NASA CONTRACTOR REPORT

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

by Rose Worobel

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<td>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.</td>
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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.
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

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

\(C_{L1}\) propeller blade integrated design lift coefficient \[
4 \int_{0.15}^{1.0} C_{LD} x^3 dx
\]

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

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

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

D propeller diameter, ft

h maximum blade section thickness, ft

J advance ratio, \[
\frac{101.4 V_k}{N D}
\]

M free stream Mach number

N propeller speed, rpm

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

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

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

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

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

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

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

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

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

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

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

\[ \rho_o/\rho \quad \Theta/\delta \]

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

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

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:

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

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

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)
C \_T \quad - \quad \text{thrust coefficient}

T \_AF \quad - \quad \text{activity factor adjustment factor to thrust coefficient (ref. 1, fig. 3A)}

TC \_L \quad - \quad \text{integrated design lift coefficient adjustment factor to thrust co-efficient (ref. 2, fig. 6)}

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:

\[ J = \frac{101.4 V}{ND} \text{K} \]

\[ C \_Q = \frac{10^{11} \text{SHP} (\rho_o/\rho)}{4 \pi N^3 D^5} \]

\[ Q \_C = \frac{10^{11} \text{SHP} (\rho_o/\rho)}{4 \pi N^3 D^5} x \frac{1}{J^2} \quad \text{for } J > 1.0 \]

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

where:

- \( \text{SHP} \) - 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, \( \text{AF} \), 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 \( \text{AF} \), \( C_{L1} \) 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 \( \text{AF} \), and 0.3 to 0.8 \( C_{L1} \). The effective torque coefficients and thrust coefficients are defined as follows:

\[
C_{QE} = \left[ C_Q \times (3/B)^{0.83} \times Q_{AF} \right] - \Delta C_{QE2} \quad (\text{PCR}/100) \quad \text{for } J \leq 1.0
\]

\[
Q_{CE} = \left[ Q_C \times (3/B)^{0.83} \times Q_{AF} \right] - \Delta Q_{CE2} \quad (\text{PCR}/100) \quad \text{for } J > 1.0
\]

\[
C_{TE} = \left[ C_T \times (3/B)^{0.83} \times T_{AF} \right] - \Delta C_{TE2} \quad (\text{PCR}/100) \quad \text{for } J \leq 1.0
\]

\[
T_{CE} = \left[ T_C \times (3/B)^{0.83} \times T_{AF} \right] - \Delta T_{CE2} \quad (\text{PCR}/100) \quad \text{for } J > 1.0
\]

where:

- \( C_Q \) - torque coefficient for \( J \leq 1.0 \)

- \( (3/B)^{0.83} \) - number of blades, B adjustment

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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:

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

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

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
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.

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<td>E</td>
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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 periods 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. $C_{L_i}$ 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:


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, 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 = \( \frac{SHP \, (\rho_o/\rho) \times 10^{11}}{2 \, N^3D^5} \)

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

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 $C_{L_{i}}$ exceeds the permissible range of 0.3 to 0.8 $C_{L_{i}}$. 

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>
<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>h-6</td>
<td>150-300</td>
<td>150-300</td>
<td>Constant Speed</td>
<td>Private (Family) Survey, Business</td>
<td>3500-6000</td>
<td>$40-120K</td>
<td>CESSNA Super Skymaster, 310Q BEECH Turboprop, Barron 56 PIPER Twin Comanche C, Aztec 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 L18, L21, L22, L23, L24 BEECH Queen Air Duke PIPER Navajo 300, Turbo Navajo NORTH AMERICAN ROCKWELL-Shrike Commander BRITISH-NORMAN ISLANDER, Helio 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>$600-600K</td>
<td>DESIVALLAND Twin Otter MOONEY MD-20 NORTH AMERICAN ROCKWELL Hawk Commander BEECH King Air HANDLEY PAGE Jetstream</td>
</tr>
</tbody>
</table>
Generalized Propeller Weight Equation:

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

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)

- \( C_W = y \left( \frac{D}{10} \right)^2 \left( \frac{B}{4} \right) \left( \frac{A.F.}{100} \right)^u \left( \frac{20,000}{ND} \right)^{0.3} \) = Counterweight Wt., lbs.

