bar{C}_d = K_1 \bar{C}_L^2 + K_2 \]  \hspace{1cm} (44)

\[ \bar{F} = \frac{(C_L^3/C_d^2)\cdot\sigma}{4} \]  \hspace{1cm} (45)

\[ V_v = \left[ \frac{\bar{W}}{2\cdot\rho\cdot A_D\cdot \bar{F}} \right]^{\frac{1}{2}} \]  \hspace{1cm} (46)
\[ F = \frac{\bar{F}}{(1 + \bar{F})^2} \quad (0 < \bar{F} < 1) \text{ Momentum Theory} \quad (47) \]

\[ F = \frac{(2\bar{F} - \sqrt{3\bar{F})}}{(4\bar{F} - 3)} \quad (\bar{F} > 1) \text{ Glauert Equation} \quad (48) \]

\[ V_f (\text{min ROD}) = 0.00867 \cdot R \cdot \text{RPM} \quad (49) \]

\[ V_v (\text{min ROD}) = 0.251 \cdot R \cdot \text{RPM} \quad (50) \]

\[ d (\text{hor glide}) = \frac{h}{\tan \gamma} \quad (51) \]

\[ \gamma = \arcsin \left( \frac{V_v}{V_f} \right) \approx 16.6^\circ \quad (52) \]

where:

- \( \bar{C}_L \) is the average coefficient of lift
- \( \bar{C}_d \) is the average coefficient of drag
- \( K_1 \) is a real number coefficient called the lift coefficient multiplier in drag coefficient terms
- \( K_2 \) is a real number coefficient equal to \( C_{d_o} \)
- \( V_v \) is the vertical velocity in a vertical autorotation (ft/min)
- \( A_D \) is the area of the rotor disc (ft²)
- \( \sigma \) is the solidity of the main rotor system
- \( \rho \) is the density of the air \( \left[ \frac{1 \text{ lb}-\text{sec}^2}{\text{ft}^4} \right] \)
- \( h \) is the height of the rotor system above the ground (ft)
\( V_f(\text{min ROD}) \) is the forward autorotative flight velocity for minimum autorotative rate of descent (kts)

\( V_v(\text{min ROD}) \) is the vertical autorotative velocity (ft/min) at the forward autorotative flight velocity for minimum autorotative rate of descent

\( d(\text{hor glide}) \) is the horizontal distance travelled on the ground (ft) at the forward autorotative flight velocity for minimum rate of descent

RPM is the rotational velocity of the main rotor system in revolutions/minute

\( \bar{F} \) is a non-dimensional coefficient

\( \bar{f} \) is a non-dimensional coefficient

W is the weight of the helicopter (lbs)

R is the radius of the rotor system (ft)

\( \gamma \) is the descent angle for minimum descent rate (degrees)
3. FLOW CHART

Start

Clear all Storage Registers

Alpha Store Al into R_{31}

Execute Subroutine "DATA"

Prompt for and input LCM into R_{90}

Recall K_1 from R_{00}, K_2 from R_{07}
while solving equation for C_L

Store Answer into R_{15}

Recall K_1 from R_{00}, K_2 from R_{07}
while solving equation for C_D

Recall C_L from R_{15}

Execute Subroutine "SD"

Solve equation for F

Store Answer into R_{14}

next page +
Yes

is \( F \leq 0 \) ?

Display \( F \)
"F=

Stop

No

Subtract 1.0

Yes

is \( F > 0 \) ?

Recall \( F \) from \( R_{14} \)
and solve Glauert
Equation for \( f \)

Recall \( F \) from \( R_{14} \)
and solve Momentum
Equation for \( f \)

Recall \( \rho \) from \( R_{11} \)

Execute Subroutine "AD"

Solve equation for
\( V_v \) (ft/min)

Display Answer "\( V_v = \)"

Recall \( \Omega \) from \( R_{0,8} \)
\( R \) from \( R_{0,5} \)
while solving
equation for
\( V_f \) (min ROD) (kts)

Display Answer
"\( V_f (\text{MIN.R.O.D.}) = \)"

Solve equation for
\( V_v \) (min ROD) (ft/min)

next page →
4. EXAMPLE PROBLEMS AND USER INSTRUCTIONS

note - if the display "F=" should appear, an error has been made in either the design or the input data itself. This will only occur when $F < 0$. Neither this program nor the theory used will be able to calculate results for this situation.

