COMPUTER PROGRAM USER'S MANUAL
FOR ADVANCED GENERAL
AVIATION PROPELLER STUDY

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A User's Manual is presented for a computer program for predicting the performance (static, flight, and reverse), noise, weight and cost of propellers for advanced general aviation aircraft of the 1980 time period. Complete listings of this computer program with detailed instructions and samples of input and output are included.
CONTENTS

SUMMARY 1

INTRODUCTION 3

SYMBOLS 5

TECHNOLOGY IDENTIFICATION 7

Propeller Performance Generalization 7
Static and Forward Flight 7
Reverse 9
Propeller Noise Generalization 11
Propeller Weight Generalization 13
Propeller Cost Generalization 13
Computer Program 14

PARAMETRIC STUDY OPTIONS 17

COMPUTER PROGRAM USAGE INSTRUCTIONS 17

Program Input 18
Program Output 21
Messages 23
Sample Cases 24

CONCLUDING REMARKS 26

REFERENCES 26

TABLES

I Advanced General Aviation Propeller Study - Aircraft Classification 27

II General Aviation - Generalized Propeller Weight Equation 28

FIGURES

1 Power Coefficient Chart for a 2-Bladed, 150 Activity Factor, 0.500 Integrated Design C_L_1 Propeller 29
FIGURES (Continued)

2  Thrust Coefficient Chart for a 2-Bladed 150 Activity Factor, 0.500 Integrated Design $C_{L_1}$ Propeller 30
3  Basic Performance Curve—Variation of Effective Torque Coefficient with Advance Ratio and Blade Angle. 31
4  Basic Performance Curve—Variation of Effective Thrust Coefficient with Advance Ratio and Blade Cycle 32
5  Basic Noise Curve. 33
6  Category I Parametric Study 34
7  Category II Parametric Study 35
8  Category IV Parametric Study 36
9  Example Reverse Thrust Variation with Landing Speed and Power Setting 37
10 Sample Input Coding 38
11 Sample Output - SHP Option 40
12 Sample Output - Thrust Option 41
13 Sample Output - 50% Stall Option 42
14 Sample Output - Reverse Thrust Option 43
1A Computer Program Flow Chart 46
2A List of Subroutines 47
3A FORTRAN IV Listing 48

APPENDIX

A  Flow Charts, Subroutine List, and FORTRAN IV Listing for Hamilton Standard Deck H432 45
SUMMARY

A major outcome of the studies sponsored by the Advanced Concept and Mission Division, A.C.M.D. of NASA under Contract No. NAS2-5885 dated 30 January 1970 as reported in CR 114289 and under Contract No. NAS2-6477 dated 6 May 1971 as reported in CR 114399 has been the development of a computer program for evaluating propeller performance (static, flight, reverse), noise, weight, and cost for general aviation aircraft propellers as a function of the prime geometric and aerodynamic variables. Propellers have been divided into five classifications which distinguish the complexity of general aviation propellers, i.e., fixed versus variable pitch, deicing capability, full feathering capability, and reverse thrust capability. Parameters that may be varied independently include number of blades, blade activity factor, blade integrated design lift coefficient, and blade tipspeed. A User's Manual for the computer program was written under Contract No. NAS2-6477 and is presented herein.

A brief description of the technology development is presented, and a complete listing of the computer program as well as detailed instructions and samples of input and output are included. Examples of parametric studies which can be made with the computer program are shown.
INTRODUCTION

Aviation forecasts for the next ten to fifteen year time period, indicate the continued steady growth of general aviation. Furthermore, it is apparent that most of these aircraft, even into the 1980 time period will be propeller driven utilizing primarily reciprocating engines with increased number of turbine engines as their economics improve. The attainment of this forecasted growth is dependent upon the continued improvement in the safety, utility, performance and cost of general aviation aircraft.

In view of this, a study was undertaken under the sponsorship of the Advanced Concept and Mission Division of NASA to derive and computerize appropriate propeller performance (static and forward flight), noise, weight and cost criteria to permit sensitivity studies of these factors to be made for advance propeller configurations designed for general aviation aircraft of the 1980 time period. This study is reported in reference 1. At NASA's request, a contract study was undertaken to provide a User's Manual which includes a complete listing of this computer program with detailed instructions on its use. Furthermore, the scope of the computer program was extended to incorporate the inclusion of the generalized integrated design lift coefficient (the only prime propeller blade shape variable not included in the original program), the computation of reverse thrust, and the refinement of the weight generalization. The technology development required to incorporate the above extensions into the computer program for inclusion in the User's Manual is presented in reference 2. The User's Manual is presented in this report.
SYMBOLS AND ABBREVIATIONS

AF  propeller blade activity factor, \( \frac{100,000}{16} \int_{-0.15}^{1.0} \left( \frac{b}{D} \right) x^3 \, dx \)

b  blade section width, ft

B  number of blades

\( C_{L_D} \)  blade section design lift coefficient

\( C_{L_1} \)  propeller blade integrated design lift coefficient 4 \( \int_{0.15}^{1.0} \frac{C_{L_D}}{x^3} \, dx \)

\( C_P \)  power coefficient, \( \frac{\text{SHP} \left( \rho_o/\rho \right) 10^{11}}{2N^3D^5} \)

\( C_Q \)  torque coefficient for \( J \leq 1.0 \), \( \frac{\text{SHP} \left( \rho_o/\rho \right) 10^{11}}{4\pi N^3D^5} \)

\( C_T \)  thrust coefficient, \( \frac{1.514 \times 10^6 T \left( \rho_o/\rho \right)}{N^2D^4} \)

D  propeller diameter, ft

h  maximum blade section thickness, ft

J  advance ratio, \( \frac{101.4 V_k}{ND} \)

M  free stream Mach number

N  propeller speed, rpm

PNL  perceived noise level, PNdB
\[ Q_C \text{ torque coefficient for } J > 1.0, \quad \frac{\text{SHP}(\rho_o/\rho) \times 10^{11}}{4\pi N^3 D^5} \times \frac{1}{J^2} \]

\[ R \text{ blade radius at propeller tip, ft} \]

\[ r \text{ radius at blade element, ft} \]

\[ \text{SHP} \text{ shaft horsepower} \]

\[ T \text{ propeller thrust, pounds} \]

\[ T_C \text{ thrust coefficient for } J > 1.0, \quad \frac{1.514 \times 10^6 T(\rho_o/\rho)}{N^2 D^4} \times \frac{1}{J^2} \]

\[ V_K \text{ freestream velocity, knots} \]

\[ x \text{ fraction of propeller tip radius, } r/R \]

\[ \beta_{3/4} \text{ propeller blade angle at } 3/4 \text{ radius} \]

\[ \rho \text{ density, lb sec}^2/\text{ft}^4 \]

\[ \rho_o \text{ density at sea level standard day, } 0.002378 \text{ lb sec}^2/\text{ft}^4 \]

\[ \rho_o/\rho \text{ } \Theta/\delta \]

\[ \Theta \text{ ratio of absolute temperature to absolute temperature at sea level, } T/T_o \]

\[ \delta \text{ ratio of static pressure to static pressure at sea level, } P/P_o \]
TECHNOLOGY IDENTIFICATION

General aviation aircraft covers a very broad spectrum of aircraft implied by the power plant size range of 100-1500 shaft horsepower. Thus, in order to provide a meaningful study within the scope intended by the Advanced Concepts and Missions Division, A.C.M.D., as an initial step under the study in reference 1 the Contractor classified into five categories the general aviation aircraft envisioned by A.C.M.D. For convenience, the categories are repeated here in Table I. Analytical generalizations for predicting the performance (static, forward flight, and reverse), noise, weight and cost of propellers for general aviation aircraft classified in Table I were established and computerized. With the aircraft and propeller requirements thus defined and the computer program having been established, comprehensive sensitivity studies of the propeller geometric and performance parameters can be conducted. Such studies were presented in reference 1 for representative aircraft from each general category described in Table I.

The details of the analytical procedures are defined in references 1 and 2. A brief description of each generalization is presented in the following text.

Propeller Performance Generalization

As a means of assessing propeller performance over the entire flight spectrum, performance generalizations were developed for predicting static and forward flight performance. Furthermore, for those aircraft incorporating propellers with the reverse thrust feature, a method of calculating reverse thrust has been included. These generalizations were made for a family of propellers spanning the prime propeller variables of 2 to 8 in number of blades, 80-200 in blade activity factor, AF, and 0.3 to 0.8 in integrated design lift coefficient, $C_{L_{1}}$.

A brief description of these generalizations is presented in the following text.

Static and forward flight. – A performance generalization was developed for predicting static and forward flight performance for general aviation propellers. Using the proven propeller performance prediction methods discussed in references 1 and 2, performance calculations were made for a family of propellers selected on the basis of propeller shapes which prior study had shown to be the most favorable for minimum weight, low noise characteristics and good performance (ref. 1, fig. 1, 2, 3 and 4 and ref 2, fig. 1). These calculations were used in developing the performance generalizations. The horsepower, thrust, propeller rotational speed, velocity and diameter were included in the non-dimensional form of power coefficient, $C_{p}$, thrust coefficient, $C_{T}$, and advance ratio, $J$ defined as follows.
\[
C_P = \frac{\text{SHP} \left( \frac{\rho_o}{\rho} \right) \times 10^{11}}{2 \ N^3 \ D^5}
\]

\[
C_T = \frac{1.514 \times 10^6 \ T \left( \frac{\rho_o}{\rho} \right)}{N^2 \ D^4}
\]

\[
J = \frac{101.4 \ V_k}{N D}
\]

where:

- \(\text{SHP}\) - shaft horsepower
- \(\rho_o/\rho\) - ratio of density at sea-level standard day to density for a specific operating condition.
- \(D\) - propeller diameter, ft
- \(N\) - propeller speed, rpm
- \(T\) - propeller thrust, pounds
- \(V_k\) - forward speed velocity, knots

Base curves were defined in this non-dimensional form for presenting the performance of 2, 4, 6 and 8 bladed propellers referenced to an activity factor of 150 and 0.5 integrated design lift coefficient. In order to minimize the number of curves and consequently the size and complexity of the computer program, the terms effective power coefficients, \(C_{PE}\) and effective thrust coefficient, \(C_{TE}\) were introduced. The effective power and thrust coefficients are defined as follows:

\[
C_{PE} = C_P \times P_{AF} \times P_{CL_i}
\]

\[
C_{TE} = C_T \times T_{AF} \times T_{CL_i}
\]

where:

- \(C_P\) - power coefficient
- \(P_{AF}\) - activity factor adjustment to power coefficient (ref. 1, fig. 3A)
- \(P_{CL_i}\) - integrated design lift coefficient adjustment factor to power coefficient (ref. 2, fig. 4)
Thus, the base curves while referenced to a basic activity factor and integrated design lift coefficient are applicable to the complete range of the prime blade shape parameters including 80-200 activity factor, 0.3 to 0.8 integrated design lift coefficient and 2 to 8 blades. This performance generalization format is shown for 2 bladed propellers referenced to 150 activity factor and 0.5 integrated design lift coefficient on figures 1 and 2 for the effective power coefficient chart and the effective thrust coefficient chart, respectively.