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

Propeller types associated with above Kw and Cw 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 CL PROPELLER
FIGURE 2. THRUST COEFFICIENT CHART FOR A 2 BLADED, 150 ACTIVITY FACTOR, 0.500 INTEGRATED DESIGN $C_{L_i}$ 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
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

FIGURE 7. CATEGORY II PARAMETRIC STUDY
4 BLADES – 0.6 C_L1

FIGURE 8. CATEGORY IV PARAMETRIC STUDY
CATEGORY V
3 BLADES/109 AF/0.509 $C_L^*$

FIGURE 9. EXAMPLE REVERSE THRUST VARIATION WITH LANDING SPEED AND POWER SETTING
### SAMPLE CASE #1

1. **Airplane in Category I**
2. **SHP Input-Tip Speed and Diameter Variation-Cost and Weight**

<p>| | | | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
<td>100.</td>
<td>0.</td>
<td>1.</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>2.1</td>
<td>1.</td>
<td>0.187</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>2.5</td>
<td>1.</td>
<td>0.</td>
<td>1.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>52.5</td>
<td>0.</td>
<td>950.</td>
<td>-100.</td>
<td>5.</td>
<td>500.</td>
</tr>
<tr>
<td>5</td>
<td>112.</td>
<td>7000.</td>
<td>115.</td>
<td>0.</td>
<td>950.</td>
<td>-100.</td>
</tr>
</tbody>
</table>

### SAMPLE CASE #2

1. **Airplane in Category II**
2. **Thrust Input-Tip Speed and Diameter Variation-Cost and Weight**

<p>| | | | | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
<td>100.</td>
<td>0.</td>
<td>1.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>2.1</td>
<td>1.</td>
<td>0.26</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>2.5</td>
<td>1.</td>
<td>0.</td>
<td>1.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>150.</td>
<td>0.</td>
<td>1.</td>
<td>40.</td>
<td>0.</td>
<td>1.</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>820.</td>
<td>0.</td>
<td>71.5</td>
<td>0.</td>
<td>850.</td>
<td>-100.</td>
<td>5.</td>
</tr>
<tr>
<td>6</td>
<td>2370.</td>
<td>7500.</td>
<td>163.2</td>
<td>0.</td>
<td>950.</td>
<td>-100.</td>
<td>5.</td>
</tr>
</tbody>
</table>

**Figure 10. Sample Input Coding**
### Sample Case #3

<table>
<thead>
<tr>
<th></th>
<th>Description</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Airplane in Category IV</td>
<td>Sample Case 3</td>
</tr>
<tr>
<td>2</td>
<td>SHP Input - Calc. tipspeed for supercent stall - cost for range quant.</td>
<td>0.327, 0.0, 0.0, 0.0, 1.0, 1000.5</td>
</tr>
<tr>
<td>3</td>
<td>0.0, 0.0, 0.0, 1.0, 0.4, 2.0, 2.0</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>10.6, 1.0, 1.0</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>104.7, 77.5, 5.0, 500.0, 1.0, 1.0</td>
<td></td>
</tr>
</tbody>
</table>

### Sample Case #4

<table>
<thead>
<tr>
<th></th>
<th>Description</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Airplane in Category V</td>
<td>Sample Case 4</td>
</tr>
<tr>
<td>2</td>
<td>Reverse thrust option</td>
<td>0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0</td>
</tr>
<tr>
<td>3</td>
<td>0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>1.5, 1.0, 0.1, 9.3, 0.0, 1.0</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>1.5, 0.0, 0.0, 0.0, 1.0, 2.0</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>3.55, 0.0, 72.0, 100.0, 80.0, 1.0</td>
<td></td>
</tr>
</tbody>
</table>

**Figure 10 (Continued). Sample input coding**
1. **Sample Case 1**

### Operating Condition

<table>
<thead>
<tr>
<th>SHP</th>
<th>NO. OF ENGINES</th>
<th>UNIT FACTOR L.C.</th>
</tr>
</thead>
<tbody>
<tr>
<td>157</td>
<td>1</td>
<td>3.22</td>
</tr>
</tbody>
</table>

### Design Flight M = 0.187

<table>
<thead>
<tr>
<th>TEMP</th>
<th>FIELD POINT FT.</th>
</tr>
</thead>
<tbody>
<tr>
<td>510</td>
<td>500</td>
</tr>
</tbody>
</table>

