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

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# Computer Program User's Manual for Advanced General Aviation Propeller Study

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.
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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, \( \frac{100,000}{16} \int_{-0.15}^{1.0} \left( \frac{b}{D} \right)^3 dx \)

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

\[ \delta \text{ ratio of static pressure to static pressure at sea level, } P/P_o \]
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, $C_L$. 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
- \(\frac{\rho_o}{\rho}\) - 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:

\[
C_{PE} = C_P \times P_{AF} \times PC_{L_1}
\]

\[
C_{TE} = C_T \times T_{AF} \times TC_{L_1}
\]

where:

- \(C_P\) - power coefficient
- \(P_{AF}\) - activity factor adjustment to power coefficient (ref. 1, fig. 3A)
- \(PC_{L_1}\) - 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 $T_C$, and advance ratio, $J$ defined as follows:

$$ J = \frac{101.4 V_K}{ND} 10^{11} \text{SHP} \left( \frac{\rho_o}{\rho} \right) $$

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

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

$$ C_T = \frac{1.514 \times 10^6 T \left( \frac{\rho_o}{\rho} \right)}{N D^4} \text{ for } J \leq 1.0 $$
The equation for $T_C$ is given by:

$$
T_C = \frac{1.514 \times 10^6 T (\rho_o/\rho)}{N^2 D^4} \times \frac{1}{J^2}
$$

for $J > 1.0$

where:

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

Base curves have been defined in this manner for a 3-bladed, 100 activity factor, AF, 0.4 integrated design lift coefficient, $C_{L1}$ propeller. The term effective torque coefficient, $C_{QE}$ or $Q_{CE}$, and effective thrust coefficient, $C_{TE}$ or $T_{CE}$, are used. As with the forward flight generalization, these base curves with appropriate adjustments for AF, $C_{L1}$ 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 $C_{L1}$. The effective torque coefficients and thrust coefficients are defined as follows:

$$
C_{QE} = \left[ C_Q \times (3/B)^{0.83} \times TAF \right] - \Delta C_{Q_{E2}} \quad (PCR/100) \quad \text{for } J \leq 1.0
$$

$$
Q_{CE} = \left[ C_Q \times (3/B)^{0.83} \times TAF \right] - \Delta Q_{C_{E2}} \quad (PCR/100) \quad \text{for } J > 1.0
$$

$$
C_{TE} = \left[ C_T \times (3/B)^{0.83} \times TAF \right] - \Delta C_{T_{E2}} \quad (PCR/100) \quad \text{for } J \leq 1.0
$$

$$
T_{CE} = \left[ T_C \times (3/B)^{0.83} \times TAF \right] - \Delta T_{C_{E2}} \quad (PCR/100) \quad \text{for } J > 1.0
$$

where:

- $C_Q$ - torque coefficient for $J \leq 1.0$
- $(3/B)^{0.83}$ - number of blades, B adjustment
\[ Q_{AF} \] - activity factor adjustment factor to torque (ref. 2, fig. 11)

\[ \Delta C_{Q_{E2}} \] - integrated design lift coefficient adjustment factor to torque for \( J \leq 1.0 \) (ref. 2, fig. 12)

\[ PCR \] - percentage of integrated design lift coefficient adjustment factor to be used (ref. 2, fig. 13)

\[ Q_C \] - torque coefficient for \( J \geq 1.0 \)

\[ \Delta Q_{C_{E2}} \] - integrated design lift coefficient adjustment factor to torque for \( J \geq 1.0 \) (ref. 2, fig. 15)

\[ C_T \] - thrust coefficient for \( J \leq 1.0 \)

\[ T_{AF} \] - activity factor adjustment factor to thrust (ref. 2, fig. 17)

\[ \Delta C_{T_{E2}} \] - integrated design lift coefficient adjustment factor to thrust for \( J \leq 1.0 \) (ref. 2, fig. 18)

\[ T_C \] - thrust coefficient for \( J \geq 1.0 \)

\[ \Delta T_{C_{E2}} \] - integrated design lift coefficient adjustment factor to thrust for \( J > 1.0 \) (ref. 2, fig. 18)

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 Cp and CT 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:

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

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

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. $C_{Li}$ 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 (213, 5F6.0) format.

1. Card number
2. Number of operating conditions with a maximum of 10
3. Initial integrated design lift coefficient \((0.3 \text{ to } 0.8 \ C_L^{L_i})\)
4. Increment of integrated design lift coefficient if a range of \(C_L^{L_i}\) is to be computed
5. Number of \(C_L^{L_i}\)'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, I3, 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
6. WT-LBS - propeller weight, lbs.
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

11. \( J \) - advance ratio = \( \frac{101.4 \ V_K}{ND} \)

12. \( C_p \) - power coefficient = \( \frac{SHP \ (\rho_o/\rho) \times 10^{11}}{2 N^3 \ D^5} \)

13. \( C_T \) - thrust coefficient = \( \frac{1.514 \times 10^6 \ T(\rho_o/\rho)}{N^2 \ D^4} \)

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
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 $C_{Li}$. 

23
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>I. Single Eng. Trainer</td>
<td>2-4</td>
<td>100-160</td>
<td>100-200</td>
<td>Fixed Pitch</td>
<td>Trainer, Private</td>
<td>1000-2500</td>
<td>$8-25K</td>
<td>SIESSNA 150, 172, Skyhawk</td>
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<tr>
<td>Fixed Gear</td>
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<td>Recip DD</td>
<td>2 Blades</td>
<td></td>
<td>Rental, Aerobatic</td>
<td></td>
<td></td>
<td>Beech Musketeer A23-19</td>
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<tr>
<td>III. Light Twins</td>
<td>4-6</td>
<td>150-300</td>
<td>150-300</td>
<td>Constant Speed</td>
<td>Private (Family)</td>
<td>3500-6000</td>
<td>$40-120K</td>
<td>CESSNA Super Skymaster, 310G</td>
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<tr>
<td></td>
<td></td>
<td>Some Small Turboprops</td>
<td></td>
<td></td>
<td>Deicing</td>
<td></td>
<td></td>
<td>PIPER Twin Comanche C, Aztec D</td>
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<tr>
<td>IV. Medium Twins</td>
<td>6-11</td>
<td>150-300</td>
<td>250-450</td>
<td>Constant Speed</td>
<td>Executive</td>
<td>6000-8000</td>
<td>$100-200K</td>
<td>CESSNA L01B, L02B, L10, L21</td>
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<tr>
<td>Retract Gear &amp; IFR Equip.</td>
<td></td>
<td>Turboprops, Recip DD &amp; Geared</td>
<td>Full Feather</td>
<td>Charter</td>
<td>Air Taxi</td>
<td></td>
<td></td>
<td>Beech Queen Air Duke</td>
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<tr>
<td></td>
<td></td>
<td>Some Small Turboprops</td>
<td>3 Blades</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>PIPER Navajo 300, Turbo Navajo</td>
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<tr>
<td>V. Heavy Twins</td>
<td>12 &amp; Up</td>
<td>175-400</td>
<td>600-1500</td>
<td>Constant Speed</td>
<td>Large Executive</td>
<td>8000-12,500</td>
<td>$400-600K</td>
<td>DESHERVILLAND Twin Otter</td>
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<td>Full Feather</td>
<td>Charter, Third</td>
<td>Tier Air Liners</td>
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<td>HANDLEY PAGE Jetstream</td>
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</table>
Generalized Propeller Weight Equation:

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

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 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>
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<td>V</td>
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<td>190</td>
<td>0.7</td>
<td>0.30</td>
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</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
FIGURE 2. THRUST COEFFICIENT CHART FOR A 2 BLADED, 150 ACTIVITY FACTOR, 0.500 INTEGRATED DESIGN $C_L_i$ PROPELLER