Since it has been projected that general aviation aircraft will be operating at significantly higher speeds by the 1980 time period, a compressibility factor, $F_t$ was derived for use with the base performance plots. The thrust is multiplied by $F_t$ (ref. 2, fig. 9) to correct for compressibility losses.

The complete generalization together with detailed computational instructions are presented in APPENDIX A of reference 1 and in reference 2.

It is to be noted that the performance predicted by this method is for the isolated propeller since no single body blockage effect could be generalized to cover the wide variety of aircraft included in general aviation.

Reverse. - The analytical method for computing reverse thrust is based on an existing Hamilton Standard procedure which was obtained by generalizing all available propeller test data. The shaft horsepower, thrust, propeller rotational speed, velocity and diameter are included in the non-dimensional form of torque coefficient, $C_Q$ or $Q_C$, thrust coefficient, $C_T$ or $TC$, and advance ratio, $J$ defined as follows:

$$ J = \frac{101.4 \, V \, K}{ND \, T \left( \frac{\rho_o}{\rho} \right)} $$

$$ C_Q = \frac{4 \pi \, N^3 \, D^5 \, \left( \frac{\rho_o}{\rho} \right)}{10^{11} \, SHP \, \left( \frac{\rho_o}{\rho} \right)} $$

$$ Q_C = \frac{4 \pi \, N^3 \, D^5 \, \left( \frac{\rho_o}{\rho} \right)}{10^{11} \, SHP \, \left( \frac{\rho_o}{\rho} \right)} \times \frac{1}{J^2} \quad \text{for} \quad J > 1.0 $$

$$ C_T = \frac{1.514 \times 10^6 \, T \left( \frac{\rho_o}{\rho} \right)}{N^2 \, D^4} \quad \text{for} \quad J \leq 1.0 $$
(1.514 x 10^6 \frac{T(\rho_o/\rho)}{N^2D^4} \times \frac{1}{j^2}) \quad \text{for } J > 1.0

where:

\begin{align*}
\text{SHP} & \quad \text{shaft horsepower} \\
\rho_o/\rho & \quad \text{ratio of density at sea level standard day to density for a specific operating condition} \\
N & \quad \text{propeller speed, rpm} \\
D & \quad \text{propeller diameter, ft} \\
T & \quad \text{propeller thrust, pounds} \\
V_K & \quad \text{forward speed velocity, knots}
\end{align*}

Base curves have been defined in this manner for a 3-bladed, 100 activity factor, AF, 0.4 integrated design lift coefficient, $C_{L_1}$ propeller. The term effective torque coefficient, $C_{Q_E}$ or $Q_{C_E}$, and effective thrust coefficient, $C_{T_E}$ or $T_{C_E}$, are used. As with the forward flight generalization, these base curves with appropriate adjustments for AF, $C_{L_1}$ and number of blades can be used in predicting reverse thrust characteristics for the family of propellers spanning 2 to 8 number of blades, 80-200 AF, and 0.3 to 0.8 $C_{L_1}$. The effective torque coefficients and thrust coefficients are defined as follows:

\begin{align*}
C_{Q_E} & = \left[ C_Q \times (3/B)^{0.83} \times Q_{AF} \right] - \Delta C_{Q_{E2}} \quad (\text{PCR}/100) \quad \text{for } J \leq 1.0 \\
Q_{C_E} & = \left[ Q_C \times (3/B)^{0.83} \times Q_{AF} \right] - \Delta Q_{C_{E2}} \quad (\text{PCR}/100) \quad \text{for } J > 1.0 \\
C_{T_E} & = \left[ C_T \times (3/B)^{0.83} \times T_{AF} \right] - \Delta C_{T_{E2}} \quad (\text{PCR}/100) \quad \text{for } J \leq 1.0 \\
T_{C_E} & = \left[ T_C \times (3/B)^{0.83} \times T_{AF} \right] - \Delta T_{C_{E2}} \quad (\text{PCR}/100) \quad \text{for } J > 1.0
\end{align*}

where:

\begin{align*}
C_Q & \quad \text{torque coefficient for } J \leq 1.0 \\
(3/B)^{0.83} & \quad \text{number of blades, B adjustment}
\end{align*}
This performance generalization format is shown for 3-bladed propellers referenced to 100 activity factor and 0.4 integrated design lift coefficient on figures 3 and 4 for the effective torque coefficients and effective thrust coefficients, respectively. The complete generalization together with detailed instructions for computing the reverse angle for a given throttle setting and the reverse thrust over the landing distance run with the propeller fixed at the reverse angle are presented in reference 2.

Propeller Noise Generalization

For assessing propeller noise, the far field perceived noise level (PNL) was selected as the noise rating scale because: 1) It is a good measurement of the relative annoyance of the various aircraft designs considered in general aviation aircraft, 2) It can be estimated by use of a relatively simple calculation procedure, and 3) It is a reasonable indication of the subjective reaction to aircraft noise.

An empirical method for predicting far-field perceived noise levels, PNdB developed at Hamilton Standard has been included in the computer program. It presents a means of calculating noise for a broad range of propeller design and operating parameters.
The required inputs to the propeller noise estimating method are:

1. Propeller diameter
2. Number of blades per propeller
3. Propeller RPM or tipspeed
4. Shaft horsepower per propeller
5. Ambient temperature
6. Aircraft forward speed
7. Number of propellers installed
8. Distance from the propeller center of the desired field point at which the noise is to be measured.

The computational procedure consists of a basic noise level (dB) curve (fig. 5) for a 4-bladed, 10.5 foot diameter propeller defined at 500 feet from the propeller center. The base curve is a function of shaft horsepower and rotational tipspeed. There are adjustments for variations in diameter, number of blades, and distance from the propeller center. Then, there is an adjustment to obtain the corresponding perceived noise level. The directivity pattern of the noise emanating from the propeller is ignored, and the perceived noise level is computed for the azimuth angle for which the noise is a maximum.

Recent test data on highly loaded low tipspeed propellers have indicated that the reduction in noise with tipspeed is a function of propeller stall characteristics. It appears that noise reductions can be achieved with decreasing tip speed at a given power only to the point where the propeller stall is limited to approximately the inner 50% of the blades. The 50% stall region is defined on the base \( \text{C}_p \) and \( \text{C}_T \) curves (fig. 1 and 2). It is recommended that propellers be selected to operate to the left of the indicated 50% stall line. The detailed procedure is explained in APPENDIX B of reference 1.

Since this generalization is for propellers only, it is emphasized that the low noise levels which may be achieved through selected design and operating conditions will not be representative of those from the complete aircraft unless a parallel effort is made to reduce the noise from other sources (particularly from the engine) as these will become predominant and set the perceived noise level of the aircraft.
Propeller Weight Generalization

A weight estimating equation (ref. 2) was derived for preliminary propeller selection studies. The propeller geometric parameters (diameter, number of blades, activity factor) and the operational parameters (SHP, RPM, Mach number) incorporated in this formula are those which experience has shown to have the most predominant effect on propeller weight and the exponents have been established empirically to best fit the weight trends of current general aviation propellers and those anticipated for the 1980 time period. The equation is presented on Table II.

The weight equation of Table II provides a useful tool for estimating propeller weight for any general aviation aircraft installation in this decade within ±10% accuracy. However, it must be remembered that parameters other than the basic geometric and performance characteristics used in this equation effect propeller weights. These are variations in propeller environmental temperatures, type of control system and the degree to which individual manufacturers design for minimum weight.

Propeller Cost Generalization

A cost equation (ref. 1) was generalized using end user price lists and weights obtained for representative industry propellers in the five general aviation aircraft categories shown in Table I. The equation is defined as follows:

\[ C = ZF (3B^{0.75} + E) \]
\[ C_1 = F (3B^{0.75} + E) \]

where:

- \( C \) - average original equipment manufacturer, O.E.M. propeller cost for a number of units/year, $/lb.
- \( C_1 \) - single unit O.E.M. propeller cost $/lb.
- \( Z \) - \( \frac{LF}{LF_1} \)
- \( LF \) - learning curve factor for a number of units/year
- \( LF_1 \) - learning curve factor for a single unit
- \( B \) - number of blades
F - single unit cost factor

E - empirical factor

For the computer program, an 89% slope learning curve was assumed. F and E factors were generated to evaluate costs of 1969 and the projected costs of 1980 time periods. The factors for propellers installed on each aircraft category are listed below.

<table>
<thead>
<tr>
<th>Category</th>
<th>1969</th>
<th>1980</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>F</td>
<td>E</td>
</tr>
<tr>
<td>I</td>
<td>3.5</td>
<td>1.0</td>
</tr>
<tr>
<td>II</td>
<td>3.7</td>
<td>1.5</td>
</tr>
<tr>
<td>III</td>
<td>3.2</td>
<td>3.5</td>
</tr>
<tr>
<td>IV</td>
<td>2.6</td>
<td>3.5</td>
</tr>
<tr>
<td>V</td>
<td>2.0</td>
<td>3.5</td>
</tr>
</tbody>
</table>

Computer Program

The performance generalization for conventional and multi-bladed propellers and the corresponding noise, weight and cost generalizations described in the previous text have been computerized. The computer program has been coded in FORTRAN IV and has been run on the IBM System/370. With this computer program, the aforementioned propeller performance characteristics can be readily calculated for a range of selected propeller geometries and desired operating conditions. Examples of parametric studies made with the computer program are presented in another section of the text.

There are four performance computation options available. First, if an engine is specified, then the operating condition is defined with the horsepower and the corresponding propeller thrust is computed. Second, if a propeller thrust requirement is defined then the thrust is included as input and the horsepower is computed, thus indicating engine size. Third, for operating conditions defined by horsepower or thrust, it is possible to define the tipspeed corresponding to 50% stall. This would be the tipspeed for minimum noise. Fourth, reverse pitch angle and the corresponding reverse thrusts for a range of landing ground roll velocities operating at the fixed reverse pitch angle are computed. The corresponding noise (PNdB), weight and cost for the first three options are calculated. The weight and cost are calculated for both the 1969 and 1980 time period where costs are based on the 89% slope learning curve and the unit costs and quantities selected by Hamilton Standard from available surveys. There are the options of varying learning curve, unit costs, and quantities.

The required inputs for all options of this computer program are the following:
Propeller

1. Diameter range
2. Number of blades range (2-8)
3. AF range (80-200)
4. $C_L$ range (0.3 - 0.8)

Operating conditions (maximum of 10) - For static and forward flight computation options, the following is required.

1. Shaft horsepower or thrust
2. Altitude, ft.
3. Velocity, knots
4. Temperature, °F
5. Tipspeed range

For the reverse flight computational option, the following is required.

1. Normal rated take-off horsepower, SHP
2. Normal rated take-off speed, rpm
3. Altitude, ft.
4. Touchdown speed, knots
5. Temperature, °F
6. Range of power settings, % of normal rated shaft horsepower
7. Type of engine, reciprocating or turbine

Other

1. Number of engines
2. Distance from the propeller center of the desired field point at which the noise is to be measured.
3. Airplane classification (Table I)
4. Flight design Mach number
5. Performance computation options
6. Cost computation options

The pertinent input-output instructions are discussed later in the text.
PARAMETRIC STUDY OPTIONS

Having developed a computer program incorporating the propeller performance, noise, weight and cost criteria, parametric studies can be undertaken to evaluate the trade-offs among these factors for propeller configurations applicable to general aviation aircraft.