For a UH-1H, Iroquois, with the following characteristics:

\[
\begin{align*}
W &= 8,200 \text{ lbs} & \text{NACA 0012 Main Rotor Blade:} \\
h &= 1,500 \text{ ft} & R &= 24 \text{ ft} \\
b &= 2 & C &= 1.75 \text{ ft} \\
\text{D.A.} &= 1,500 \text{ ft} & C_d &= .0098 + .0120C_L^2
\end{align*}
\]
Ω = 324 RPM → 33.927 radians/sec

find the rate of descent in a vertical autorotation, \( V_v \); the forward flight autorotative velocity for minimum rate of descent, \( V_f(\text{min ROD}) \); the vertical velocity for the minimum rate of descent, \( V_v(\text{min ROD}) \); and the horizontal glide distance travelled during the autorotation, \( d(\text{hor glide}) \).

Keystrokes: Display:

[XEQ] [ALPHA] AUTO [ALPHA]
1 [R/S] C=?
1.75 [R/S] R=?
24 [R/S] b=?
2 [R/S] CdO=?
.0098 [R/S] RV=?
33.927 [R/S] H=?
1,500 [R/S] W=?
8,200 [R/S] D.A.=?
1,500 [R/S] LCM=?
.012 [R/S] \( V_v \)=
[R/S] 2885.69
[R/S] \( V_f(\text{MIN R.O.D.}) = \)
[R/S] 67.92
[R/S] \( V_v(\text{MIN R.O.D.}) = \)
[R/S] 2043.85
[R/S] \( d(\text{HOR. GLIDE}) = \)
[R/S] 5031.70
[R/S] CHANGE?
It is now desired to increase the weight from 8,200 to 9,500 lbs:

1 [R/S]  
[LN]  
9,500 [R/S]  
0 [R/S]  
[R/S]  
[R/S]  
[R/S]  
[R/S]  
It is now desired to decrease the rotor rotational velocity from 33.927 to 32.88 radians/second. This is 314 RPM.

1 [R/S]  
[1/x]  
32.88 [R/S]  
0 [R/S]  
[R/S]  
[R/S]  
[R/S]  
[R/S]  
160
note - A reduced rate of descent during a forward flight autorotation can be achieved by attaining as low a rotor speed as possible without exceeding published limits (stall). Below a certain rotational velocity, rate of descent increases again, and the higher the weight, the higher the RPM at which this reversal occurs. [Ref. 6] Also, the forward speed for minimum descent rate is not the same forward speed for maximum glide distance. The forward speed for maximum glide distance will be higher than the forward speed for minimum descent rate. This "stretching the glide" not only results in a longer horizontal glide distance, but also results in an increased rate of descent. [Ref. 6]
11 1/X
12 3
13 *
14 RCL 07
15 *
16 SQRT
17 STO 15
18 X+2
19 RCL 00
20 *
21 RCL 07
22 +
23 X+2
24 1/X
25 RCL 15
26 3
27 Y+X
28 *
29 XEQ "SD"
30 *
31 4
32 /
33 STO 14
34 X<=0?
35 GTO 01
36 1
37 -
38 X>0?
39 GTO 02
40 2
41 +
42 X+2
43 1/X
44 RCL 14
45 *
46 GTO 03
47 LBL 02
48 RCL 14
49 3
50 *
51 SQRT
52 CHS
53 RCL 14
54 2
55 *
56 +
57 RCL 14
58 4
59 *
60 3
61 -
62 /
1. PURPOSE

This main program computes the various power requirements in terms of horsepower for a tandem rotor aircraft in either hovering flight or forward (straight and level) flight. The various calculated power requirements are displayed as follows:

Display:

\[
\begin{align*}
\text{PI}(\text{TL}) &= \text{induced power with tip losses} \\
\text{PI}(\text{TL+GE}) &= \text{induced power with tip losses plus ground effect} \\
\text{PO} &= \text{profile power for a single rotor system} \\
\text{PO}(\text{TDM}) &= \text{profile power for the tandem rotor system} \\
\text{PT}(\text{TDM}) &= \text{total power for the tandem rotor system}
\end{align*}
\]

Explanation:

\[
\begin{align*}
\text{PI}(\text{TL}) &= \text{induced power with tip losses} \\
\text{PI}(\text{TL+GE}) &= \text{induced power with tip losses plus ground effect} \\
\text{PO} &= \text{profile power for a single rotor system} \\
\text{PO}(\text{TDM}) &= \text{profile power for the tandem rotor system} \\
\text{PT}(\text{TDM}) &= \text{total power for the tandem rotor system}
\end{align*}
\]

2. EQUATIONS

\[
P_T = P_i + P_o + P_p
\]

(20)

where:

\[
\begin{align*}
P_T &= \text{the total power required} \\
P_i &= \text{the induced power required} \\
P_o &= \text{the profile power required} \\
P_p &= \text{the parasite power required}
\end{align*}
\]

No other equations are found in the program. Consult the subroutine listings for the various equations used.
3. FLOWCHART

Start

- Clear all Storage Registers
- Alpha Store T1 into R31
- Execute Subroutine "DATA"
- Execute Subroutine "VT"
- Execute Subroutine "AD"
- Execute Subroutine "CT"

Divide C_T by 2 and Store Answer into R14

- Execute Subroutine "TL"
- Execute Subroutine "AE"

Yes=1

Hovering Flight?

No=0

- Prompt for and convert \( V_f \) from (kts) to (ft/sec)
  Store into R25

- Prompt for and input \( f_f \) into R25

next page +
Execute Subroutine "PIT"

Execute Subroutine "AD"

Execute Subroutine "SD"

Execute Subroutine "PO"

Multiply $P_o$ by 2 and Display Answer "PO(TDM)"

Store answer into $R_{21}$

Recall $V_f$ from $R_{25}$

Yes

is $V_f=0$?

No

Execute Subroutine "PP"

Recall $P_o$ from $R_{21}$

$P_f$ from $R_{13}$

while solving equation for $P_T$ (hp)

Display Answer "PT(TDM)"

Execute Subroutine "CG"

Stop
4. EXAMPLE PROBLEMS AND USER INSTRUCTIONS

Find the hover power requirements for a CH-47D, Chinook, under the following conditions:

\[
\begin{align*}
C &= 2.667 \text{ ft} \\
\bar{R} &= 30.0 \text{ ft} \\
b &= 3 \\
W &= 45,000 \text{ lbs} \\
d &= 38.917 \text{ ft} \\
\Omega &= 225 \text{ RPM} + 23.56 \text{ rads/sec} \\
\bar{C}_{d_o} &= 0.008 \\
h &= 35 \text{ ft} \\
D.A. &= 1,500 \text{ ft}
\end{align*}
\]

Keystrokes:

[XEQ] [ALPHA] TANDEM [ALPHA] [ALPHA]

(Rectangular Blade? 1 is Yes, 0 is No)

1 [R/S] C=?
2.667 [R/S] R=?
30 [R/S] b=?
3 [R/S] C_dO=?
.008 [R/S] RV=?
23.56 [R/S] H=?
35 [R/S] W=?
45,000 [R/S] D.A.=?
1,500 [R/S] d=?
38.917 [R/S] HOVER?