$J = \frac{10^4 V_K}{N D}$

$C_T = 1.514 \times 10^6 \frac{T}{p_0 \rho}$

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

WHERE

$V_K$ = KNOTS TRUE AIRSPEED
$N$ = PROPELLER RPM
$D$ = PROPELLER DIAMETER - FT
$T$ = PROPELLER THRUST - POUNDS
$\rho_0 / \rho$ = DENSITY RATIO
$T_{AF}$ = ACTIVITY FACTOR ADJUSTMENT
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
PROPELLER INPUT HORSEPOWER

FIGURE 5. BASIC NOISE CURVE
2 BLADES – 1 OOAF – 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 $C_L_i$

**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**

**T.O. AT 500' SIDELINE**

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

4 BLADES – 0.6 C_L1
FIGURE 9. EXAMPLE REVERSE THRUST VARIATION WITH LANDING SPEED AND POWER SETTING

CATEGORIES V
3 BLADES/109 AF/0.509 $C_L$

- $\beta = -12.9^\circ$, 100% THROTTLE SETTING
- $\beta_{3/4} = -11.2^\circ$, 80%
- $\beta_{3/4} = -9.2^\circ$, 60%

LANDING SPEEDS, KNOTS

REVERSE THRUST
POUNDS

SHP

PROPELLER, RPM

0 10 20 30 40 50 60 70

0 2000 2100 2200

0 200 400 600 800 1000 1200
### UAC CODING FORM # 3

**ENGINEER:** ROSE WOROBEL  
**MAIL ADDRESS:** AERODYNAMICS  
**EXTENSION:** 306

**TITLE:** GENERAL AVIATION PROPELLER STUDY  
**ANALYST:**  
**SHEET 1 OF 2**

---

**SAMPLE CASE #1**

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<td>SAMPLE CASE 1</td>
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<td>2</td>
<td>SHP INPUT - TIPSPEED AND DIAMETER VARIATION - COST AND WEIGHT</td>
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<td>7000.</td>
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**SAMPLE CASE #2**

|   |   |   |   |   |   |   |   |   |
|---|---|---|---|---|---|---|---|
| 1 | AIRPLANE IN CATEGORY II |   | SAMPLE CASE 2 |   |   |   |   |
| 2 | THRUST INPUT - TIPSPEED AND DIAMETER VARIATION - COST AND WEIGHT |   |   |   |   |   |   |   |
| 3 |   | 1. | 2. | .26% |   |   |   |   |
| 4 |   | 6. | 2. | 2. | 150. | 0. | 1. | 4. | 0. | 1. |
| 5 |   | 2.5 | 0. | 1. |   |   |   |   |   |   |
|   | 2820. | 0. | 71.2 | 0. | 850. | -100. | 4. | 500. | 0. | 1. |
|   | 2370. | 7500. | 163.2 | 0. | 950. | -100. | 4. |   |   |   |

---

**FIGURE 10. SAMPLE INPUT CODING**
### UAC Coding Form #3

**Engineer:** Rose Worobel  
**Mail Address:** Aerodynamics  
**Extension:** 306

**Title:** General Aviation Propeller Study  
**Analyst:**  
**Sheet 2 of 2**

---

#### Sample Case #3

1. **Airplane in Category IV**

#### Sample Case 3

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#### Sample Case #4

1. **Airplane in Category V**

#### Sample Case 4

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<td>6</td>
<td>7</td>
<td>8</td>
<td>9</td>
<td>10</td>
<td>11</td>
<td>12</td>
<td>13</td>
<td>14</td>
<td>15</td>
</tr>
<tr>
<td>---</td>
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<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>5</td>
<td>6</td>
<td>7</td>
<td>8</td>
<td>9</td>
<td>10</td>
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<td>14</td>
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<td>16</td>
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<td>---</td>
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<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.** 3.22

#### SHP Input—Tip Speed and Diameter Variation—Cost and Weight

<table>
<thead>
<tr>
<th>Diameter (in)</th>
<th>Tip Speed (ft/s)</th>
<th>Thrust (lb)</th>
<th>Power (HP)</th>
<th>PNL</th>
<th><strong>1970 Technology</strong></th>
<th><strong>1980 Technology</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td><strong>Quantity</strong></td>
<td><strong>$Cost</strong></td>
</tr>
<tr>
<td>6.00</td>
<td>267</td>
<td>0</td>
<td>16.4</td>
<td>1</td>
<td>1.4000</td>
<td>0.1782</td>
</tr>
<tr>
<td>6.00</td>
<td>280</td>
<td>0</td>
<td>19.4</td>
<td>1.000</td>
<td>0.1742</td>
<td>0.710</td>
</tr>
<tr>
<td>6.00</td>
<td>290</td>
<td>0</td>
<td>23.7</td>
<td>1.000</td>
<td>0.1782</td>
<td>0.814</td>
</tr>
<tr>
<td>6.00</td>
<td>300</td>
<td>0</td>
<td>29.3</td>
<td>1.000</td>
<td>0.1782</td>
<td>0.939</td>
</tr>
<tr>
<td>6.00</td>
<td>350</td>
<td>0</td>
<td>35.9</td>
<td>1.000</td>
<td>0.1782</td>
<td>1.110</td>
</tr>
<tr>
<td>8.00</td>
<td>179</td>
<td>0</td>
<td>13.1</td>
<td>1.000</td>
<td>0.1782</td>
<td>0.643</td>
</tr>
<tr>
<td>8.00</td>
<td>202</td>
<td>0</td>
<td>28.1</td>
<td>1.000</td>
<td>0.1782</td>
<td>0.718</td>
</tr>
<tr>
<td>8.00</td>
<td>292</td>
<td>0</td>
<td>20.1</td>
<td>1.000</td>
<td>0.1782</td>
<td>0.814</td>
</tr>
<tr>
<td>8.00</td>
<td>282</td>
<td>0</td>
<td>28.0</td>
<td>1.000</td>
<td>0.1782</td>
<td>0.939</td>
</tr>
<tr>
<td>8.00</td>
<td>550</td>
<td>0</td>
<td>30.0</td>
<td>1.000</td>
<td>0.1782</td>
<td>1.110</td>
</tr>
</tbody>
</table>

**Integrated Design Cl**: 0.500

---

**Figure 11. Sample Output—SHP Option**
HAMPTON STANDARD COMPUTER DECK NO. H432
COMPUTES PERFORMANCE, NOISE, WEIGHT, AND COST FOR
GENERAL AVIATION PROPELLERS

1. AIRPLANE IN CATEGORY 11

2. THRUST INPUT—TIPSPEED AND DIAMETER VAR. — COST AND WEIGHT

OPERATING CONDITION

<table>
<thead>
<tr>
<th>THRUST</th>
<th>NO. OF ENGINES</th>
<th>UNIT FACTOR L.C.</th>
</tr>
</thead>
<tbody>
<tr>
<td>820</td>
<td>1</td>
<td>3.22</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>V-KTAS</th>
<th>DESIGN FLIGHT M</th>
<th>1000 FACTOR L.C.</th>
</tr>
</thead>
<tbody>
<tr>
<td>71.2</td>
<td>0.756</td>
<td>1.02</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>TEMP R</th>
<th>FIELD POINT FT.</th>
</tr>
</thead>
<tbody>
<tr>
<td>51.9</td>
<td>500</td>
</tr>
</tbody>
</table>

NUMBER OF BLADES = 4.