The variety of parametric studies which can be performed with this computer program are illustrated in figures 6 through 9. A study for fixed pitch propellers associated with aircraft Category I is shown as figure 6. Curves of performance (T.O., climb and cruise), noise, weight and cost were plotted versus tipspeed for constant values of diameter for 2 bladed, 100 activity factor, 0.5 integrated design lift coefficient propellers for a specific engine application. The SHP was defined and the corresponding thrust was computed. Propeller blade angles as independent variables have been included in the performance curves. Thus, the blade angle providing the best performance compromise for take-off, climb and cruise can be selected as desired by the particular operator. Similar data can be plotted for a range of number of blades, activity factors and integrated design lift coefficients. From an inspection of such curves, the effects of the primary geometric and operating parameters can be evaluated and a propeller selected as the best compromise for the particular application. A similar study is shown for variable pitch propellers applicable to aircraft Category II for a 4 bladed, 150 activity factor, 0.5 integrated design lift coefficient propellers on figure 7. For this example, the thrust requirements were defined and the corresponding SHP's were computed. The minimum tipspeeds shown as end points for each of the curves in figures 6 and 7 represent the tipspeed corresponding to the 50% blade stall lines shown in figures 1 and 2.

An optimum low noise study based on the assumption that the propeller is always operating at the tipspeed corresponding to 50% stall at take-off and consequently minimum noise can be made as shown on figure 8. The study was made for a representative airplane in Category IV showing a variation in diameter and activity factor for a fixed number of blades and integrated design lift coefficient.

A reverse thrust study is shown on figure 9 for a propeller applicable for Category V. Reverse thrust angles were computed for several throttle settings. Then, reverse thrust, and the corresponding shaft horsepower and propeller rotational speeds were computed for the velocity range corresponding to ground roll. The corresponding runway landing distances can be computed and the reverse angle selected corresponding to the required runway distance.

COMPUTER PROGRAM USAGE INSTRUCTIONS

The flow chart, subroutine list, and FORTRAN IV listings for the computer program (Hamilton Standard deck H432) are included as APPENDIX A. The detailed description of input and output are presented in the following text.
Program Input

The input to the program is defined in the following text.

Cards 1 and 2 include the card number in column 3 and any legal Hollerith punched in columns 4 through 80.

Card 3 contains the following input data in an (I3, 3X, 10F6.0) format:

1. Card number
2. Number of engines
3. Airplane classification (Table I)
4. Flight design Mach number

Items 5 through 11 include the various cost options. Code all of these items as zero if the cost criteria built into the computer program is to be used. This criteria is defined in the section on cost generalization. If any deviations are required, the following additional information must be coded.

Learning curve variation. - It is based on assuming that a learning curve is a straight line when plotted on log paper. The learning curve is replaced as follows:

5. Learning curve factor for single unit
6. Learning curve factor for 1000 units

Unit cost factor, C1. - If a revision in unit cost is required, code as follows:

7. $C_1$ - single unit O.E.M. propeller cost, $/lb. for 1970
8. $C_1$ - single unit O.E.M. propeller cost, $/lb. for 1980

Quantities variations. - To investigate the effects of quantity changes on cost, code as follows:

9. Initial quantity to be used
10. Increment to quantity
11. Number of different quantities

Card 4 contains the following input data in an (I3, 3X, 9F6.0) format where:
1. Card number
2. Initial diameter
3. Increment in diameter if a range of diameters are to be computed
4. Number of diameters
5. Initial activity factor (80-200 AF)
6. Increment of activity factor if a range of AF is to be computed
7. Number of activity factors
8. Initial number of blades (2-8 blades)
9. Increment in number of blades, if a range of blades is to be computed
10. Number of number of blades

Card 5 contains the following input data in a (2I3, 5F6.0) format.

1. Card number
2. Number of operating conditions with a maximum of 10
3. Initial integrated design lift coefficient (0.3 to 0.8 $C_{L_i}$)
4. Increment of integrated design lift coefficient if a range of $C_{L_i}$ is to be computed
5. Number of $C_{L_i}$'s
6. For reverse thrust calculation option if blade angle $\beta_{3/4}$ radius is given, code 2. If $\beta_{3/4}$ radius is to be computed, code 1.
7. For reverse thrust calculation option, code 1. for turbine engines and 2. for reciprocating engines.

Subsequent cards are coded as follows with (3X, 1I3, 10F6.0) format for each operating condition. The number of these cards must be equal to the number specified in 2 on card 5.

1. Computational option
Code option = 1 - for defining condition with SHP

        option = 2 - for defining condition with thrust

        option = 3 - for reverse thrust calculation

2. Shaft horsepower or thrust per propeller depending on option selected in 1 above.

        option = 1 - SHP

        option = 2 - Thrust

        option = 3 - SHP for zero velocity, full throttle setting

3. Altitude in feet

For options 1 and 2, forward flight calculations, code

4. Velocity, knots true airspeed

5. Temperature, °F - code 0, for standard day

6. Initial tipspeed, $\frac{\pi ND}{60}$, fps

7. Increment of tipspeed

8. Number of tipspeeds

9. Distance of field point at which noise is to be computed. Directivity for peak noise is automatically used. The noise calculation should be made for take-off conditions only; code = 0, when no noise calculation is to be made.

10. Code = 1, for computing the tipspeed corresponding to 50% stall. The option should be used for take-off conditions only.

11. Code = 1, if cost and weight are to be computed. This option must be used with a take-off condition.

For option 3, reverse thrust calculation, code

4. Landing touch down speed, knots true airspeed

5. Temperature, °F
6. RPM for zero velocity, full throttle setting
7. First power setting
8. Increment of power setting
9. Number of power settings
10. Reverse angle, $\beta_{3/4}$ if item 6 on card 5 is coded as 2.

For subsequent cases, repeat all the input data previously specified. For termination, include two blank cards and a third card with 99 coded in an I6 format.

Program Output

The input prints out initially and then the pertinent data under the following headings for options 1 and 2 for forward flight:

1. **DIAM-FT** - propeller diameter, ft.
2. **T.S. FPS** - tipspeed, fps
3. **THRUST or SHP** - dependent on which option is selected
4. **PNL** - perceived noise in PNdB, value corresponds to the number of engines specified in the input.

The following cost and weight data prints out when computations are requested.

5. **QUANTITY** - number of units to be included in cost computation
7. **$COST** - propeller cost in dollars

The weight and cost are included for both 1970 and 1980 technology.

8. **ANGLE** - propeller blade angle in degrees at 3/4 radius which is of particular interest in analyzing fixed pitch propellers.

The following data is included as additional information. For example, from an examination of these parameters, an indication of the presence and magnitude of compressibility losses and the blade loading characteristics may be established.

9. **FT** - compressibility correction
10. $M$ - free stream Mach number

\[ M = \frac{101.4 \, V_K}{\text{ND}} \]

11. $J$ - advance ratio

\[ J = \frac{\text{SHP} \left( \frac{\rho_o}{\rho} \right) \times 10^{11}}{2 \, N^3 \, D^5} \]

12. $C_p$ - power coefficient

\[ C_p = \frac{1.514 \times 10^6 \, T(\rho_o/\rho)}{N^2 \, D^4} \]

13. $C_T$ - thrust coefficient

For option 3, reverse thrust calculation, the following data prints out.

1. **DIA. FT.** - propeller diameter, ft.

2. **PERCENT THROTTLE** - specifies what percent of normal rated power was used.

3. **REVERSE ANGLE** - reverse angle at 3/4 radius

4. **V-KNOTS** - landing run velocity

5. **REVERSE THRUST** - reverse thrust corresponding to 4 above

6. **SHP** - shaft horsepower corresponding to 4 above

7. **RPM** - propeller speed corresponding to 4 above

The input propeller and operating condition parameters for the parametric studies are varied as follows in the output print outs. For option 1 and 2, forward flight calculations, the calculations are made for the input ranges in the following order:

1. Tipspeed

2. Diameter

3. Number of blades

4. Integrated design lift coefficient

5. Activity factor

6. Operating condition

22
For the option where tipspeed for 50% stall is to be defined, the computations are made for the input ranges as follows:

1. Diameter
2. Number of blades
3. Activity factor
4. Integrated design lift coefficient
5. Operating condition

For option 3, reverse thrust calculation, the calculations are made for the input ranges in the following order.

1. Throttle setting
2. Diameter
3. Number of blades
4. Activity factor
5. Integrated design lift coefficient
6. Operating condition

MESSAGES

A series of messages print out which indicate that the limits of the generalizations have been exceeded. These are listed below.

1. 'INPUT ERROR IW = I2, IC = I2' - the input item specifying which option is to be used has been included as other than 1., 2. or 3., the only option values.

2. 'ILLEGAL ACTIVITY FACTOR = F8.1' - the input AF exceeds the permissible 80-200 AF range.

3. 'ILLEGAL NUMBER OF BLADES = F8.1' - the input number of blades exceeds the permissible 2-8 blades.

4. 'ILLEGAL INTEGRATED DES. CL = F8.1' - the input $C_{Li}$ exceeds the permissible range of 0.3 to 0.8 $C_{Li}$.
5. 'ADVANCE RATIO TOO HIGH' - check to see that input diameter, RPM, and velocity are correct. The advance ratio limits are 0 to 5.

6. 'FAILED STALL ITERATION' - problem encountered in defining tipspeed corresponding to 50% stall. If this message is encountered, check input for SHP, RPM, altitude, velocity, and diameter.

7. ******* - print out under PNL indicates that the propeller is operating at a condition where it is more than 50% stalled.

8. ******* - printout under SHP or THRUST indicates that this condition is off the limits of the performance curves.

Sample Cases

Input coding sample cases for the four performance computation options are shown on figure 10 and the output presented as figures 11 through 14 respectively. The sample cases are presented in the following order.

1. The condition is defined by SHP and tipspeed variation. Performance and cost calculations based on the information included in the computer program is requested.

2. The condition is defined by a thrust requirement and tipspeed variation. Only performance calculations are requested.

3. The condition is defined by SHP. Tipspeed corresponding to 50% stall and cost for a span of quantities will be computed.

4. Reverse thrusts are required for a given propeller geometry for a range of throttle settings.

Computer Running Time

The computer program has been run on an IBM-System/370. Approximately 1000 operating conditions are computed per minute.
CONCLUDING REMARKS

1. Generalizations of analytical methods for accurately predicting propeller performance, noise, weight and cost for general aviation aircraft application have been made.