**Number of Blades** = 7

**Activity Factor** = 100

<table>
<thead>
<tr>
<th>DIA. , T.S.FPS</th>
<th>THRUST</th>
<th>PNL</th>
<th>ANGLE</th>
<th>FT</th>
<th>M</th>
<th>J</th>
<th>CP</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.00</td>
<td>267</td>
<td>0.0</td>
<td>16.4</td>
<td></td>
<td>0.1782</td>
<td>0.642</td>
<td>0.0321</td>
</tr>
<tr>
<td>6.00</td>
<td>280</td>
<td>0.0</td>
<td>19.8</td>
<td></td>
<td>0.1782</td>
<td>0.718</td>
<td>0.0437</td>
</tr>
<tr>
<td>6.00</td>
<td>280</td>
<td>0.0</td>
<td>23.7</td>
<td></td>
<td>0.1782</td>
<td>0.814</td>
<td>0.0672</td>
</tr>
<tr>
<td>6.00</td>
<td>265</td>
<td>0.0</td>
<td>28.3</td>
<td></td>
<td>0.1782</td>
<td>0.939</td>
<td>0.1007</td>
</tr>
<tr>
<td>6.00</td>
<td>252</td>
<td>0.0</td>
<td>35.9</td>
<td></td>
<td>0.1782</td>
<td>1.110</td>
<td>0.1554</td>
</tr>
<tr>
<td>8.00</td>
<td>179</td>
<td>0.0</td>
<td>13.1</td>
<td></td>
<td>0.1782</td>
<td>0.649</td>
<td>0.0181</td>
</tr>
<tr>
<td>8.00</td>
<td>292</td>
<td>0.0</td>
<td>20.1</td>
<td></td>
<td>0.1782</td>
<td>0.814</td>
<td>0.0367</td>
</tr>
<tr>
<td>8.00</td>
<td>282</td>
<td>0.0</td>
<td>24.2</td>
<td></td>
<td>0.1782</td>
<td>0.939</td>
<td>0.0564</td>
</tr>
<tr>
<td>8.00</td>
<td>280</td>
<td>0.0</td>
<td>30.0</td>
<td></td>
<td>0.1782</td>
<td>1.110</td>
<td>0.0930</td>
</tr>
</tbody>
</table>

**Integrated Design CL = 0.500**

---

**Figure 11. Sample Output - SHP Option**
### Airplane in Category I

#### Sample Case 2

**Thrust Input - Tipspeed and Diameter Var. - Cost and Weight**

#### Operating Condition

**Thrust** = 820,  
**No. of Engines** = 4,  
**Unit Factor L.C.** = 3.22

**V-KTAS** = 71.2,  
**Classification** = 2.

**Temp R** = 519,  
**Field Point FT.** = 500.

**Number of Blades** = 4.

**Activity Factor** = 150.

**Integrated Design CL** = 0.500

#### Table

<table>
<thead>
<tr>
<th>DIA. FT.</th>
<th>T.S.FPS</th>
<th>SHP</th>
<th>PNL</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>850.00</td>
<td>226</td>
<td>0</td>
<td>21.5</td>
<td>1.00</td>
<td>0.2534</td>
<td>1.019</td>
<td>0.0919</td>
<td>0.0739</td>
</tr>
<tr>
<td>6.00</td>
<td>790.00</td>
<td>213</td>
<td>0</td>
<td>17.8</td>
<td>1.00</td>
<td>0.2534</td>
<td>1.019</td>
<td>0.0919</td>
<td>0.0739</td>
</tr>
<tr>
<td>6.00</td>
<td>750.00</td>
<td>208</td>
<td>0</td>
<td>21.5</td>
<td>1.00</td>
<td>0.2534</td>
<td>1.019</td>
<td>0.0919</td>
<td>0.0739</td>
</tr>
<tr>
<td>6.00</td>
<td>650.00</td>
<td>213</td>
<td>0</td>
<td>17.3</td>
<td>1.00</td>
<td>0.2534</td>
<td>1.019</td>
<td>0.0919</td>
<td>0.0739</td>
</tr>
<tr>
<td>6.00</td>
<td>500.00</td>
<td>242</td>
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<td>147</td>
<td>1.00</td>
<td>0.2534</td>
<td>1.019</td>
<td>0.0919</td>
<td>0.0739</td>
</tr>
<tr>
<td>6.00</td>
<td>550.00</td>
<td>233</td>
<td>0</td>
<td>19.1</td>
<td>1.00</td>
<td>0.2534</td>
<td>1.019</td>
<td>0.0919</td>
<td>0.0739</td>
</tr>
</tbody>
</table>