<table>
<thead>
<tr>
<th>DIA. FT.</th>
<th>T.S.FPS</th>
<th>SHP</th>
<th>PNL</th>
<th>ANGLE FT</th>
<th>M</th>
<th>J</th>
<th>CP</th>
<th>CT</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.00</td>
<td>850.0</td>
<td>226</td>
<td>0.</td>
<td>21.5</td>
<td>1.00</td>
<td>0.234</td>
<td>J</td>
<td>0.0919</td>
</tr>
<tr>
<td>6.00</td>
<td>750.0</td>
<td>213</td>
<td>0.</td>
<td>21.5</td>
<td>1.00</td>
<td>0.234</td>
<td>J</td>
<td>0.1259</td>
</tr>
<tr>
<td>6.00</td>
<td>650.0</td>
<td>209</td>
<td>0.</td>
<td>21.5</td>
<td>1.00</td>
<td>0.234</td>
<td>J</td>
<td>0.1291</td>
</tr>
<tr>
<td>6.00</td>
<td>550.0</td>
<td>213</td>
<td>0.</td>
<td>17.8</td>
<td>1.00</td>
<td>0.234</td>
<td>J</td>
<td>0.3170</td>
</tr>
<tr>
<td>6.00</td>
<td>450.0</td>
<td>262</td>
<td>0.</td>
<td>29.0</td>
<td>1.00</td>
<td>0.234</td>
<td>J</td>
<td>0.0538</td>
</tr>
<tr>
<td>6.00</td>
<td>350.0</td>
<td>232</td>
<td>0.</td>
<td>25.1</td>
<td>1.00</td>
<td>0.234</td>
<td>J</td>
<td>0.0711</td>
</tr>
<tr>
<td>6.00</td>
<td>250.0</td>
<td>215</td>
<td>0.</td>
<td>29.1</td>
<td>1.00</td>
<td>0.234</td>
<td>J</td>
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</tr>
<tr>
<td>6.00</td>
<td>150.0</td>
<td>275</td>
<td>0.</td>
<td>34.3</td>
<td>1.00</td>
<td>0.234</td>
<td>J</td>
<td>0.1747</td>
</tr>
</tbody>
</table>

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. TIPSPEED FOR 50 PERCENT STALL - COST FOR RANGE QUANTITY.

OPERATING CONDITION

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>SHP = 340.</td>
<td>NO. OF ENGINES = 2.</td>
<td>UNIT FACTOR L.C. = 3.22</td>
</tr>
<tr>
<td>ALT-FT = 0.</td>
<td>DESIGN FLIGHT M., = 0.327</td>
<td>1000 FACTOR L.C. = 1.02</td>
</tr>
<tr>
<td>V-KTAS = 77.5</td>
<td>CLASSIFICATION = 4.</td>
<td>FIELD POINT FT. = 500.</td>
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</table>

NUMBER OF BLADES = 4.
ACTIVITY FACTOR = 200.
INTEGRATED DESIGN CL = .600

<table>
<thead>
<tr>
<th>DIA. FT.</th>
<th>T.S. FPS</th>
<th>THRUST PNL</th>
<th>QUANTITY</th>
<th>WT-LBS</th>
<th>$COST</th>
<th>ANGLE</th>
<th>FT</th>
<th>M</th>
<th>J</th>
<th>CP</th>
<th>CT</th>
</tr>
</thead>
<tbody>
<tr>
<td>8.</td>
<td>345.</td>
<td>818.</td>
<td>77.</td>
<td>1.</td>
<td>228.</td>
<td>7106.</td>
<td>1.</td>
<td>185.</td>
<td>7770.</td>
<td>46.3</td>
<td>1000</td>
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<tr>
<td>1001.</td>
<td>228.</td>
<td>2252.</td>
<td>1001.</td>
<td>185.</td>
<td>2463.</td>
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<tr>
<td>3001.</td>
<td>228.</td>
<td>1876.</td>
<td>3001.</td>
<td>185.</td>
<td>2052.</td>
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<td>185.</td>
<td>1956.</td>
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<td></td>
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<tr>
<td>NUMBER OF BLADES = 6.</td>
<td>ACTIVITY FACTOR = 200.</td>
<td>INTEGRATED DESIGN CL = .600</td>
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<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>DIA. FT.</th>
<th>T.S. FPS</th>
<th>THRUST PNL</th>
<th>QUANTITY</th>
<th>WT-LBS</th>
<th>$COST</th>
<th>ANGLE</th>
<th>FT</th>
<th>M</th>
<th>J</th>
<th>CP</th>
<th>CT</th>
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<tbody>
<tr>
<td>8.</td>
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<td>828.</td>
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<td>11926.</td>
<td>1.</td>
<td>245.</td>
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<td>306.</td>
<td>3790.</td>
<td>1001.</td>
<td>245.</td>
<td>4084.</td>
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<tr>
<td>3001.</td>
<td>306.</td>
<td>3149.</td>
<td>3001.</td>
<td>245.</td>
<td>3403.</td>
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<td></td>
<td></td>
<td></td>
<td></td>
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<td>306.</td>
<td>3002.</td>
<td>4001.</td>
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<td>3244.</td>
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</table>

FIGURE 13. SAMPLE OPTION — 50% STALL OPTION
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

(SHIP)

OPTION

(REVERSE THRUST)

(101)

CALCULATES SHP FOR GIVEN THRUST

CALCULATES SHP REVERSE ANGLE AND REVERSE THRUST

Determine tipspeed at which blade will be 50% stalled

CALCULATES THRUST FOR GIVEN SHP

IS NOISE REQ'D?

CALCULATES NOISE

ARE WEIGHT & COST REQ'D?

CALCULATES WEIGHT

CALCULATES COST

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
REVHT
UNINT
BIQUAD

Figure 2A  LIST OF SUBROUTINES
REAL*8  BLANK
COMMON/AFCOR/AFCE,AFCTE,XFT
COMMON/ASTRK/CPAST,CAST,ASTERK
COMMON/CPCTE/CPCE,CTE,BLLL
DIMENSION FC(10),ALTPR(11),PRESSR(11),RORD(10),ZMS(2)
DIMENSION DIST(10),CQUN(2,11),COSTO(10),COST8(10)
DIMENSION BHPG(10),THRG(10),TIPS(11)
COMMON /ZINPUT/
BHP(10),THRSTG(10),TIPS(11)
IWIC(10),NOF,D,DD,ND,AF,DAF,NAF,BLDN,BLAD,LBL,DTS(10),NTS(11)
DIMENSION DISTX,XNOE,XTCON,ZNWT,STAMT(10),CFT,CLF,CK70,CK80,CAMT,DAMT,NAFT
DIMENSION FC~10~rCALTPR~ll~~PRESSR~ll~~RORO~lO~~ZMS~Z~
DIMENSION CJIST~lO)rCOUAN~2rll)rCOST70(101rCOST8OtlO~
COMMON /ZINPUT/
BHP~10~~THRUST~10~rALT~lO~rVKTAS~lO~~T~lO~~TS~lO~
*IWIC(lO)
TNOFIDIDD,NDIAF*DAFINAFIBLADN.D~LADN,D~L~D,
DTS(lO)rNDTSI.10)
DIST~XNOE~kTCON~ZMWT~STALIT~lO~~CLFl~CLF~CK70~C~80~CAMT~DAMT~NAMT
DCOST(10),CLII,DCLI,ZNCLI,RTC,ROPCPWI(10),NPCPWI(10),BETA(10),
4PCPW(10),RPMC(10),ANDVK(10)
DATA  ALTPR
/0.,10000.,20000.,30000.,40000.,50000.,
X60000.,70000.,80000.,90000.,100000./
DATA  PRESSR
/1.0.,6877.,4595.,2970.,1851.,1145.,07078.,
X.04419.,02741.,01699.,01054/
DATA  BLANK/6H /
701 CONTINUE
710 CONTINUE
702 CONTINUE
703 CONTINUE
704 CONTINUE
705 CONTINUE
706 CONTINUE
707 CONTINUE
709 CONTINUE
711 CONTINUE
712 CONTINUE
713 CONTINUE
714 CONTINUE
715 CONTINUE
716 CONTINUE
717 CONTINUE
718 CONTINUE
719 CONTINUE
720 CONTINUE
721 CONTINUE
722 CONTINUE
723 CONTINUE
724 CONTINUE
725 CONTINUE
726 CONTINUE
727 CONTINUE
728 CONTINUE
729 CONTINUE
730 CONTINUE
731 CONTINUE
732 CONTINUE
733 CONTINUE
734 CONTINUE
735 CONTINUE
736 CONTINUE
737 CONTINUE
738 CONTINUE
739 CONTINUE
740 CONTINUE
741 CONTINUE
742 CONTINUE
743 CONTINUE
744 CONTINUE
745 CONTINUE
746 CONTINUE
747 CONTINUE
748 CONTINUE
749 CONTINUE
750 CONTINUE
751 CONTINUE
752 CONTINUE
753 CONTINUE
754 CONTINUE
755 CONTINUE
756 CONTINUE
757 CONTINUE
758 CONTINUE
759 CONTINUE
760 CONTINUE
761 CONTINUE
762 CONTINUE
763 CONTINUE
764 CONTINUE
765 CONTINUE
766 CONTINUE
767 CONTINUE
768 CONTINUE
769 CONTINUE
770 CONTINUE
771 CONTINUE
772 CONTINUE
773 CONTINUE
774 CONTINUE
775 CONTINUE
776 CONTINUE
777 CONTINUE
778 CONTINUE
779 CONTINUE
780 CONTINUE
781 CONTINUE
782 CONTINUE
783 CONTINUE
784 CONTINUE
785 CONTINUE
786 CONTINUE
787 CONTINUE
788 CONTINUE
789 CONTINUE
790 CONTINUE
791 CONTINUE
792 CONTINUE
793 CONTINUE
794 CONTINUE
795 CONTINUE
796 CONTINUE
797 CONTINUE
798 CONTINUE
799 CONTINUE
800 CONTINUE
801 CONTINUE
802 CONTINUE
803 CONTINUE
804 CONTINUE
805 CONTINUE
806 CONTINUE
807 CONTINUE
808 CONTINUE
809 CONTINUE
810 CONTINUE
811 CONTINUE
812 CONTINUE
813 CONTINUE
814 CONTINUE
815 CONTINUE
816 CONTINUE
817 CONTINUE
818 CONTINUE
819 CONTINUE
820 CONTINUE
821 CONTINUE
822 CONTINUE
823 CONTINUE
824 CONTINUE
825 CONTINUE
826 CONTINUE
827 CONTINUE
828 CONTINUE
829 CONTINUE
830 CONTINUE
831 CONTINUE
832 CONTINUE
833 CONTINUE
834 CONTINUE
835 CONTINUE
836 CONTINUE
837 CONTINUE
838 CONTINUE
839 CONTINUE
840 CONTINUE
841 CONTINUE
842 CONTINUE
843 CONTINUE
844 CONTINUE
845 CONTINUE