2. The generalizations have been computerized in FORTRAN IV for the IBM System/370.

3. The computer program offers many options for performing parametric propeller studies for general aviation aircraft.

4. Computer program listings and detailed input and output instructions are presented.
REFERENCES


# TABLE I
ADVANCED GENERAL AVIATION PROPELLER STUDY

## AIRCRAFT CLASSIFICATION

<table>
<thead>
<tr>
<th>Aircraft Class</th>
<th>Seats</th>
<th>Cruise Vel., MPH</th>
<th>Engine Power</th>
<th>Propeller Type</th>
<th>Application</th>
<th>Gross Weight, lbs.</th>
<th>Price Range</th>
<th>Example Aircraft</th>
</tr>
</thead>
<tbody>
<tr>
<td>III. Light Twins Retract Gear IFR Equip.</td>
<td>4-6</td>
<td>150-300</td>
<td>150-300</td>
<td>2 Blades</td>
<td>Private (Family), Survey, Business</td>
<td>3500-6000</td>
<td>$40-120K</td>
<td>CESSNA Super Skymaster, 310Q BEECH Turboprop, Barren 55 PIPER Twin Comanche C, Astec D MOONEY Aerostar</td>
</tr>
<tr>
<td>IV. Medium Twins Retract Gear IFR Equip.</td>
<td>6-11</td>
<td>150-300</td>
<td>250-450</td>
<td>Constant Speed</td>
<td>Executive Charter, Air Taxi</td>
<td>6000-8000</td>
<td>$100-200K</td>
<td>CESSNA 401B, 602B, 610, 621 BEECH Queen Air Duke PIPER Navajo 300, Turbo Navajo NORTH AMERICAN ROCKWELL Shrike Commander BRITISH-NORWICH ISLANDER, Helico Twin Stallion</td>
</tr>
<tr>
<td>V. Heavy Twins Retract Gear IFR Equip.</td>
<td>11 &amp; Up</td>
<td>175-400</td>
<td>600-1500</td>
<td>Constant Speed</td>
<td>Large Executive Charter, Third Tier Air Liners</td>
<td>8000-12,500</td>
<td>$400-600K</td>
<td>DESHAVILLAND Twin Otter MOONEY MD-20 NORTH AMERICAN ROCKWELL Hawk Commander BEECH King Air HANDLEY PAGE Jetstream</td>
</tr>
</tbody>
</table>
**Generalized Propeller Weight Equation:**

\[ W_T = K_W \left[ \frac{D}{10} \right]^2 \left( \frac{B}{4} \right)^{0.7} \left( \frac{A.F.}{100} \right)^u \left( \frac{N}{20,000} \right)^v \left( \frac{SHP}{100^2} \right)^{0.12} (M + 1)^{-0.5} \] + C_W

Where:

- \( W_T \): Prop. Wet Weight, lbs. (excludes spinner, deicing & governor)
- \( D \): Prop. Dia., Ft.
- \( B \): No. of Blades
- \( A.F. \): Blade Activity Factor
- \( N \): Prop. Speed, RPM (take-off)
- \( SHP \): Shaft Horsepower, HP (take-off)
- \( M \): Mach No. (Design Condition: Max Power Cruise)
- \( C_W \): Counterweight Wt., lbs.

\( K_W, C_W, u, v \) and \( y \) values for use in the weight equation are taken from the table below:

<table>
<thead>
<tr>
<th>Aircraft Class</th>
<th>Technology</th>
<th>1970</th>
<th>1980</th>
<th>( K_W )</th>
<th>( u )</th>
<th>( v )</th>
<th>( y )</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>(1)</td>
<td>(1)</td>
<td></td>
<td>170</td>
<td>0.9</td>
<td>0.35</td>
<td>0</td>
</tr>
<tr>
<td>II</td>
<td>(2)</td>
<td>(2)</td>
<td></td>
<td>200</td>
<td>0.9</td>
<td>0.35</td>
<td>0</td>
</tr>
<tr>
<td>III</td>
<td>(3)</td>
<td>(3)</td>
<td></td>
<td>220</td>
<td>0.7</td>
<td>0.40</td>
<td>5.0</td>
</tr>
<tr>
<td>IV</td>
<td>(3)</td>
<td>(4)</td>
<td></td>
<td>190</td>
<td>0.7</td>
<td>0.40</td>
<td>3.5</td>
</tr>
<tr>
<td>V</td>
<td>(3)</td>
<td>(5)</td>
<td></td>
<td>190</td>
<td>0.7</td>
<td>0.30</td>
<td>0</td>
</tr>
</tbody>
</table>

Propeller types associated with above \( K_W \) and \( C_W \) are as follows:

1. All fixed-pitch props
2. Mc Cauley non-counterweighted, non-feathering, constant speed props
3. All Hartzell, all Hamilton Standard small props, and feathering Mc Cauley
4. Fiberglass-bladed, constant speed, counterweighted, full feathered
5. Fiberglass-bladed, constant-speed, double-acting (non-counterweighted), full feathered, reverse
**FIGURE 1.** POWER COEFFICIENT CHART FOR A 2 BLADED, 150 ACTIVITY FACTOR, 0.500 INTEGRATED DESIGN $C_L$; PROPELLER
$J = \frac{10 \pi V_K}{N D}$

$C_T = 1.514 \times 10^6 \frac{T(\rho_1/\rho)}{N^2 D^4}$

$C_{TE} = C_T \times T_{AF} \times T_{CL_i}$

**WHERE**

$V_K$ - KNOTS TRUE AIRSPEED

$N$ - PROPELLER RPM

$D$ - PROPELLER DIAMETER - FT

$T$ - PROPELLER THRUST - POUNDS

$\rho_1/\rho$ - DENSITY RATIO

$T_{AF}$ - ACTIVITY FACTOR ADJUSTMENT

$T_{CL_i}$ - INTEGRATED DESIGN CL$_i$ PROPELLER

**FIGURE 2. THRUST COEFFICIENT CHART FOR A 2 BLADED, 150 ACTIVITY FACTOR, 0.500 INTEGRATED DESIGN CL$_i$ PROPELLER**
FIGURE 3. BASIC PERFORMANCE CURVE VARIATION OF EFFECTIVE TORQUE COEFFICIENT WITH ADVANCE RATIO & BLADE ANGLE
FIGURE 4. BASIC PERFORMANCE CURVE VARIATION OF EFFECTIVE THRUST COEFFICIENT WITH ADVANCE RATIO & BLADE ANGLE
FIGURE 5. BASIC NOISE CURVE
2 BLADES - 1 OQAF - 0.5 $C_{L_i}$

MAXIMUM CRUISE
112 SHP - 7000 - 115 KNOTS

CLIMB 150 SHP - SL - 70.5 KNOTS

T.O. 150 SHP - S.L. - 52.5 KNOTS

FIGURE 6. CATEGORY I PARAMETRIC STUDY
4 BLADES – 150 AF – 0.5 $C_{L_1}$

MINIMUM CRUISE
370# THRUST – 7500 – 163.2 KNOTS

CLIMB 700 THRUST – S.L. – 95.5 KNOTS

T.O. 820 THRUST – S.L. – 71.2 KNOTS

FIGURE 7. CATEGORY II PARAMETRIC STUDY
FIGURE 8. CATEGORY IV PARAMETRIC STUDY

4 BLADES – 0.6 $C_L_i$

[Graphs showing noise, cost, stall speed, and takeoff weight as a function of diameter for different conditions.]
FIGURE 9. EXAMPLE REVERSE THRUST VARIATION WITH LANDING SPEED AND POWER SETTING
### SAMPLE CASE #1

<table>
<thead>
<tr>
<th>Airplane in Category I</th>
<th>Sample Case 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>1.87</td>
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<td>4</td>
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<td>5</td>
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<tr>
<td>6</td>
<td>150</td>
</tr>
<tr>
<td>7</td>
<td>115</td>
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### SAMPLE CASE #2

<table>
<thead>
<tr>
<th>Airplane in Category II</th>
<th>Sample Case 2</th>
</tr>
</thead>
<tbody>
<tr>
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</tr>
<tr>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>1.2</td>
</tr>
<tr>
<td>4</td>
<td>150</td>
</tr>
<tr>
<td>5</td>
<td>71.2</td>
</tr>
</tbody>
</table>

---

**Figure 10. Sample Input Coding**

### UAC Coding Form #3

**Job No.:** ACCT. NO: W.O. NO:  
**Title:** GENERAL AVIATION PROPELLER STUDY  
**Analyst:** SHEET 2 OF 2  
**Engineer:** ROSE WOOLGEL  
**Mail Address:** AERODYNAMICS  
**Extension:** 306

---

#### Sample Case #3

<table>
<thead>
<tr>
<th>1</th>
<th>AIRPLANE IN CATEGORY IV</th>
<th>SAMPLE CASE 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>SHP INPUT - CALC. TSPEED FOR SUPERCEST SALL - COST FOR RANGE QUAI.</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>2.  4.  .327  .0  .0  .0  1.  1000.  5.</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>8.  0.  1.  200.  0.  1.  4.  2.  2.</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>1.6  .0  1.</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>1340.  0.  77.5  0.</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>500.  1.  1.</td>
<td></td>
</tr>
</tbody>
</table>

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#### Sample Case #4

<table>
<thead>
<tr>
<th>1</th>
<th>AIRPLANE IN CATEGORY IV</th>
<th>SAMPLE CASE 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>REVERSE THRUST OPTION</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>2.  5.  .271</td>
<td></td>
</tr>
<tr>
<td>4</td>
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<td></td>
</tr>
<tr>
<td>5</td>
<td>1.509  .0  1.  2.</td>
<td></td>
</tr>
<tr>
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<td>3552.  0.  72.  0.  200.  100. -20.  3.</td>
<td></td>
</tr>
</tbody>
</table>

---

**Figure 10 (Continued). Sample Input Coding**
### Sample Case 1

**Operating Condition**

- **SHP =** 157
- **No. of Engines =** 1
- **Unit Factor L/C. =** 3.27
- **V-KTAS =** 57.5
- **Classification =** 1
- **Temp =** 510
- **Field Point Ft. =** 500

**Diameter Variation - Cost and Weight**

| Dia. Ft. | T.S.F.P.S. Thrust | PNL | Quantity | WT. lbs | $Cost | Quantity | WT. lbs | $Cost | Angle | Ft. | M | J | CP | CT |
|----------|------------------|-----|----------|---------|-------|----------|---------|-------|-------|-----|---|---|---|----|----|
| 3.26     | 543              | 101 | 1910     | 36      | 215   | 2230     | 36      | 210   | 13.3  | 1000 | 0.0794 | 0.293 | 0.0349 | 0.0694 |
| 3.50     | 540              | 97  | 1910     | 34      | 207   | 2230     | 34      | 202   | 16.5  | 1000 | 0.0794 | 0.328 | 0.0487 | 0.0863 |
| 3.75     | 516              | 92  | 1910     | 33      | 198   | 2230     | 33      | 193   | 20.4  | 1000 | 0.0794 | 0.372 | 0.0709 | 0.1055 |
| 4.00     | 500              | 97  | 1910     | 31      | 188   | 2230     | 31      | 184   | 25.8  | 1000 | 0.0794 | 0.429 | 0.1089 | 0.1283 |
| 4.50     | 477              | 97  | 1910     | 29      | 178   | 2230     | 29      | 173   | 33.8  | 1000 | 0.0794 | 0.507 | 0.1798 | 0.1440 |
| 4.75     | 474              | 97  | 1910     | 59      | 357   | 2230     | 59      | 348   | 8.8   | 1000 | 0.0794 | 0.292 | 0.1956 | 0.0377 |
| 5.00     | 483              | 97  | 1910     | 57      | 343   | 2230     | 57      | 335   | 11.5  | 1000 | 0.0794 | 0.328 | 0.0274 | 0.0524 |
| 5.50     | 516              | 92  | 1910     | 55      | 309   | 2230     | 55      | 300   | 15.0  | 1000 | 0.0794 | 0.372 | 0.0399 | 0.0713 |