(Execute Hovering Flight Only? 1 is Yes, 0 is No)

1 [R/S] PI(TL)=
[R/S] 4,263.48
[R/S] PI(TL+GE)=

166
3,957.54

PO= 350.46

PO(TDM) = 700.93

PT(TDM) = 4,658.47

(Change Data? 1 is Yes, 0 is No)

1 [R/S] C RV b R W

It is desired at this point to increase the number of rotor blades per rotor system from 3 to 4. To observe what effect this change will have on the hover power requirements, press the key on the calculator keyboard directly beneath the variable in need of change. In this case the [\(\sqrt{x}\)] key is directly beneath the b in the display:

[\(\sqrt{x}\)] b=?

4 [R/S] CHANGE?

(Any Further Changes? 1 is Yes, 0 is No)

0 [R/S] d=?

The calculator has returned to the top of the main program and now presents the opportunity to change the distance between the rotor shafts, d. In this example, d remains the same:

38.917 [R/S] HOVER?
Find the forward flight (straight and level) power requirements for a CH-46E, Sea Knight, under the following flight conditions:

- \( C = 1.5625 \text{ ft} \)
- \( R = 25.5 \text{ ft} \)
- \( b = 3 \)
- \( W = 22,000 \text{ lbs} \)
- \( d = 33.33 \text{ ft} \)
- \( h = 2,000 \text{ ft} \)

\( \Omega = 264 \text{ RPM} \rightarrow 27.64 \text{ rads/sec} \)

\( \overline{C_d}_{0} = .009 \)

\( D.A. = 2,000 \text{ ft} \)

\( V_f = 100 \text{ kts} \)

\( f_f = 44.3 \text{ ft}^2 \)

Keystrokes:

\[
\begin{align*}
1 \text{ [R/S]} & \quad \text{PI(TL)} = 4,227.80 \\
\text{[R/S]} & \quad \text{PI(TL+GE)} = 3,924.43 \\
\text{[R/S]} & \quad \text{PO} = 467.28 \\
\text{[R/S]} & \quad \text{PO(TDM)} = 934.57 \\
\text{[R/S]} & \quad \text{PT(TDM)} = 4,859.00 \\
\text{[R/S]} & \quad \text{CHANGE?} = 0.00
\end{align*}
\]

Display:

\[
\begin{align*}
\text{REC?} & \quad 1 \\
\text{C=} & \quad 1.5625 \text{ [R/S]} \\
\text{R=} & \quad 25.5 \text{ [R/S]}
\end{align*}
\]
25.5 [R/S]  
b=?
3 [R/S]  
CdO=?
.009 [R/S]  
RV=?
27.64 [R/S]  
H=?
2,000 [R/S]  
W=?
22,000 [R/S]  
D.A.=?
2,000 [R/S]  
d=?
33.33 [R/S]  
HOVER?
0 [R/S]  
FOR V=?
100 [R/S]  
F.P.A.(FF)=?
44.3 [R/S]  
PI(TL)=
[R/S]  
3,235.14
[R/S]  
GE=0
[R/S]  
PO=
[R/S]  
238.65
[R/S]  
PO(TDM)=
[R/S]  
477.30
[R/S]  
PP=
[R/S]  
434.78
[R/S]  
PT(TDM)=
[R/S]  
4,147.22
[R/S]  
CHANGE?
1 [R/S]  
C RV b R W

It is desired at this point to decrease the forward flight velocity, $V_f$, from 100 to 50 knots. To observe what effect
this change will have on the forward flight power requirements flag 04 must be set to return to the main program where it then becomes possible to change \( V_f \). The flowchart for subroutine "CG" depicts this process. In order to initiate this procedure, pick a variable and input its original value. In this example, \( W \) is used:

\[
\begin{align*}
\text{[LN]} & \quad \text{W=}? \\
22,000 \quad \text{[R/S]} & \quad \text{CHANGE?} \\
0 \quad \text{[R/S]} & \quad \text{d=}? \\
33.33 \quad \text{[R/S]} & \quad \text{HOVER?} \\
0 \quad \text{[R/S]} & \quad \text{FOR V=}? \\
50 \quad \text{[R/S]} & \quad \text{F.P.A.(FF)=?} \\
44.3 \quad \text{[R/S]} & \quad \text{PI(TL)=} \\
& \quad \text{3,085.23} \\
& \quad \text{GE=}0 \\
& \quad \text{PO=} \\
& \quad \text{203.54} \\
& \quad \text{PO(TDM)=} \\
& \quad \text{407.08} \\
& \quad \text{PP=} \\
& \quad \text{54.35} \\
& \quad \text{PT(TDM)=} \\
& \quad \text{3,546.66} \\
& \quad \text{CHANGE?} \\
0 \quad \text{[R/S]} & \quad \text{0.00}
\end{align*}
\]
5. PROGRAMS & SUBROUTINES USED