FIGURE 3A. FORTRAN IV LISTING
CALL COST (WTCON, BLADT, CLF1, CLF, CK70, CK80, CAMT, DAMT, NAMT, CQUAN(1,1), WT70, WT80, COST70, COST80, CCLFI, CCLF, CK70, CK80, IENT)

GO TO (210,230), 1W

WRITE (6,220) BHP(IC),XNOE,CCLFI

220 FORMAT( ' SHP = ',F7.0,9X,'NO. OF ENGINES = ',F5.0,9X,'UNIT FACTOR 1L.C. = ',F5.2)

GO TO 250

WRITE (6,220) THRUST(IC),XNOE,CCLFI

230 FORMAT( ' THRUST = ',F7.0,9X,'NO. OF ENGINES = ',F5.0,9X,'UNIT FACTOR 1L.C. = ',F5.2)

240 FORMAT( ' 1R L.C. = ',F5.2/* V-KTAS = ',F7.1,9X,'CLASSIFICATION = ',F5.0/* TE 2MP R = ',F7.0,9X,'FIELD POINT FT. = ',F5.0)

GO TO 270

250 FORMAT( ' 1R L.C. = ',F5.2/* V-KTAS = ',F7.1,9X,'CLASSIFICATION = ',F5.0/* TE 2MP R = ',F7.0,9X,'FIELD POINT FT. = ',F5.0)

GO TO 270

WRITE (6,260) ALTI(C),ZMWT,CCLF,VTAS(IC),WTCON,T(IC),DIST(IC), CK80

260 FORMAT( ' 1R L.C. = ',F5.2/* V-KTAS = ',F7.1,9X,'CLASSIFICATION = ',F5.0/* TE 2MP R = ',F7.0,9X,'FIELD POINT FT. = ',F5.0)

GO TO 270

WRITE (6,270) BHP(1C),RPMG( IC),VK( IC),ALT( IC),T( IC)

270 FORMAT( ' FULL THROTTLE SHP = ',F6.0/22X,'FULL THROTTLE RPM = 1*,F6.0/22X,'FULL TOUCH DOWN V-KNOTS = ',F6.0/22X,'FULL ALTITUDE FEET = ',F6.0/22X,'FULL TEMPERATURE RANGE = ',F6.0/22X)

DO 1200 IAF=1,NAF

1200 CONTINUE

C INTEGRATED DESIGN CL LOOP

NCLI=2,NCLI+1

CL=CCLI-1

DO 1001 ICL=1,NCLI

FIGURE 3A. FORTRAN IV LISTING (CONTINUED)
IF (CLI.LE.80001.AND.CLI.GE.29999) GO TO 875
WRITE (6,870) CLI
870 FORMAT(116ILLEGAL INTEGRATED DESIGN CL =',F5.3)
GO TO 1001
875 CONTINUE
C NO. OF BLADES LOOP
BLADT=BLADN-DBLAO
DO 1000 IB=1,NBL
BLADT=BLADT+DRLAD
IF(BLAOT.LE.6.AND.BLADT.GE.2.) GO TO 888
WRITE(6,887) BLADT
887 FORMAT('ILLEGAL NO. OF BLADES = ',F8.1)
GO TO 1000
888 CONTINUE
C PRINT APPROPRIATE HEADING
IF (IW .LT.3) GO TO 2700
WRITE (6,2650) BLADT,AFT,CLI
2650 FORMAT('O'NUMBER OF BLADES=',F3.0,*  ACTIVITY FACTOR=',F4.0,* INTEGRATED DESIGN CL=',F4.3/)
WRITE (6,2660)
2660 FORMAT(13X,'THROTTLE REVERSE',8X,'REVERSE'5X,'DIA.FT SETTING A 1NGLE V-KNOTS THRUST SHP RPM'/)
GO TO 30
2700 WRITE (6,20) BLADT,AFT,CLI
20 FORMAT('O' NUMBER OF BLADES=',F3.0,18X'ACTIVITY FACTOR=',F4.0, X18X INTEGRATED DESIGN CL=',F4.3)
GO TO 500
21 WRITE (6,22)
22 FORMAT('O' DIA.FT. T.S.FPS THRUST PNL ANGLE FT M J CP CT'/)
GO TO 30
24 WRITE(6,25)
25 FORMAT('O' DIA.FT. T.S.FPS SHP PNL ANGLE FT M J CP CT'/)
GO TO 30
500 WRITE (6,550),IW
550 FORMAT(13X,'DIA.FT. T.S.FPS SHP PNL ANGLE FT M J CP CT'/)
GO TO 30
510 WRITE (6,520)
520 FORMAT(10*,30X*** 1970 TECHNOLOGY *** *** 1980 TECHNOLOGY ***/ 1'DIA.FT. T.S.FPS THRUST PNL QUANTITY WT-LBS $COST QUANTITY 2WT-LBS $COST ANGLE FT M J CP CT'/)
GO TO 30
550 WRITE (6,560)
560 FORMAT(10*,30X*** 1970 TECHNOLOGY *** *** 1980 TECHNOLOGY XXX'/ 1'DIA.FT. T.S.FPS SHP PNL QUANTITY WT-LBS $COST QUANTITY 2WT-LBS $COST ANGLE FT M J CP CT'/)
30 CONTINUE
0900 ILINE=ILINE+6
C DIAMETER LOOP
DIA=D-DO
DO 800 ID=1,NB
DIA=DIA+DO
IF (IW.EQ.3) GO TO 3000
C TIPSPEED LOOP
IF (STALIT.50)GO TO 310
0930 DTS(IC)=0.
0940 TRIG=0.
**FORTRAN IV Level 20.1**