**Sample Output**

#### FIGURE 11. SAMPLE OUTPUT — SHP OPTION
### Operating Condition
- **THRUST** = 820
- **ALT-FT** = 0
- **V-KTAS** = 71.2
- **TEMP R** = 519

**Number of Blades** = 4
- **Activity Factor** = 150

### Integrated Design CL = 0.500

<table>
<thead>
<tr>
<th>DIA.FT</th>
<th>T.S.FPS</th>
<th>SHP</th>
<th>DNL</th>
<th>QUANTITY</th>
<th>WT-LBS</th>
<th>$COST</th>
<th>1970 TECHNOLOGY</th>
<th>1990 TECHNOLOGY</th>
<th>ANGLE</th>
<th>FT</th>
<th>M</th>
<th>J</th>
<th>CP</th>
<th>CT</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.00</td>
<td>840.</td>
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<td>0.</td>
<td>21.5</td>
<td>1.000</td>
<td>0.2534</td>
<td>1.019</td>
<td>0.0919</td>
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<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>6.00</td>
<td>790.</td>
<td>218.</td>
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<td>21.5</td>
<td>1.000</td>
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<tr>
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<td>209.</td>
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<td>31.5</td>
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<td>0.2534</td>
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<td>0.</td>
<td>31.5</td>
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<tr>
<td>6.00</td>
<td>550.</td>
<td>212.</td>
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<td>31.5</td>
<td>1.000</td>
<td>0.2534</td>
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<td>0.1264</td>
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<td>660.</td>
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<td>31.5</td>
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<td>1.333</td>
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<td>21.5</td>
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<td>0.0739</td>
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</tr>
</tbody>
</table>

### Operating Condition
- **THRUST** = 370
- **ALT-FT** = 750
- **V-KTAS** = 153.2
- **TEMP R** = 492

**Number of Blades** = 4
- **Activity Factor** = 150

**Integrated Design CL** = 0.500

---

**FIGURE 12. SAMPLE OUTPUT — THRUST OPTION**
HAMILTON STANDARD COMPUTER DECK NO. H432
COMPUTES PERFORMANCE, NOISE, WEIGHT, AND COST FOR
GENERAL AVIATION PROPELLERS

1 AIRPLANE IN CATEGORY IV
SAMPLE CASE 3

2 SHP INPUT-CALC. TIIPSPEED FOR 50 PERCENT STALL-COST FOR RANGE QUANT.

OPERATING CONDITION

<table>
<thead>
<tr>
<th>SHP</th>
<th>NO. OF ENGINES</th>
<th>UNIT FACTOR L.C.</th>
</tr>
</thead>
<tbody>
<tr>
<td>340</td>
<td>2</td>
<td>3.22</td>
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</table>

<table>
<thead>
<tr>
<th>ALT-FT</th>
<th>DESIGN FLIGHT M.</th>
<th>1000 FACTOR L.C.</th>
</tr>
</thead>
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<td>0</td>
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<td>1.02</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>V-KTAS</th>
<th>CLASSIFICATION</th>
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</thead>
<tbody>
<tr>
<td>77.5</td>
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</table>

<table>
<thead>
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<th>FIELD POINT FT.</th>
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<td>519</td>
<td>500</td>
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</table>

<table>
<thead>
<tr>
<th>NO. OF BLADES</th>
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<tbody>
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### 1970 TECHNOLOGY

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<th>$COST</th>
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### 1980 TECHNOLOGY

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FIGURE 13. SAMPLE OPTION - 50% STALL OPTION
### Hamiltion Standard Computer Deck No. H439

Computes performance, noise, weight, and cost for general aviation propellers

1. **Airplane in Category IV**
2. **Reverse Thrust Option**

#### Reverse Thrust Computation

**Reciprocating Engine**

- **Full Throttle SHP** = 550
- **Full Throttle RPM** = 2200
- **Touch Down V-Knots** = 72
- **Altitude Feet** = 0
- **Temperature Ranking** = 419

**Number of Blades** = 3, **Activity Factor** = 1.0, **Integrated Design CL** = 9.0

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<th>Reverse</th>
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**Figure 14. Sample Output - Reverse Thrust Option**
APPENDIX A

FLOW CHART, SUBROUTINE LIST AND FORTRAN IV LISTING FOR
HAMILTON STANDARD DECK H432

Hamilton Standard computer deck H432 computes propeller performance (static, flight, and reverse), noise, weight and cost for a broad spectrum of propeller geometric configurations over the complete range of potential operating conditions.

The flow chart is presented on figure 1A, the list of subroutines on figure 2A, and the FORTRAN IV listing on figure 3A.
INPUT DATA FOR ONE CASE

SETUP DIAMETER
ACTIVITY FACTOR
NUMBER OF BLADES
TIPSPEED
CONDITIONS

TYPE
(102)

SHP

OPTION
(101)

REVERSE THRUST

(DETERMINE TIPSPEED AT WHICH BLADE WILL BE 50% STALLED)

CALCULATES THRUST FOR GIVEN SHP

CALCULATES SHP FOR GIVEN THRUST

CALCULATES REVERSE ANGLE AND REVERSE THRUST

IS NOISE REQ'D?

CALCULATES NOISE

ARE WEIGHT & COST REQ'D?

YES

CALCULATES WEIGHT

NO

CALCULATES COST

(WAIT)

PRINT RESULTS

HAVE ALL CONDITIONS FOR THIS CASE BEEN COMPUTED?

YES

NO

FIGURE 1A COMPUTER PROGRAM FLOW CHART
HAMILTON STANDARD DECK H432

Computer Program for Advanced General Aviation
Propeller Studies

MAIN
INPUT
PERFM
ZNOISE
WAIT
COST
REVTHT
UNINT
BIQUAD

Figure 2A  LIST OF SUBROUTINES
REAL*8 BLANK
COMMON/AFCOR/AFCPE,AFCTE,XFT
COMMON/ASTRK/CPAST,CAST,ASTERK
COMMON/CPECTE/CE,CTE,BLLL
DIMENSION FC(10),ALTPR(11),PRESSR(11),RORDT(10),ZMS(2)
DIMENSION DI(10,CQUNAI(11),COSTO(10),COST810)
DIMENSION BHPG(10),THRGST(10),TIPS(11)
COMMON/ZINPUT/ BHPG(10),THRSTG(10),TIPS(11)
DATA ALTPR/0,10000,20000,30000,40000,50000,60000,70000,80000,90000,100000/
DATA PRESSR/0,6877,4595,2970,1851,1145,07078/
X60000,70000,80000,90000,100000/ X
DATA BLANK/6H /
REAL*8 BLANK
COnHOH/AFCOR/AFCPE,AFCTE,XFT
COMHON/ASTRK/CPAST,CAST,ASTERK
COMHON/CPECTE/CE,CTE,BLLL
DIMENSION FC(10),ALTPR(11),PRESSR(11),RORDT(10),ZMS(2)
DIMENSION DI(10,CQUNAI(11),COSTO(10),COST810)
DIMENSION BHPG(10),THRGST(10),TIPS(11)
COMMON/ZINPUT/ BHPG(10),THRSTG(10),TIPS(11)
DATA ALTPR/0,10000,20000,30000,40000,50000,60000,70000,80000,90000,100000/
DATA PRESSR/0,6877,4595,2970,1851,1145,07078/
X60000,70000,80000,90000,100000/ X
DATA BLANK/6H /
FORTRAN IV G LEVEL 20.1 MAIN DATE = 72034 10/08/04

0046 200 IENT=1
0047 CALL COST (WTCON, BLADT, CLF1, CLF, CK70, CK80, CAMT, DAMT, NAMT, CQUAN(N1, 1)
0048 1, WTWT, WT80, COST70, COST80, CCLF1, CCLF, CK70, CK80, IENT)
0049 GO TO (210, 230), I1W
0050 210 WRITE (6, 220) BHP(IC), XNOE, CCLFL
0051 220 FORMAT(* SHP = *, F7.0, 9X, NO. OF ENGINES = *, F5.0, 9X, UNIT FACTOR
0052 * L.C. = *, F5.2)
0053 GO TO 250
0054 240 FORMAT(* THRUST = *, F7.0, 9X, NO. OF ENGINES = *, F5.0, 9X, UNIT FACTOR
0055 * L.C. = *, F5.2)
0056 250 WRITE (6, 240) THRUST(IC), XNOE, CCLFL
0057 252 FORMAT(* ALT-FT = *, F7.0, 9X, DESIGN FLIGHT M. = *, F5.3, 9X, 1000 FACTO
0058 * 1R L.C. = *, F5.2/ V-KTAS = *, F7.0, 9X, *CLASSIFICATION = *, F5.0/ TE
0059 * 2MP R = *, F7.0, 9X, * FIELD POINT FT. = *, F5.0)
0060 GO TO 270
0061 260 WRITE (6, 260) ALT(IC), ZMWT, CCLF, VKTAS(IC), WTCON, T(IC), DIST(IC)
0062 262 FORMAT(* ALT-FT = *, F7.0, 9X, * DESIGN FLIGHT M. = *, F5.3, 9X, 1000 FACTO
0063 * 1R L.C. = *, F5.2/ V-KTAS = *, F7.0, 9X, *CLASSIFICATION = *, F5.0/ TE
0064 * 2UNIT COST 1970 = *, F5.1/ TEMP R = *, F7.0, 9X, * FIELD POINT FT. = *
0065 * 3, F5.0, 9X, UNIT COST 1980 = *, F5.1)
0066 GO TO 270
0067 270 WRITE (6, 270) BHP(1C), RPMG(1C), ANDVK(1C)
0068 270 FORMAT(* FULL THROTTLE SHP = *, F6.0/22X, FULL THROTTLE RPM = *
0069 * 1F6.0, 22X*, TOUCH DOWN V-KNOTS = *, F6.0/22X, ALTITUDE FEET = *
0070 * 2F6.0/22X, TEMPERATURE RANKINE = *, F6.0/) 270
0071 DO 1200 IAF=1, NAF
0072 IF (AF1.E.200., AND. AFT.GE.80.) GO TO 182
0073 WRITE (6, 1200) IAF
0074 1200 FORMAT(* TURBINE ENGINE//)
0075 GO TO 2400
0076 2300 WRITE(6, 2350)
0077 2350 FORMAT(* TURBINE ENGINE//)
0078 2400 WRITE (6, 2400) BHP(IC), RPMG(IC), ANDVK(IC)
0079 2500 FORMAT(* FULL THROTTLE SHP = *, F6.0/22X, FULL THROTTLE RPM = *
0080 * 1F6.0, 22X*, TOUCH DOWN V-KNOTS = *, F6.0/22X, ALTITUDE FEET = *
0081 * 2F6.0/22X, TEMPERATURE RANKINE = *, F6.0/) 270
0082 270 DO 1200 IAF=1, NAF
0083 AFT=AFT+DAF
0084 IF(AFT.LE.100..AND. AFT.GE.99.) GO TO 182
0085 WRITE(6, 181) AFT
0086 181 FORMAT(* ILLEGAL ACTIVITY FACTOR = *, F8.1)
0087 GO TO 1200
0088 182 CONTINUE
0089 C INTEGRATED DESIGN CL LOOP
0090 NCLI=2NCLI+1
0091 CLI=CLL(D-0CLI
0092 DO 1001 ICL=1, NCLI