"AD"  "ECHORD"  "SD"
"AE"  "GE"  "TANDEM"
"CG"  "PI" at label "TJ"  "TL"
"CT"  "PIT"  "VT"
"DATA"  "PO"  "PP"

6. PROGRAM LISTINGS

PROGRAM

01 LBL "TAN DEM"
02 CLRG
03 "T1"
04 ASTO 31
05 XEQ "DAT" A
06 LBL "T1"
07 XEQ "VT"
08 XEQ "AD"
09 XEQ "CT"
10 XEQ "PP"
11 / 2
12 STO 14
13 XEQ "TL"
14 XEQ "AE"
15 "HOVER?"
16 PROMPT
17 X>0?
18 GTO 02
19 "FOR Y=?"

20 PROMPT
21 1.68894 22 *
23 STO 25
24 "F.P.A.< FF>=?"

25 PROMPT
26 STO 26

27 LBL 02
28 XEQ "PIT"
29 XEQ "AD"
30 XEQ "SD"
31 XEQ "PO"
32 2
33 *
34 "PO<TDM>

35 PROMPT
36 VIEW X
37 STOP
38 STO 21
39 RCL 25
40 X=0?
41 GTO 03
42 XEQ "PP"
43 LBL 03
44 RCL 21
45 +
46 RCL 18
47 +
48 "PT<TDM>

49 PROMPT
50 VIEW X
51 STOP
52 XEQ "CG"
53 END
CHECKS

1. PURPOSE

This program performs a short series of checks on several important parameters. It is executed immediately following the execution of one of the main programs. This program recalls and uses data that the previously executed program has put into storage. The various parameters that are checked are displayed as follows:

Display: Explanation:
SOLID= the solidity of the rotor system
U= the advance ratio
M(TIP)= the Mach Number at the tip of the advancing rotor blade
D.L.= the disc loading of the rotor system

2. EQUATIONS

\[ a = \sqrt{\gamma \cdot g \cdot R \cdot T(°R)} \]  
\[ T(°K) = T(°C) + 273.16 \]  
\[ T(°R) = T(°K) \div 0.5555 \]  
\[ M_T = \frac{V_f + V_T}{a} \]  
\[ \mu = \frac{V_f}{V_T} \]  
\[ \text{DISC LOADING} = \frac{W}{A_D} \]
where:

\[ T(°C) \] is the temperature in degrees centigrade
\[ T(°K) \] is the temperature in degrees kelvin
\[ T(°R) \] is the temperature in degrees rankine
\[ g_c \] is the gravitational constant \[
\frac{32.174 \text{ lb}_m\text{-ft}}{\text{lb}_f\text{-sec}^2}
\]
\[ A_D \] is the rotor disc area \((\text{ft}^2)\)
\[ M_T \] is the Mach Number at the tip of the advancing rotor blade
\[ V_f \] is the forward velocity of the helicopter \((\text{ft/sec})\)
\[ V_T \] is the tip speed of the rotor blade \((\text{ft/sec})\)
\[ R \] is the gas constant for air \[
\frac{53.3 \text{ ft-lb}_f}{\text{lb}_m\text{-°R}}
\]
\[ W \] is the weight \((\text{lbs})\)
\[ \mu \] is the advance ratio
\[ a \] is the sonic velocity \((\text{ft/sec})\)
\[ \gamma \] is the ratio of specific heats \((1.4 \text{ for air})\)
3. FLOWCHART