MAIN

DATE = 72034 10/08/04

0135 NTS=10
0136 TIPSOG(1)=700.
0137 TIPSPO=700.
0138 GO TO 320.
0139 310 TIPSPO=TIPSPO-DTS(IC)
0140 NTS=NTS+1
0141 320 GO 600 ITC=1,NTS
0142 TIPSPO=TIPSPO+DTS(IC)

### C Mach Number Calculation and Advance Ratio J

0143 ZMS(1)=.001512*VKTAS(IC)*FC(IC)
0144 ZMS(2)=TIPSPO*FC(IC)/1120.
0145 ZM=ZMS(1)
0146 340 ZJI=5.309*VKTAS(IC)/TIPSPO
0147 IF(ZJI.EQ.0.) ZM=ZMS(2)
0148 IF(STALIT(IC).LE..50.000.AND.ZJI.LE.5.0) GO TO 342
0149 IF(STALIT(IC).GT..50.000.AND.ZJI.LE.3.0) GO TO 342
0150 WRITE(6,341)
0151 341 FORMAT(' ADVANCE RATIO TOO HIGH = ', F8.4)
0152 GO TO 600
0153 342 CONTINUE

### C Iteration on CT or CP to Get 50 Percent Stall Tipspeed

0154 IF(IN=0
0155 IF(STALIT(IC).LE..50.0) GO TO 399
0156 IWSV=1W
0157 Ia=J
0158 CALL PERFY (3,CP,ZJI,AFT,BLADT,CLT,CT,ZMS,7710)
0159 IWS=IWSV
0160 IF(IWS.EQ.2.0) GO TO 712
0161 711 BHPG((IT)=2.0*TIPSOG(ITS)**2*6966.*CP/(1.515E06*RORO(IC))
0162 IF(ABS(BHPG(IC)-BHPG(ITS)).GE..005*BHPG(ITS)) GO TO 705
0163 THRUST(IC)=CT*TIPSPO**2*6966.76
0164 TRIG=1.
0165 GO TO 720
0166 705 IF(ITS.EQ.1) GO TO 7000
0167 TIPSOG((ITS+1)=IALOG(BHPG(ITS)-IALOG(BHPG((ITS-1)))*TIPSOG((ITS)-
0168 TIPSOG((ITS-1)/IALOG(BHPG((ITS))-IALOG(BHPG((ITS-1)))+TIPSOG((ITS-1)
0169 GO TO 700
0170 7000 TIPSOG(2)=400.
0171 TIPSPO=TIPSOG((ITS+1)
0172 GO TO 600
0173 712 THRSTG((ITS)=TIPSOG((ITS)**2*364.76*CT/(1.515E06*RORO(IC))
0174 IF(ABS(THRSTG(ITS)-THRSTG((ITS)).GE..005*THRSTG(ITS)) GO TO 722
0175 TIPSPO=TIPSOG((ITS)
0176 BHPG=CP*2.0*TIPSPO**3*364.76*CT/(1.515E06*RORO(IC))
0177 IF(IN.EQ.1) GO TO 720
0178 722 IF(ITS.EQ.1) GO TO 7000
0179 TIPSOG((ITS+1)=IALOG(THRSTG((ITS))-IALOG(THRSTG((ITS-1)))*TIPSOG((ITS)-
0180 TIPSOG((ITS-1)/IALOG(THRSTG((ITS))-IALOG(THRSTG((ITS-1)))+TIPSOG
0181 2((ITS-1)
0182 709 TIPSPO=TIPSOG((ITS+1)
0183 IF(NTS.NE.ITS) GO TO 600
0184 IF(IT=6,598)
0185 598 FORMAT (' FAILED STALL ITERATION // 11)
0186 GO TO 700

### C END OF TIPSPO ITERATION 50 PERCENT STALL

### C Calculation of Required CP or CT

0185 399 IF(IW=114000,400,430

**FIGURE 3A. FORTRAN IV Listing (Continued)**
FIGURE 3A. FORTRAN IV LISTING (CONTINUED)
0238 588 CONTINUE
0239 730 GO TO 40
0240 731 WRITE(6,32) DIA,TIPSPD,THRUST(IC),PNL,BLLLl,XTF,ZM1,ZJI,CP,CT
0241 32 FORMAT(F7.2,F7.0,F9.0,F6.0,F6.1,F8.3,F7.4,F8.3,2F8.4)
0242 734 WRITE(6,32) DIA,TIPSPD,BHP(IC),PNL,BLLL|.XTF,ZM1,ZJI,CP,CT
0244 34 IF(ISTRIG.EQ.1.) GO TO 750
0245 730 IF(ISTALL.EQ.2) GO TO 800
0246 IF(IFIN.EQ.7710) GO TO 800
0247 600 CONTINUE
0248 600 IF (IW.LT.3) GO TO 750
0249 C REVERSE THRUST CALCULATION
0250 3000 IRT=NPCPWIIC)
0251 3100 PCPW=PCPW(ICI)
0252 3200 DO 3900 I=1,IRT
0253 3200 IF (RTC-1.) 3200,3100,3200
0254 3100 CP=BHP(ICI)*PCPW*ROP0(ICI)*10,E10/(2.0*RPMC(ICI)**3*DIA**5*100.)
0255 3200 CALL REVTHT (RTC,RTT,AFI,CLT,BLAHT,DiA,CP,BETA(ICI),ROPO(ICI),
0256 1BHP(ICI) ,RPMC(ICI),PCPW,ANDVK(ICI))
0257 3200 PCPW=PCPW+DPDW(ICI)
0258 3900 CONTINUE
0259 750 CONTINUE
0260 800 CONTINUE
0261 1000 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)
FORTRAN IV G LEVEL 20.1

PERFM  DATE = 72034  10/08/04

X 1560.2249.3108.4026
X 0.311.0.320.0.360.0.434.0.691.1.074
X 0.380.0.800.1.494.2.364.3.486.4.760
X 4*0.
X -.0228-.0109-.0324.1.326.2.578.3.999
X .5664.7.227.2*0./

0017 DATA CPCLI/.0114,.0294,.0491,.0698,.0913,.1486,.2110,.2802,.3589
1.4443,.5368,.6255.0.0000
2.0294,.0478,.0678,.0893,.1118,.1702,.2335,.3018,.3775,.4610,.5505
3.6331.0.0000
4.0270,.0324,.0486,.0671,.0875,.1094,.1326,.1935,.2576,.3259,.3990
5.4805,.5664,.6438
6.0490,.0524,.0684,.0868,.1074,.1298,.1537,.2169,.2827,.3512,.4235
7.5025,.5848,.6605
8.0705,.0763,.0891,.1074,.1281,.1509,.1753,.2407,.3093,.3775,.4496
9.5265,.6065,.6826
A.0915,.0973,.1114,.1290,.1494,.1723,.1972,.2646,.3345,.4047,.4772
B.5532,.6307,.7092/

0018 DATA CPEC / .01.,.02.,.03.,.04.,.05.,.06.,.08.,.10.,.15.,.20.,.25,
1.30.,.35.,.40/

0019 DATA CTANG
X 1608.1767.1848.1858
X .0205.0.0691.1.141.1.529.1.785.1.860
X 4*0.
X -.0976-.0566-.0556-.0645-.1156-.1589
X -.1133-.0624-.0111-.0772-.1329-.1776
X -.1132-.0356-.0479-.1161-.1711-.2111
X -.0776-.0159-.0391-.0868-.1279-.1646
X -.1228-.0221-.0633-.1309-.1858-.2314
X 4*0.
X .0426.0.0633.0.0853.1.1011.1.649.2.204
X .0318.1.116.1.909.2.650.3.241.3.423
X 4*0.
X -.1761-.0960-.0083.1.114.2.032.2.834
X .3487.3.596.2*0./