FIGURE 3A. FORTRAN IV LISTING (CONTINUED)
CL1 = CLI + DCLI

IF (CLI .LE. .80001. AND. CLI .GE. .29999) GO TO 875

WRITE (6, 870) CLI

870 FORMAT (' ILLEGAL INTEGRATED DESIGN CL = ', F5.3)

GO TO 1001

875 CONTINUE

C NO. OF BLADES LOOP

BLADT = BLADN - DBLA0

DO 1000 IB = 1, NBL

BLADT = BLADT + DRLAD

IF (BLAOT .LE. .AND. BLADT .GE. 2.) GO TO 888

WRITE (6, 887) BLADT

887 FORMAT (' ILLEGAL NO. OF BLADES = ', F8.1)

GO TO 1000

1000 CONTINUE

C PRINT APPROPRIATE HEADING

IF (IW .LT. 3) GO TO 2700

WRITE (6, 2650) BLADT, AFT, CLI

2650 FORMAT (' NUMBER OF BLADES = ', F3.0, ' ACTIVITY FACTOR = ', F4.0, ' INTEGRATED DESIGN CL = ', F4.3)

WRITE (6, 2660)

2660 FORMAT (' THROTTLE REVERSE', F8.1, ' REVERSE', F5.1, ' DIAMETER SETTING A SINGLE V-KNOTS THRUST SHP RPM')

GO TO 30

2700 WRITE (6, 20) BLADT, AFT, CLI

20 FORMAT (' NUMBER OF BLADES = ', F3.0, ' ACTIVITY FACTOR = ', F4.0, ' INTEGRATED DESIGN CL = ', F4.3)

GO TO 1001

21 WRITE (6, 22)

22 FORMAT (' DIA. FT. T.S.FPS THRUST SHP NALG FT M J CP CT')

GO TO 30

24 WRITE (6, 25)

25 FORMAT (' DIA. FT. T.S.FPS SHP NALG FT M J CP CT')

GO TO 30

500 GO TO (510, 550), IW

510 WRITE (6, 520)

520 FORMAT (' 1970 TECHNOLOGY *** 1980 TECHNOLOGY ***

1 DIA. FT. T.S.FPS THRUST SHP QUANTITY WT-LBS $COST QUANTITY

2 WT-LBS $COST ANGLE FT M J CP CT')

GO TO 30

550 WRITE (6, 560)

560 FORMAT (' 1970 TECHNOLOGY *** 1980 TECHNOLOGY XXX'

1 DIA. FT. T.S.FPS SHP QUANTITY WT-LBS $COST QUANTITY

2 WT-LBS $COST ANGLE FT M J CP CT')

GO TO 30

30 CONTINUE

ILINE = ILINE + 6

C DIAMETER LOOP

DIA = D - DD

DO 800 ID = 1, ND

800 DIAD = D - DD

IF (IW .EQ. 3) GO TO 3000

C TIP SPEED LOOP

IF (ISTAETIC) .LE. 50) GO TO 310

033 DTS(IIC) = 0.

034 TRIG = 0.

FIGURE 3A. FORTRAN IV LISTING (CONTINUED)
C MACH NUMBER CALCULATION AND ADVANCE RATIO J

C ITERATION ON CT OR CP TO GET 50 PERCENT STALL TIPSPEED

C END OF TIPSPD ITERATION 50 PERCENT STALL
C CALCULATION OF REQUIRED CP OR CT

0135                NTS=10
0136                TIPSDG(1)=700.
0137                TIPSPD=700.
0138                GO TO 320.
0139 310 TIPSPD=TS((IC)-DTS(IC))
0140                NTS=NNTS(IC)
0141 320 DO 600 ITS=1,NTS
0142                TIPSPD=TIPSPD+DTS(IC)
0143                NTS=NDTS
0144 600 CONTINUE

C

C Figure 3A, FORTRAN IV Listing (Continued)
0186 400 CP=BHP(IC)*10.E10*RORD(IC)/(2.0*TIPSPD**2*DIA**2*6966.)
0187 CALL PSEFM (IC,CP,ZJI,AFT,BLADT,CLI,CT,ZMS,LIMIT)
0188 420 THRUST(1)=CT*TIPSPD**2*DIA**2/(1.515E06*RORD(1))**364.76*XFT
0189 IF (CT.EQ.ASTERK) THRUST(1)=999999999.
0190 GO TO 460
0191 430 CT=THRUST(1)*1.515E06*RORD(1)/TIPSPD**2*DIA**2*364.76
0192 CALL PSEFM (Z,CP,ZJI,AFT,BLADT,CLI,CT,ZMS,LIMIT)
0193 450 BHP(1)=CP*2.0*TIPSPD**2*DIA**2/1.515E06*RORD(1)**364.76*XFT
0194 IF (CP.EQ.ASTERK) BHP(1)=999999999.
0195 460 IF (CP.NE.ASTERK) GO TO 720
0196 PNL=999999999.
0197 W70=999999
0198 W80=999999
0199 CT70(1)=999999
0200 CT80(1)=999999
0201 GO TO 730
0202 720 PNL=0.0
0203 ISTALL=0
0204 IF (DIST(1).LE.0.) GO TO 461
0205 CALL ZNOISE (BLADT,DIA,TIPSPD,VKTAS(1),BHP(1),DIST(1),PNL,
1F(C(1)),XNOE)
0206 CPA=CP
0207 CTA=CT
0208 BLLL=BLLL
0209 XFT=XFT
0210 IWSV=IW
0211 IW=3
0212 CALL PSEFM (3,CP,ZJI,AFT,BLADT,CLI,CT,ZMS,7710)
0213 CPS=CP
0214 CP=CPA
0215 CT=CTA
0216 BLLL=BLLL
0217 XFT=XFT
0218 IW=IWSV
0219 IF (CP.GT.CPS) PNL=999999999.
0220 CONTINUE
0221 461 CONTINUE
0222 W70=999999
0223 W80=999999
0224 CT70(1)=999999
0225 IF (NCOST.EQ.1) 730,725,720
0226 725 IF (NOST.EQ.1) CALL WAIT(WTCON,ZMWT,BHP(1),DIA,AFT,BLADT,TIPSPD,
1WT70,WT80)
0227 IENT=2
0228 CALL COST (WTCON,BLADT,CLF1,CLF,CK70,CK80,CMAT,DMAT,NA1,CQ1N(1,1),
1WT70,WT80,COST70,COST80,CCLR,CLCLR,CK70,CK80,IENT)
0229 GO TO (570,580),IW
0230 570 WRITE (6,575)DIA,TIPSPD,THREUT(1),PNL,CQ1N(1,1),WT70,COST70(1),
1CQ1N(2,1),WT80,COST80(1),BLLL,XFT,ZM1,ZJI,CP,CT
0231 575 FORMAT (2F7.0,F9.0,F6.0,2F8.0,F9.0,2F8.0,F9.0,F9.1,F6.3,F7.4,F8.3,
12F8.4)
0232 GO TO 585
0233 580 WRITE (6,575)DIA,TIPSPD,BHP(1),PNL,CQ1N(1,1),WT70,COST70(1),
1CQ1N(2,1),WT80,COST80(1),BLLL,XFT,ZM1,ZJI,CP,CT
0234 585 IF (NAMT.EQ.1) 40,40,586
0235 586 DO 588 I=2,NAMT
0236 WRITE (6,587)CQ1N(1,1),WT70,COST70(1),CQ1N(2,1),WT80,COST80(1)
0237 587 FORMAT (29X,2F8.0,F9.0,2F8.0,F9.0)

FIGURE 3A. FORTRAN IV LISTING (CONTINUED)
0238   588 CONTINUE
0239   GO TO 40
0240   730 GO TO (31,34),1W
0241   31 WRITE(6,32) DIA,TIPSPD,THRUST(IC),PNL,BLLLL,XFT,ZM1,ZJI,CP,CT
0242   32 FORMAT(F7.2,F7.0,F9.0,F6.1,F8.3,F7.4,F8.3,2F8.4)
0243   GO TO 40
0244   34 WRITE(6,32) DIA,TIPSPD,BHP(IC),PNL,BLLLL,XFT,ZM1,ZJI,CP,CT
0245   40 IF(ISTALL.EQ.2) GO TO 750
0246   IF(IFIN.EQ.7710) GO TO 800
0247   600 CONTINUE
0248   IF (IW.LT.3) GO TO 750
0249   IF (TRIG,EQ.1.) GO TO 750
0250   3000 IRT=NPCPW(IC)
0251     PCPWC=PCPW(IC)
0252     DO 3900 I=1,IRT
0253     IF (RTC-1.) 3200,3100,3200
0254     3100 CP=BHP(IC)*PCPWC*ROD(IC)*10.E10/(2.0*RPMC(IC)**3*DIAX**5*100.)
0255     3200 CALL REVHTHT (RTC,ROT,AFT,CLT,BLADT,DIA,CP,BETA(IC),ROD(IC),
0256       1BHP(IC),RPMC(IC),PCPWC,ANDVK(IC))
0257     PCPWC=PCPWC+DPFW(IC)
0258   3900 CONTINUE
0259   750 CONTINUE
0259   800 CONTINUE
0260   1000 CONTINUE
0261   1001 CONTINUE
0262   1200 CONTINUE
0263   700 CONTINUE
0264   GO TO 701
0265   END

FIGURE 3A. FORTRAN IV LISTING (CONTINUED)
FIGURE 3A. FORTRAN IV LISTING (CONTINUED)
**FIGURE 3A. FORTRAN IV LISTING (CONTINUED)**
FIGURE 3A. FORTRAN IV LISTING (CONTINUED)
<table>
<thead>
<tr>
<th>FORTRAN IV G LEVEL</th>
<th>PERFM</th>
<th>DATE = 72034</th>
</tr>
</thead>
<tbody>
<tr>
<td>20.1</td>
<td></td>
<td>10/08/04</td>
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```
X
X.*4891.,5549.,6043.,6415/*
DATA DUM4 /
X 4*0.,
X
X.*3831.,4508.,5035.,5392/,
C
X 4*0.,
X
X.*5655.,6536.,2*0.,
X
X.*6410.,7032.,2*0.,
X
X.*7308.,3*0.,
X
X.*5899.,6722.,7302.,7761/,
X
```

<table>
<thead>
<tr>
<th>0027</th>
</tr>
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<tbody>
<tr>
<td>DATA DUM4 /</td>
</tr>
<tr>
<td>X 4*0.,</td>
</tr>
<tr>
<td>X.*3831.,4508.,5035.,5392/,</td>
</tr>
<tr>
<td>C X 4*0.,</td>
</tr>
<tr>
<td>X.<em>5655.,6536.,2</em>0.,</td>
</tr>
<tr>
<td>X.<em>6410.,7032.,2</em>0.,</td>
</tr>
<tr>
<td>X.<em>7308.,3</em>0.,</td>
</tr>
<tr>
<td>X.*5899.,6722.,7302.,7761/,</td>
</tr>
</tbody>
</table>