Start

Recall $\sigma$ from $R_{19}$ and Display Answer "SOLID=

Recall $V_f$ from $R_{25}$ $V_T$ from $R_{13}$ while solving equation for $\mu$

Display Answer "U="

Recall $V_f$ from $R_{25}$ $V_T$ from $R_{13}$

Prompt for $T(\circ C)$

Solve equations for $a$ then $M_T$

Display Answer "M(TIP)="

Recall $W$ from $R_{19}$ $A$ from $R_{12}$ $D$ while solving equation for Disc Loading

Display Answer "D.L.="

Stop
4. EXAMPLE PROBLEMS AND USER INSTRUCTIONS

Execute program "FORFLT" for the CH-53E under the following characteristics and flight conditions:

\[
\begin{align*}
C &= 2.44 \text{ ft} \\
R &= 39.5 \text{ ft} \\
b &= 7 \\
h &= 1000 \text{ ft} \\
W &= 70,000 \text{ lbs} \\
\Omega &= 179 \text{ RPM + 18.743 rads/sec} \\
\Omega &= 179 \text{ RPM + 18.743 rads/sec} \\
V_f &= 140 \text{ kts} \\
f_f &= 63.57 \text{ ft}^2 \\
\overline{C}_{d_0} &= .009 \\
\text{D.A.} &= 1000 \text{ ft}
\end{align*}
\]

Keystrokes:

[XEQ] [ALPHA] FORFLT [ALPHA] 
140 [R/S] 
63.57 [R/S] 
1 [R/S] 
2.44 [R/S] 
39.5 [R/S] 
7 [R/S] 
.009 [R/S] 
18.743 [R/S] 
1000 [R/S] 
70,000 [R/S] 
1000 [R/S] 
[R/S] 
[R/S] 
[R/S] 
[R/S] 
Display:

FOR V=? 
F.P.A.(FF)=? 
REC? 
C=? 
R=? 
b=? 
CdO=? 
RV=? 
H=? 
W=? 
D.A.=? 
PI= 
1662.62 
PI(TL)= 
1699.10 
GE=0
Now, execute program "CHECKS" in order to make a quick check on $\sigma$, $\mu$, $M_T$, and Disc Loading. The temperature is 13° C

Keystrokes:

Display:

\[
\begin{align*}
[XEQ] \text{[ALPHA]} \text{CHECKS [ALPHA]} & \quad \text{SOLID}=0.1376 \\
[R/S] & \quad U=0.3194 \\
[R/S] & \quad T=? \\
13 \; [R/S] & \quad M(TIP)=0.8783 \\
[R/S] & \quad D.L.=14.2808
\end{align*}
\]

It is important to note here that the blade loading is above 10 lbs/ft$^2$. This generates high induced velocities, which in turn can make operations in unimproved sites hazardous due to flying debris. Also, it becomes increasingly difficult to obtain safe autorotational characteristics at these higher disc loadings. [Ref. 7]

The tip Mach Number is above 0.85. This means that the advancing rotor blade is entering the transonic flow region and shock wave formation will lead to wave drag.
Blade stall effects on the retreating rotor blade have started prior to this. Therefore the actual horsepower required in forward flight will be somewhat higher due to the effects of compressibility and blade stall. [Ref. 3]

5. PROGRAMS & SUBROUTINES USED

"CHECKS"

6. PROGRAM LISTINGS

```
PROGRAM
01 LBL "CHECKS"
02 FIX 4
03 RCL 19
04 "SOLID=
05 ARCL X
06 AVIEW
07 STOP
08 RCL 25
09 RCL 13
10 /
11 "U=
12 ARCL X
13 AVIEW
14 STOP
15 RCL 25
16 RCL 13
17 +
18 "T=?"
19 PROMPT
20 273.16
21 +
22 .5555
23 /
24 2400.324
25 *
26 SQRT
27 /
28 "M<TIP>

29 ARCL X
30 AVIEW
31 STOP
32 RCL 10
33 RCL 12
34 /
35 "D.L.="
36 ARCL X
37 AVIEW
38 END
```

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