0020 DATA CPSITAR/.05.,.12.,.22.,.35.,.49.,.65.,.82.,.1.01.,.1.19
2.16.,.29.,.49.,.75.,.1.05.,.1.37.,.1.74.,.2.13.,.2.53
3.30.,.47.,.75.,.1.11.,.1.51.,.1.96.,.2.41.,.2.86.,.3.30
4.45.,.71.,.1.03.,.1.40.,.1.89.,.2.45.,.2.96.,.3.55.,.4.1/

0021 DATA CYCLI/.0013.,.0211.,.0407.,.0600.,.0789.,.1.251.,.1.702.,.2.117.,.2.501,
1.2840.,.3128.,.3.3160.0.00
2.0158.,.0362.,.0563.,.0761.,.0954.,.0419.,.1.868.,.2.287.,.2.669.,.3.013.,.3.317
3.3466.0.00
4.00.,.0083.,.0297.,.0507.,.0713.,.0916.,.1.114.,.1.585.,.2.032.,.2.456.,.2.834
5.3191.,.3.487.,.3.626
6.0130.,.0208.,.0428.,.0645.,.0857.,.1.064.,.1.267.,.1.748.,.2.195.,.2.619.,.2.995
7.3350.,.3.647.,.3.802
8.026.,.0331.,.0552.,.0776.,.0994.,.1.207.,.1.415.,.1.907.,.2.357.,.2.778.,.3.156
9.3505.,.3.980.,.3.990
A.0965.,.0449.,.0672.,.0899.,.1.125.,.1.344.,.1.556.,.2.061.,.2.517.,.2.937.,.3.315
8.3656.,.3.963.,.4.186/

0022 DATA CTEC /
.01.,.03.,.05.,.07.,.09.,.1.12.,.1.16.,.2.0.,.2.24.,.2.28.,.3.2.,.3.6.,.40
1.44/

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

PERFM  DATE =  72034  10/08/04

0027  
X 4691,5549,6043,6415/
DATA DUM4 /
X 4*0, 
X 3831,4508,5035,5392,
C 4*0, 
X 5655,6536,2*0, 
X 6410,7032,2*0, 
X 7308,3*0, 
X 5899,6722,7302,7761,
X 4165,1040,1597,3671,5289,6556/

0028  
DATA INN / 10,6,8,8,7,10,6, 
OC29  
DATA NCLX / 12,12,14,14,14, 
0030  
DATA NJ / 1,2,3,4,5,6,7, 
0031  
DATA PFCL1/1,68,1,405,1,0,655,442,255,102, 
0032  
DATA TFCL1/1,22,1,105,1,0,882,792,665,540, 
0033  
DATA XLB / 2*,4,6,8, 
0034  
DATA XPCL1/4,26,2,285,1,780,1,568,1,452,1,300,1,220,1,160,1,110, 
1,085,1,054,1,048,0,0, 
21,652,1,408,1,292,1,228,1,188,1,132,1,105,1,080,1,058,1,042,1,029, 
31,022,0,0, 
41,41,1,1,1,1,1,1,1,1,1,1,1,1,1, 
5,551,619,712,775,815,865,881,910,928,941,958,970, 
6,475, 
7,382,436,545,625,682,726,775,804,835,864,889,914,935, 
8,946, 
9,293,433,436,520,585,635,670,730,770,807,835,871,897, 
A,909, 
0035  
DATA XCTCL1/22,85,2,40,1,75,1,529,1,412,1,268,1,191,1,158,1,130, 
1,122,1,108,1,108,0,0, 
21,880,1,400,1,268,1,208,1,170,1,110,1,089,1,071,1,060,1,054,1,051, 
31,048,0,0, 
41,41,1,1,1,1,1,1,1,1,1,1,1,1,1, 
5,000,399,694,787,831,860,881,908,926,940,945,951,958, 
6,958, 
7,000,251,539,654,719,760,788,831,865,885,900,910,916, 
8,916, 
9,0,1852,442,565,635,681,716,769,809,838,855,874,881, 
A,881, 
0036  
DATA ZJCL /0,5,1,0,1,5,2,0,2,5,3,0,3,5,4,0,4,5,0, 
0037  
DATA ZJJ /0,0,5,1,1,5,2,3,5, 
0038  
DATA ZJSTAL/0,4,8,1,2,1,6,2,0,2,4,2,8,3,2, 
0039  
DATA ZMCRO/.928,.916,.901,.884,.865,.845, 
0040  
DATA ZMCRLL /0,131,299,415,505,578,620,630,630,630, 
1,0,164,287,400,467,556,595,605,605,605, 
2,0,140,276,387,469,534,571,579,579,579, 
3,0,135,265,372,452,512,547,554,554,554, 
4,0,130,252,357,434,490,522,526,526,526, 
5,0,125,240,339,416,469,498,500,500,500, 
0041  
DATA ZMMCL/1,6,12,*,0,2,0,4,0,6,0,8,10,1,0,1,0,4,0,8,8,12, 
1,16,2,0,2,4,2,8,3,2,3,6,4,0, 
21,4,1,1,1,1,1,1,1,1,1,1, 
FIGURE 3A, FORTRAN IV LISTING (CONTINUED)
FORTRAN IV  G LEVEL  20.1  PERFM  DATE = 72035  17/32/24

3.979, 981, 984, 987, 950, 593, 996, 100, 1.00, 1.00, 1.00, 1.00,
4.964, 945, 950, 958, 966, 975, 984, 990, 996, 999, 1.00, 1.00,
5.901, 905, 912, 927, 942, 954, 964, 974, 984, 990, 990, 900,
6.862, 866, 875, 882, 890, 926, 942, 957, 970, 980, 984, 984,
7.806, 813, 825, 851, 877, 904, 924, 939, 952, 961, 971, 976/.

0042  KK=1
0043  'ASTERK=999999.
0044  AN ADJUSTMENT FOR CP AND CT FOR AF
0045  CALL UNINT ' (6, AFVAL(1), AFCPC(1,K), AFT, AFCP(K), LIMIT)
0046  CALL UNINT ' (6, AFVAL(1), AFCTC(I,K), AFT, AFCT(K), LIMIT)
0047  120 CONTINUE
0048  DO 100 K=1,2
0049  AFCP(K)=AFCP(2)
0050  100 AFCT(K)=AFCT(2)
0051  IF(ZJI*GT.5) GO TO 105
0052  AFCPE=AFCP(2)-AFCP(1)+AFCP(1)
0053  AFCTE=AFCT(2)-AFCT(1)+AFCT(1)
0054  GO TO 110
0055  105 AFCPE=AFCP(2)
0056  AFCTE=AFCT(2)
0057  110 IF(ZJI.GT.1.0) GO TO 140
0058  NBFG=1
0059  NEND=4
0060  GO TO 148
0061  140 IF(ZJI.GT.1.5) GO TO 142
0062  NBFG=2
0063  NEND=5
0064  GO TO 148
0065  142 IF(ZJI.GT.2.0.AND.IW.LT.3) GO TO 147
0066  NBFG=3
0067  NEND=6
0068  GO TO 148
0069  147 NBFG=4
0070  NEND=7
0071  148 CONTINUE
0072  NCLT=0
0073  DO 130 II=1,6
0074  IZ=II
0075  IF(ABS(CLI-CCLI(II)).LT..009) GO TO 135
0076  130 CONTINUE
0077  IF(CLI.GT..6) GO TO 131
0078  NCLT=1
0079  NCLTT=4
0080  GO TO 119
0081  131 IF(CLI.GT..7)GO TO 132
0082  NCLT=2
0083  NCLTT=5
0084  GO TO 119
0085  132 NCLT=3
0086  NCLTT=6
0087  GO TO 119
0088  135 NCLT=12
0089  NCL=1
0090  NCLTT=12
0091  119 CONTINUE
0092  NB = BLADT+1
0093  LMOD=MOD(NB,2)+1