``` FORTRAN IV LISTING (CONTINUED) ```
FIGURE 3A. FORTRAN IV LISTING (CONTINUED)
LOO

101 DO 300 K=NBEG,NEND
102 208 DO TO (210,250,212),IW
103 212 CALL UNINT (9,ZJSTAL,CTSTAL(1,L),ZJJ(K),CTT(K),LIMIT)
104 CALL UNINT (9,ZJSTAL,CPSTAL(1,L),ZJJ(K),CPP(K),LIMIT)
105 CALL UNINT (INN(K),CPANG(1,K,L),BLDANG(1,K),CPP(K),BLL(K),LIMIT)
106 210 CPE=CPE*AFCT(K)
107 CALL UNINT (I4,CPE(K),BLDCR(1,L),CPE,PBL,IMIT)
108 CPE1=CPE*PBL*PCLI(K)
109 NNLCT=NNLCT
110 DO 215 KL=NNLCT,NNLCTT
111 CALL UNINT (NCLX(NNLCT),CPCLI(1,NNLCT),XPCLI(1,NNLCT),CPE,PXI
112 1(KL),LIMIT)
113 IF (LIMIT.EQ.1) GO TO 591
114 215 NNCLT=NNLCT+1
115 IF (NCL.EQ.1) GO TO 220
116 CALL UNINT (4,CCLI(NNLCT),PCLI(NNLCT),CLI,PCLI,LIMIT)
117 GO TO 221
118 220 PCLI=PCLI(NNLCT)
119 221 CONTINUE
120 CPE=CPE*PCLI
121 CALL UNINT (INN(K),CPANG(1,K,L),BLDANG(1,K),CPE,BLL(K),LIMIT)
122 CALL UNINT (INN(K),BLDANG(1,K),CTANG(1,K,L),BLL(K),CTT(K),LIMIT)
123 IF (LIMIT.EQ.0) GO TO 211
124 GO TO 591
125 CONTINUE
126 250 NNCLT=NNLCT
127 2200 DO 250 KL=NNLCT,NNLCTT
128 CTA(1)=CT
129 CTA(2)=1.5*CT
130 DO 2600 J=1,5
131 NFTX=KJ
132 CTE1=CTA(KJ)*AFCT(K)
133 CALL UNINT (I4,CTE1,1,BTDCR(1,L),CPE,TBL,IMIT)
134 CTE1=CTE1*TBL*TFCLI(KL)
135 CALL UNINT (NCLX(NNLCT),CTCLI(1,NNLCT),XTCLI(1,NNLCT),CPE,TCLI
136 1(KL),LIMIT)
137 IF (LIMIT.EQ.1) GO TO 591
138 9998 IF(ZJJ(K).EQ.0.) GO TO 4000
139 CALL UNINT (11,ZJCLI(1),ZMCRL(1,NNLCT),ZJJ(K),ZMCRT,LIMIT)
140 9999 DMN=ZMS(1)-ZMCRT
141 GO TO 4000
142 ZMCRT=ZMCRT(NNLCT)
143 DMN=ZMS(2)-ZMCRT
144 4050 XFFT(KL)=1.0
145 400 IF(DMN)=2300,2300,252
146 252 CTE2=CTE1*TFCLI(KL)
147 CALL BIQUAD (ZMCR1,DMN,CTE2,XFFT(KL),LIMIT)
148 2300 CTA(KJ)=CT-CTA(KJ)*XFFT(KL)
149 IF(FCTA(KJ).EQ.0..AND.KJ.EQ.1) GO TO 2700

FIGURE 3A, FORTRAN IV LISTING (CONTINUED)
IF(KJ.LE.1) GO TO 2600
IF(ABS(CTAI(KJ-1)-CTAI(KJ))/CTAI(KJ).GT.0.01) GO TO 2700
CTAI(KJ-1)=CTAI(KJ-1)*(CTAI(KJ)-CTAI(KJ-1))/CTAI(KJ)-CTAI(KJ-1) .

2600 CONTINUE
WRITE (6,391)
2700 CTX(K)=CTAI(NFTX)/XFT(K)
260 NNCLT=NNCLT+1
IF(NNCLT.EQ.1) GO TO 270
CALL UNINT(4,CTN(NNCLT),TXCL(NNCLT),CTI,CTL,LIMIT)
CALL UNINT(4,CTI(NNCLT),XFT(NNCLT),CTI,CTT(K),LIMIT)
GO TO 271
270 TCLI=TXCLI(NNCLT)
XFT(K)=XFT(K)
CTT(K)=CTT(NNCLT)
271 CTE=CTT(K)*AFCT(K)*CTL
CALL UNINT(INN(K),CTN(NNCLT),CTN(NNCLT),LIMIT)
CALL UNINT(INN(K),CTN(NNCLT),CTN(NNCLT),LIMIT)
IF(LIMIT.EQ.0.0) GO TO 2501
GO TO 591
2501 CONTINUE
300 CONTINUE
310 CALL UNINT(4,ZJ(J(NBEG),BLL(NBEG),ZJI,BLL(I),LIMIT)
312 BLL=BL(I)
GO TO (310,350,310),1W
314 CALL UNINT(4,ZJ(J(NBEG),BLL(NBEG),ZJI,CTT(I),LIMIT)
315 CTG(I)=100
316 CTG(2)=200
317 CALL UNINT(7,ZJ(J(I),TFCLI(I),ZJI,TFCLI(I),LIMIT)
318 DO 390 IL=1,5
319 CT=CTG(I)
320 CTE=CTG(I)*AFCT
321 CALL UNINT(14,CTEC(I),BTDCR(I,E),CTE,TBL,LIMIT)
322 CTE=CTE*TBL*TFCLI
323 NNCLT=NNCLT
324 CALL UNINT(4,CTI(NNCLT),TXCL(NNCLT),CTI,CTT(NNCLT),LIMIT)
325 IF (LIMIT.EQ.1) GO TO 591
326 IF(ZJI.EQ.0.) GO TO 3000
328 CALL UNINT(11,ZJ(1),ZMCRL(1,NNCLT),ZJI,ZMCRT,LIMIT)
329 DMN=ZMS(I)-ZMCR
330 GO TO 3050
331 ZMCR=ZMCR(NNCLT)
332 DMN=ZMS(2)-ZMCR
333 XFT(KL)=1.0
334 IF(DMN) 396,396,399
335 CTE=CTE*TXCLI(KL)*TBL
336 CALL BQUAD(1ZMMC,1,DMN,CTE,XFT(KL),LIMIT)
337 NNCLT=NNCLT+1
338 IF(NNCLT.EQ.1) GO TO 395
339 CALL UNINT(4,CTI(NNCLT),TXCL(NNCLT),CTI,CTL,LIMIT)
340 CALL UNINT(4,CTI(NNCLT),XFT(NNCLT),CTI,XTL(L),LIMIT)
341 IF(XFT.GT.1.0) XFT=1.0
342 GO TO 394
343 TCLI=TXCLI(NNCLT)
344 XFT=XFT(NNCLT)

FIGURE 3A. FORTRAN IV LISTING (CONTINUED)
CT=CTG(IL)

CTE=CTG(IL)*AFCTE*TCII

CTG(IL)=CTE-CTIT(IBB)

IF(ABS(CTG(IL)/CTT(IBB)).LT..001) GO TO 392

IF(IL.LE.1) GO TO 390

CTG(IL+1)=CTG(IL-1)*(CTG(IL)-CTG(IL-1))/(CTG(IL)-CTG(IL-1)+

CTG(IL-1)

390 CONTINUE

WRITE (6,391)

391 FORMAT (' INTEGRATED DESIGN CL ADJUSTMENT NOT WORKING PROPERLY FOR
XR CT DEFINITION')

392 CTTT(IBB)=CT

GO TO (360,350,340),IW

350 CALL UNINT (4,ZJJ(NBEG),XFT1(NBEG),ZJI,XFT,LIMIT)

IF(XFT.GT.1.)XFT=1.0

340 CALL UNINT (4,ZJJ(NBEG),CPP(NBEG),ZJI,CPPP(IBB),LIMIT)

CPG(1)=.150

CPG(2)=.200

CALL UNINT (4,ZJJ(NBEG),PFCLI(NBEG),ZJI,PFCLI,LIMIT)

DO 290 IL=1,5

CP=CPG(IL)

CPE=CPG(IL)*AFCPE

CALL UNINT (1,PPEC(1),BLDCR(IL-1),CPE,BLL,LIMIT)

CPE=CPE*PBL*PFCLI

NNCL=NNCL

DO 280 KL=NNCL,NNCL+1

CALL UNINT (NCLX(NNCL),CPCLI(NNCL),XPCLI(IL),NNCL,LIMIT)

280 CONTINUE

IF (LIMIT.EQ.1) GO TO 591

280 NNCL=NNCL+1

IF(NNCL.EQ.1) GO TO 282

CALL UNINT (4,CPCLI(NNCL),XPCLI(NNCL),CLIL,LIMIT)

282 CONTINUE

284 CP=CPG(IL)

284 CP=CPG(IL)

CPG(IL)=CPE-CPPP(IBB)

IF(AVS(CTG(IL)/CPPP(IBB)).LE..001) GO TO 287

IF(IL.EQ.1) GO TO 290

CPG(IL+1)=CTG(IL-1)*(CTG(IL)-CTG(IL-1))/(CTG(IL)-CTG(IL-1)+

CPG(IL-1)

290 CONTINUE

WRITE (6,285)