FIGURE 3A. FORTRAN IV LISTING (CONTINUED)
C J INTERPOLATION

0101 DO 300 K=NBEG,NEND
0102 208 GO TO (210,250,212),IW
0103 212 CALL UNINT (9,ZJSTAL,CTSTAL(1,L),ZJJ(K),CTT(K),LIMIT)
0104 CALL UNINT (9,ZJSTAL,CPSTAL(1,L),ZJJ(K),CPP(K),LIMIT)
0105 CALL UNINT (INN(K),CPANG(1,K,L),BLDANG(1,K),CPP(K),BLL(K),LIMIT)
0106 210 CPE=CPE*AFCT(K)
0107 CALL UNINT (14,CPE(1),BLDCL(1,L),CPE,PBL,IMIT)
0108 CPE1=CPE*PBL*PCLI(K)
0109 NNCLT=NNCLT
0110 DO 215 KL=NNCLT,NCLTT
0111 CALL UNINT (NCLX(NNCLT),CPCLI(1,NNCLT),XPCLI(1,NNCLT),CPE1,PXCLI
1(KL),LIMIT)
0112 215 IF (LIMIT.EQ.1) GO TO 591
0113 215 NNCLT=NNCLT+1
0114 IF (INCL.EQ.1) GO TO 220
0115 CALL UNINT (4,CCLI(NNCLT),PXCLI(NNCLT),CLI,PCLI,LIMIT)
0116 GO TO 221
0117 220 PCLI=PXCLI(NNCLT)
0118 221 CONTINUE
0119 CPE=CPE*PCLI
0120 CALL UNINT (INN(K),CPANG(1,K,L),BLDANG(1,K),CPP,BLL(K),LIMIT)
0121 CALL UNINT (INN(K),BLDANG(1,K),CTANG(1,K,L),BLL(K),CTT(K),LIMIT)
0122 IF (LIMIT.EQ.0) GO TO 211
0123 GO TO 591
0124 211 CONTINUE
0125 GO TO 2501
0126 250 NNCLT=NCLT
0127 2200 DO 260 KL=NCLT,NCLTT
0128 CTA(1)=CT
0129 CTA(2)=1.5*CT
0130 DO 2600 KJ=1,5
0131 NFTX=KJ
0132 CTE=CPE(KJ)*AFCT(K
0133 CALL UNINT(14,CTE(1),BTDCR(1,L),CTE,TBL,IMIT)
0134 CTE1=CTE1*TFCLI(K)
0135 CALL UNINT (NCLX(NNCLT),CTCLI(1,NNCLT),XTCLI(1,NNCLT),CTE1,TXCLI
1(KL),LIMIT)
0136 260 IF (LIMIT.EQ.1) GO TO 591
0137 9998 IF (ZJJ(K).EQ.0.) GO TO 4000
0138 CALL UNINT (11,ZJCLI(1),ZMCRL(1,NNCLT),ZJJ(K),ZMCRT,LIMIT)
0139 9999 DM=ZMS(1)-ZMCRT
0140 4000 ZMCR=ZMCRD(NNCLT)
0141 DM=ZMS(2)-ZMCRT
0142 4050 XFFT(KL)=1.0
0143 IF (DMN).GT.2300,GO TO 2700
0144 252 CTE2=CTE1*XCLI(KL)/TFCLI(K)
0146 CALL BQUAD (ZMMG,1,DMN,CTE2,XFFT(KL),LIMIT)
0147 2300 CTA(KJ)=CT-CTA(KJ)*XFFT(KL)
0148 IF (CTA(KJ).EQ.0..AND.KJ.EQ.1) GO TO 2700

FIGURE 3A, FORTRAN IV LISTING (CONTINUED)
IF(KJ.LE.1) GO TO 2600
0150 IF(ABS(CTAI(KJ-1)-CTAI(KJ))/CTAI(KJ).LE..001) GO TO 2700
0151 CTA(KJ+1)=CTAI(KJ-1)*CTAI(KJ-1)/(CTAI(KJ-1)-CTAI(KJ-1))
0152 CONTINUE
0153 2600 CONTINUE
0154 WRITE (6,391)
0155 2700 CTKU(KU)=CTAI(NFTX)/XFFT(KL)
0156 NNCLT=NNCLT+1
0157 IF (NNCLT.EQ.1) GO TO 270
0158 CALL UNINT (4,CCLI(NNCLT),XCL(NNCLT),CLI,TCLI,LIMIT)
0159 CALL UNINT (4,CCLI(NNCLT),XFTI(KL),LIMIT)
0160 GO TO 271
0161 270 TCLI=TXCLI(NNCLT)
0162 XFTI(K)=XFFT(NNCLT)
0163 CTT(K)=TNN(CNCT)
0164 271 CTE=CTT(K)*AFCT(K)*TCLI
0165 CALL UNINT(IDN(I),CTANG1(K,L),BDANG1(K,L),CTE,BLL(K),LIMIT)
0166 CALL UNINT (1DIN(I),CPANG1(K,L),BLL(K),CPP(K),LIMIT)
0167 IF(LIMIT.EQ.0) GO TO 2501
0168 GO TO 591
0169 2501 CONTINUE
0170 300 CONTINUE
0171 CALL UNINT (4,ZJJ(NBEG),BLL(NBEG),ZJI,BLL(I),LIMIT)
0172 BLLL=BLLI(I)
0173 GO TO (310,350,310),1W
0174 CALL UNINT (4,ZJJ(NBEG),CTN(NBEG),ZJI,CTTT(L),LIMIT)
0175 CTG(1)=.100
0176 CTG(2)=.200
0177 CALL UNINT (7,ZJJ(I),TFCLI(I),ZJI,TFCLI,LIMIT)
0178 DO 390 IL=1,5
0179 CTE=CTG(II)*AFCTE
0180 CALL UNINT (4,CTEC(II),BTDCLR(II),CTE,TBL,LIMIT)
0181 CTE=CTE*TBL*TFCLII
0182 390 TCLI=TXCLI(I)
0183 XFT(K)=XFFT(KL)
0184 CALL UNINT (NCLX(NNCLT),CTCLI(I,NNCLT),XFTI(KL),LIMIT)
0185 CALL UNINT (NCLX(NNCLT),CTCLI(I,NNCLT),XFTI(KL),CNCLT,CTE1,TXCLI(I)
0186 IF (LIMIT.EQ.1) GO TO 591
0187 IF(ZJL.EQ.0) GO TO 395
0188 CALL UNINT(I1,ZJCLI,I),ZMCRL(I,NNCLT),ZJI,ZZCRL,LIMIT)
0189 DMN=ZMS(I1)-ZMCRT
0190 GO TO 3050
0191 3000 ZMCRT=ZMCRT+DMN(NNCLT)
0192 DMN=ZMS(2)-ZMCRT
0193 3050 XFFT(KL)=1.0
0194 IF(DMN) 396,396,399
0195 399 CTE2=CTE*TXCLI(KL)*TBL
0196 CALL BIQUAD (ZMMC,1,DMN,CTE2,XFFT(KL),LIMIT)
0197 396 NNCLT=NNCLT+1
0198 IF (NNCLT.EQ.1) GO TO 395
0199 CALL UNINT (4,CCLI(NNCLT),TXCLI(NNCLT),CLI,TCLI,LIMIT)
0200 CALL UNINT (4,CCLI(NNCLT),XFFT(NNCLT),CLI,XFT,LIMIT)
0201 IF(XFT.GT.1.0) XFT=1.0
0202 GO TO 394
0203 395 TCLI=TXCLI(NNCLT)
0204 XFT=XFFT(NNCLT)

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)
SUBROUTINE WAIT (WTCON, ZMWT, BHP, DIA, AFT, BLADT, TIPSPO, WT70, WT80)

IF(WTCON.LE.0.) RETURN

ZND=TIPSPO*60.*3.14159

ZN=ZND/DIA

ZK2=(DIA/10.)*2

ZK3=(BLADT/4.)*7

ZK4=AFT/100.

ZK5=ZND/20000.

ZK6=(BHP/10./DIA**2)*12

ZK7=(ZMWT+1.01)**5

WTFC=ZK2*ZK3*ZK6*ZK7

C WTCO DEFINES AIRPLANE CATEGORY

IWTCO=WTCO

ZC=3.5*ZK2*BLADT*ZK4**2*(1./ZK5)**3

GO TO (10,20,30,40,50), IWTCO

10 WT70=170.*WTFC*ZK4**.9*ZK5**.35

WT80=WT70

GO TO 60

20 WT70=200.*WTFC*ZK4**.9*ZK5**.35

WT80=WT70

GO TO 60

30 WT70=220.*WTFC*ZK4**.7*ZK5**.4+ZC*(5.0/3.5)

WT80=WT70

GO TO 60

40 WTFC=WTFC*ZK4**.7*ZK5**.4

WT70=270.*WTFC+ZC*(5.0/3.5)

WT80=190.*WTFC+ZC

GO TO 60

50 WT70=220.*WTFC*ZK4**.7*ZK5**.4+ZC*(5.0/3.5)

WT80=190.*WTFC*ZK4**.7*ZK5**.3

RETURN

FND

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

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FIGURE 3A, FORTRAN IV LISTING (CONTINUED)
SUBROUTINE UNINT ( N, XA, YA, X, Y, L)  

REWITTEN SEPTEMBER 18, 1967  

UNIVARIATE TABLE ROUTINE WITH SEPERATE ARRAYS FOR X AND Y - S 66  

THIS ROUTINE INTERPOLATES OVER A 4 POINT INTERVAL USING A  
VARIATION OF 2ND DEGREE INTERPOLATION TO PRODUCE A CONTINUITY  
OF SLOPE BETWEEN ADJACENT INTERVALS.  

DIMENSION XA(1), YA(1), D(4), P(5)  

L=0  

I=1  

TEST FOR OFF LOW END  NO # YFS  

IF ( XA(1)-X ) 100, 150, 10  

10  

L=1  

GO TO 150  

150  

NO 120 I=2,N  

IF ( XA(I)-X ) 120, 150, 200  

120 CONTINUE  

TEST FOR OFF HIGH END  

I = N  

L = 2  

150  

Y = YA(I)  

GO TO 999  

700  

IF(I-N) 240, 220, 240  

220  

FIRST INTERVAL  

RA = 1.  

GO TO 400  

400  

TEST FOR LAST INTERVAL  

240  

IF(I-N) 300, 250, 300  

300  

LAST INTERVAL  

250  

JX1 = N-3  

RA = 0.  

GO TO 400  

400  

LAST INTERVAL  

240  

IF(I-N) 300, 250, 300  

300  

GET COEFFICIENTS AND RESULTS  

J = JX1  

500  

NO 500 I=1,3  

507  

P(I) = XA(J+1) - XA(J)  

509  

D(I) = X - XA(J)  

511  

J = J+1  

513  

P(4) = P(1) + P(2)  

515  

P(5) = P(2) + P(3)  

517  

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(1)/P(4) * D(2) - RB/P(2)  
2 * D(4) + YA(JX1+2) *(RA/P(2) * D(1)/P(4) * D(2) - RB/P(2)  
3 * D(2)/P(3) * D(4) + YA(JX1+3) * RB/P(5) * D(2)/P(3) * D(3)  

999  

RETURN  

END  

FIGURE 3A, FORTRAN IV LISTING (CONTINUED)
SUBROUTINE RIQUAD (T, I, X(I), Y(I), Z, K)
ENTRY RIQUAD (T, I, X(I), Y(I), Z, K)
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.

DIMENSION T(I), XC(4), D(4), P(5), Y(4), C(4)
C
C EQUIVALENCE (XC(1), D(1))
C
C TABLE SET UP
C T(1) < # TABLE NUMBER
C T(2) < # NUMBER OF X< VALUES
C T(3) < # NUMBER OF Y< VALUES, FOR UNIVARIATE TABLE
C T(4) < # VALUES OF X< IN ASCENDING ORDER

NX = T(I+1)
NY = T(I+2)
J1 = I+3
J2 = J1 + NX - 1
X = X1

C SEARCH IN X SENSE
L = 0
C
GO TO 1000
C
RETURN HERE FROM SEARCH OF X
200 K = XX
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
C
RETURN HERE WITH COEFF. TEST FOR UNIVAR. OR BIVARIATE
220 IF (NY) 300,210,300
210 Z=0.

C SEARCH IN Y SENSE
JX1 < SUBSCRIPT OF 1ST Y
GO TO 1000
C
K = K+3*KK
C
SUBSCRIPT = HASF NO. OF COL. NO. OF YS
JY = J2+1 + (JX-1)*NY + JX1-J1
C
DO 550 M=1,4
550 JY = JY+1

C
C PRINT C. IN X SENSE
500 K = K+3*KK
C
SUBSCRIPT = HASF NO. OF COL. NO. OF YS
JY = J2+1 + (JX-1)*NY + JX1-J1
C
DO 550 M=1,4
550 JY = JY+1

FIGURE 3A. FORTRAN IV LISTING (CONTINUED)
FORTRAN IV G LEVEL 20.1  Riquad  DATE = 72031 08/48/14

550 JY = JY + 1

C GET COEFF, IN Y SFENSE

600 Z = 0.

DO 700 J=1,4

700 Z = Z + C(J)*Y(J)

9999 RETURN

C SEARCH ROUTINE - INPUT J1,J2,X

1000 KX = 0

DO 1040 J=1010,1050,1050

1040 CONTINUE

C OFF HIGH END

X = T(J2)

KX = 2

C USE LAST 4 POINTS AND CURVE B

1050 JX1 = J2-3

1051 RA = 0.

GO TO 1600

C TEST FOR - OFF LOW END, FIRST INTERVAL, OTHER

1053 IF(T(J)-X)1050,1050,700

1054 IF(T(J)-X)1080,1090,1100

1055 1082 KX = 1

1056 X = T(J1)

1057 1090 JX1 = J1

1058 RA = 1.

GO TO 1600

C TEST FOR LAST INTERVAL NO, YES, NO

1100 IF(J-J1-11800,1800,1800

1101 JX1 = J1

1102 IF(T(J)-X)1080,1090,1100

1103 X = T(J1)

1104 RA = 1.

GO TO 1400

C TEST FOR LAST INTERVAL NO, YES, NO

1150 IF(J-J1-11800,1800,1800

1151 JX1 = J1

1152 IF(T(J)-X)1080,1090,1100

1153 RA = 1.

GO TO 1400

C COEFFICIENT ROUTINE - INPUT X, X1, X2, X3, Y1, RA, RB

2000 DO 2010 J=1,3

2010 PI(J) = XC(J+1)-XC(J)

2011 PI(4)=P(1)+P(2)

2012 PI(5)=P(2)+P(3)

2040 DO 2020 J=1,4

2020 DI(J) = X-XC(J)

2021 C(1)=RA/P(1)*D(2)/P(4)*D(3)

2022 C(2)=(-RA/P(1))*D(1)/P(2)*D(3)+(RB/P(2))*D(2)/P(3)*D(4)

2023 C(3)=(RA/P(2))*D(1)/P(4)*D(2)-(RB/P(2))*D(2)/P(3)*D(4)

2024 C(4)=(RB/P(5))*D(2)/P(3)*D(3)

C RETURN TO MAIN BODY

600 IF(L) 600,200,600

END

FIGURE 3A. FORTRAN IV LISTING (CONCLUDED)