285 FORMAT (' INTEGRATED DESIGN CL ADJUSTMENT NOT WORKING PROPERLY FOR
CP DEFINITION')

287 CPPP(IBB)=CP

286 L=L+1

287 CONTINUE

IF(NBB=1) 510,590,510

510 CALL UNINT (4,XLB1(IL),BLL1(IL),BLADT,BLLL,LIMIT)

520 CALL UNINT (4,XLB1(IL),CTT1(IL),BLADT,CT,LIMIT)

530 CALL UNINT (4,XLB1(IL),CPPP1(IBB),BLADT,CP,LIMIT)

590 CONTINUE

CP=ASTERK

FIGURE 3A. FORTRAN IV LISTING (CONTINUED)
FIGURE 3A. FORTRAN IV LISTING (CONTINUED)
FIGURE 3A. FORTRAN IV LISTING (CONTINUED)
<table>
<thead>
<tr>
<th>Line</th>
<th>Code</th>
</tr>
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<tbody>
<tr>
<td>0009</td>
<td><code>DATA DIAM /5.0,6.5,8.5,11.5,14.5,18.5,25.0/</code></td>
</tr>
<tr>
<td>0010</td>
<td><code>DATA RBL /2.3,4.6,/</code></td>
</tr>
<tr>
<td>0011</td>
<td><code>TMT= SORT(TIPSPI*2+VKTAS */.5925)**2)/1120.*FC</code></td>
</tr>
<tr>
<td>0012</td>
<td><code>NBR=1</code></td>
</tr>
<tr>
<td>0013</td>
<td><code>IB=BLADT-1.0+.001</code></td>
</tr>
<tr>
<td>0014</td>
<td><code>GO TO (2,2,2,5,6,6,6),1B</code></td>
</tr>
<tr>
<td>0015</td>
<td><code>2 KK=IB</code></td>
</tr>
<tr>
<td>0016</td>
<td><code>GO TO 7</code></td>
</tr>
<tr>
<td>0017</td>
<td><code>5 NBR=4</code></td>
</tr>
<tr>
<td>0018</td>
<td><code>KK=1</code></td>
</tr>
<tr>
<td>0019</td>
<td><code>GO TO 7</code></td>
</tr>
<tr>
<td>0020</td>
<td><code>6 KK=4</code></td>
</tr>
<tr>
<td>0021</td>
<td><code>NBR=4</code></td>
</tr>
<tr>
<td>0022</td>
<td><code>7 CONTINUE</code></td>
</tr>
<tr>
<td>0023</td>
<td><code>DO 8 K=KK,NBR</code></td>
</tr>
<tr>
<td>0024</td>
<td><code>DO 9 I=1,7</code></td>
</tr>
<tr>
<td>0025</td>
<td><code>CALL UNIT(13,TMTH(1),PNLC(I,I,K),TMT,PNLA(I),LIMIT)</code></td>
</tr>
<tr>
<td>0026</td>
<td><code>CALL UNIT(7,DIA(1),PNLA(I),DIA,PNLB(K),LIMIT)</code></td>
</tr>
<tr>
<td>0027</td>
<td><code>PNLD = PNLB(KK)</code></td>
</tr>
<tr>
<td>0028</td>
<td><code>IF (IS.EQ.5) CALL UNIT(4,RA(1),PNLB(1),BLADT,PNLD,LIMIT)</code></td>
</tr>
<tr>
<td>0029</td>
<td><code>RMT = TIPSPI/1120.</code></td>
</tr>
<tr>
<td>0030</td>
<td><code>SPL = 107.7+ 6.6*ALOG(BHP )-4.34*ALOG(BLADT)**2*DIA**2*DIST**2/</code></td>
</tr>
<tr>
<td>0031</td>
<td><code>XXNOF) + 38.1* RMT + PNLD</code></td>
</tr>
<tr>
<td>0032</td>
<td><code>IF(LIMIT.NE.0) SPL=999999.</code></td>
</tr>
<tr>
<td>0033</td>
<td><code>RETURN</code></td>
</tr>
</tbody>
</table>

FIGURE 3A. FORTRAN IV LISTING (CONTINUED)
FIGURE 3A. FORTRAN IV LISTING (CONTINUED)
FIGURE 3A. FORTRAN IV LISTING (CONTINUED)
FIGURE 3A. FORTRAN IV LISTING (CONTINUED)
FIGURE 3A. FORTRAN IV LISTING (CONTINUED)
0063      1000 FORMAT (13E10.4)
0064          IF(VKC(I).GT.ANDVK) GO TO 90
0065      80 CONTINUE
0066      90 NOUNT=ANDVK/10.*.2*
0067          TRIG=0.
0068          VK=0.
0069     DO 100, I=1,NOUNT
0070       CALL UNINT (NNJ,VKC(I),BHPC(I),VK,SHPV,LIMIT)
0071       CALL UNINT (NNJ,VKC(I),RPMC(I),VK,RPMV,LIMIT)
0072       CALL UNINT (NNJ,VKC(I),THRSTC(I),VK,THRSTV,LIMIT)
0073       IF(SHPV.GT.BHIP) SHPV=BHIP
0074       IF(RPMV.GT.RPMI) RPMV=RPMI
0075       IF(I.GT.1) GO TO 94
0076       WRITE (6,97) DIA,PCPW,THETA,VK,THRSTV,SHPV,RPMV
0077    92 FORMAT (F10.1,F9.0,F9.1,F9.0,F8.0,F7.0)
0078     GO TO 98
0079    94 WRITE (6,96) VK,THRSTV,SHPV,RPMV
0080    96 FORMAT (2AX,F8.1,F9.0,F8.0,F7.0)
0081    98 IF(TRIG.EQ.1.) GO TO 110
0082       VK=VK+10.
0083       IF(VK.LT.ANDVK) GO TO 100
0084          VK=ANDVK
0085       TRIG=1.
0086     100 CONTINUE
0087    110 RETURN
0088       END

FIGURE 3A, FORTRAN IV LISTING (CONTINUED)
SUBROUTINE UNINT ( N, XA, YA, X, Y, L)
C RFWRITTEN  SEPTEMBER 18, 1967
C UNIVARIATE TABLE ROUTINE WITH SEPERATE ARRAYS FOR X AND Y - S 66
C
C THIS ROUTINE INTERPOLATES OVER A 4 POINT INTERVAL USING A
C VARIATION OF 2ND DEGREE INTERPOLATION TO PRODUCE A CONTINUITY
C OF SLOPE BETWEEN ADJACENT INTERVALS.
C
DIMENSION XA(1), YA(I), D(4), P(I)
L=0
I=1

C TEST FOR OFF LOW END NO # YES
0005 IF ( XA(I)-X ) 100, 150, 10
0006 10 L=1
0007 GO TO 150
0008 100 NO 120 I=2,N
0009 IF ( XA(I)-X ) 120, 150, 200
0010 120 CONTINUE
C OFF HIGTH END
0011 I = N
0012 L= 2
0013 150 Y= YA(I)
0014 GO TO 999
C TEST FOR FIRST INTERVAL
0015 700 IF(I-2) 240, 220, 240
C FIRST INTERVAL
0016 220 JX1 = 1
0017 RA = 1
0018 GO TO 400
C TEST FOR LAST INTERVAL
0019 240 IF(I-N) 300, 250, 300
C LAST INTERVAL
0020 250 JX1 = N-3
0021 RA = 0
0022 GO TO 400
0023 300 JX1 = I-2
0024 RA = (XA(I)-X) / (XA(I)-XA(I-1))
0025 400 RB = 1 - RA
C
C GET COEFFICIENTS AND RESULTS
0026 J = JX1
0027 NO 500 I=1,3
0028 P(I) = XA(J+1) - XA(J)
0029 D(I) = X - XA(J)
0030 500 J = J+1
0031 P(4) = X - XA(J)
0032 P(4) = P(1) + P(2)
0033 P(5) = P(2) + P(3)
C
RESULT
Y = YA(JX1) * RA/P(1) * D(2)/P(4) * D(3) +
1 YA(JX1+1) * (-RA/P(1) * D(1)/P(2) * D(3) + RB/P(2) * D(3)/P(5)
2 *D(4)) + YA(JX1+2) *(RA/P(2) * D(1)/P(4) * D(2) - RB/P(2)
3 *D(4)/P(3) * D(4)) + YA(JX1+3) * RB/P(5) * D(2)/P(3) * D(3)
0035 999 RETURN
0036 END

FIGURE 3A. FORTRAN IV LISTING (CONTINUED)
SUBROUTINE BIQUAD (T, I, XI, YI, Z, K)
ENTRY BIQUAD (T, I, XI, YI, Z, K)
C THIS ROUTINE INTERPOLATES OVER A 4 POINT INTERVAL USING A
C VARIATION OF 2ND DEGREE INTERPOLATION TO PRODUCE A CONTINUITY
C OF SLOPE BETWEEN ADJACENT INTERVALS.
C DIMENSION T(I), XC(4), D(4), P(5), Y(4), C(4)
C EQUIVALENCE (XC(I), D(I))
C TABLE SET UP
C T < # TABLE NUMBER
C T X I < # NUMBER OF X VALUES
C T Y I < # NUMBER OF Y VALUES. FOR UNIVARIATE TABLE
C T Y I < # VALUES OF X IN ASCENDING ORDER
NX = T(I+1)
NY = T(I+2)
J1 = I+3
J2 = J1 + NX - 1
X = XI
SEARCH IN X SENSE
L = 0
GO TO 1000
RETURN HERE FROM SEARCH OF X
100 K = KK
JX = JX1
C THE FOLLOWING CODE PUTS X AND/OR Y VALUES IN XC BLOCK
DO 110 J=1,4
XC(J) = T(JX1)
110 JX1 = JX1+1
C GET COEFF. IN X SENSE
GO TO 2000
RETURN HERE WITH COEFF. TEST FOR UNIVARIE OR BIVARIATE
200 IF (NY) 300,210,300
210 Z=0.
220 JY = JX+NX
DO 220 J=1,4
Z = Z + (J)*T(JY)
230 JY = JY+1
GO TO 230
C UNIVARIATE TABLE
300 L = 1
X = YI
J1 = J2+1
J2 = J1+NY-1
SEARCH IN Y SENSE JX1 = SUBSCRIPT OF 1ST Y
GO TO 1000
500 K = K+3*KX
C INTERPOLATE IN X SENSE
C SUBSCRIPT = HASF NO. OF COL. NO. OF YS
JY = J2+1 + (JX-1)*NY + JX1-J1
DO 550 M=1,4
550 JX = JY
Y(M) = 0.
DO 520 J=1,4
Y(M) = Y(M) + C(J)*T(JX)
520 JX = JX+NX

FIGURE 3A. FORTRAN IV LISTING (CONTINUED)
FORTRAN IV  G LEVEL  20.1  

RIQUAD  
DATE = 72031  

0038 550 JY = JY+1  
C
0039 GET COEFF. IN Y SFNSE  
0040 600 Z = 0.  
0041 DO 700 J=1,4  
0042 700 Z = Z + C(J)*Y(J)  
0043 9999 RETURN  
C
0044 SFARCH ROUTINE - INPUT J1,J2,X  
0045 -OUTPUT RA,RR,KX,JX1  
0046 1000 KX = 0  
0047 DO 1010 J=1010 J=1, J2  
0048 IF :T(J)-X) 1010,1050,1050  
0049 1010 CONTINUE  
C
OFF HIGH END  
0050 X = T(J2)  
0051 KX = 2  
C
USF LAST 4 POINTS AND CURVE B  
0052 1020 JX1 = J2+3  
0053 RA = 0.  
0054 GO TO 1600  
C
TEST FOR - OFF LOW END, FIRST INTERVAL, OTHER  
0055 1050 IF(J-J1-1) 1050, 1080 , 1090 , 1100  
0056 1080 T(J)-X) 1082,1090,1082  
0057 1090 KX = 1  
0058 JX1 = J1  
0059 RA = 1.  
0060 GO TO 1600  
C
TEST FOR LAST INTERVAL NO, YES,  
0061 IF (J-J2) 1100,1500,1500  
0062 JX1 = J-2  
0063 1500 RA = (T(J)-X)>(T(J)-T(J-1))  
0064 1600 RB = 1. - RA  
C
RETURN BACK TO MAIN BODY  
0065 IF (L) 500, 100, 500  
C
COEFFICIENT ROUTINE - INPUT X, X1, X2, X3, X4, RA, RB  
0066 2000 NO 2010 J=1,3  
0067 P(J)=X(J+1)-X(J)  
0068 P(4)=P(1)+P(2)  
0069 NO 2020 J=1,4  
0070 D(J)=X-X(J)  
0071 C(J)=(RA/P(1))*D(2)/P(4) D(3)  
0072 C(2)=-(RA/P(1))*D(1)/P(2) D(3)+(RB/P(2))*D(3)/P(5) D(4)  
0073 C(3)=(RA/P(2))*D(1)/P(4) D(2)-(RB/P(2))*D(2)/P(3) D(4)  
0074 C(4)=(RB/P(5))*D(2)/P(3) D(3)  
C
RETURN TO MAIN BODY  
0075 IF(L) 600,200,600  
0076 END  
C
FIGURE 3A. FORTRAN IV LISTING (CONCLUDED)  

NASA-Langley, 1972 — 2  

73