**Operating Condition**

**Thrust** = 370,  
**No. of Engines** = 1,  
**Design Flight M** = 0.762

**V-KTAS** = 71.2,  
**Classification** = 2.

**Temp R** = 492,  
**Field Point FT.** = 0.

**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. TIPSPEED 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>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>ALT-FT</th>
<th>DESIGN FLIGHT M.</th>
<th>1000 FACTOR L.C.</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.327</td>
<td>1.02</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>V-KTAS</th>
<th>CLASSIFICATION</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>77.5</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>TEMP R</th>
<th>FIELD POINT FT.</th>
</tr>
</thead>
<tbody>
<tr>
<td>519</td>
<td>500</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>DIA. FT. T.S.FPS</th>
<th>THRUST PNL</th>
<th>QUANTITY WT-LBS</th>
<th>$COST QUANTITY WT-LBS</th>
<th>$COST ANGLE FT M J CP CT</th>
</tr>
</thead>
<tbody>
<tr>
<td>8. 345</td>
<td>818</td>
<td>77</td>
<td>1. 228. 2106. 1. 185. 7770.</td>
<td>46.3 1.000 0.1172 1.194 0.9333 0.4473</td>
</tr>
<tr>
<td>1001</td>
<td>228</td>
<td>2252. 1001</td>
<td>185. 2463.</td>
<td></td>
</tr>
<tr>
<td>3001</td>
<td>228</td>
<td>1876. 3001</td>
<td>185. 2052.</td>
<td></td>
</tr>
<tr>
<td>4001</td>
<td>228</td>
<td>1788. 4001</td>
<td>185. 1956.</td>
<td></td>
</tr>
</tbody>
</table>

NUMBER OF BLADES = 6.
ACTIVITY FACTOR = 200.
INTEGRATED DESIGN CL = .600

<table>
<thead>
<tr>
<th>DIA. FT. T.S.FPS</th>
<th>THRUST PNL</th>
<th>QUANTITY WT-LBS</th>
<th>$COST QUANTITY WT-LBS</th>
<th>$COST ANGLE FT M J CP CT</th>
</tr>
</thead>
<tbody>
<tr>
<td>8. 282</td>
<td>828</td>
<td>74</td>
<td>1. 306. 11926. 1. 245. 12887.</td>
<td>51.2 1.000 0.1172 1.459 1.7021 0.6759</td>
</tr>
<tr>
<td>1001</td>
<td>306</td>
<td>3780. 1001</td>
<td>245. 4084.</td>
<td></td>
</tr>
<tr>
<td>3001</td>
<td>306</td>
<td>3149. 3001</td>
<td>245. 3403.</td>
<td></td>
</tr>
<tr>
<td>4001</td>
<td>306</td>
<td>3002. 4001</td>
<td>245. 3244.</td>
<td></td>
</tr>
</tbody>
</table>

FIGURE 13. SAMPLE OPTION - 50% STALL OPTION
HAMILTON STANDARD COMPUTER DECK NO. H432
COMPUTES PERFORMANCE, NOISE, FIGHT, AND COST FOR
GENERAL AVIATION PROPELLERS

1. AIRPLANE IN CATEGORY IV
   SAMPLE CASE 4

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 = 519.

NUMBER OF BLADES = 9, ACTIVITY FACTOR = 100, INTEGRATED DESIGN CL = 503

<table>
<thead>
<tr>
<th>THROTTLE REV MET</th>
<th>REVERSE REV MET</th>
<th>REV MET SHP</th>
<th>RPM</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.5 100. -12.9</td>
<td>0.0 524. 580. 2109.</td>
<td>619 547. 2198.</td>
<td></td>
</tr>
<tr>
<td>2.0 714. 543. 2172.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>70. 822. 938. 2151.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>60. 914. 941. 2124.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>50. 1049. 523. 2092.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>60. 1179. 914. 2056.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>70. 1313. 501. 2013.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9.5 40. -11.2</td>
<td>0.0 380. 440. 2119.</td>
<td>449 437. 2187.</td>
<td></td>
</tr>
<tr>
<td>2.0 565. 436. 2170.</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>40. 672. 436. 2149.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>40. 710. 425. 2124.</td>
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<td></td>
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</tr>
<tr>
<td>50. 918. 419. 2093.</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>60. 1035. 412. 2059.</td>
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<td></td>
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<tr>
<td>70. 1171. 404. 2029.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>77. 1294. 402. 2010.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9.5 60. -9.2</td>
<td>0.0 708. 330. 2200.</td>
<td>291 320. 2184.</td>
<td></td>
</tr>
<tr>
<td>10. 794. 294. 2184.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20. 386. 326. 2162.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>30. 495. 321. 2143.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>40. 612. 318. 2117.</td>
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<td></td>
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<tr>
<td>50. 737. 313. 2047.</td>
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<td></td>
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<tr>
<td>60. 961. 308. 2044.</td>
<td></td>
<td></td>
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<tr>
<td>70. 1007. 309. 2019.</td>
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</tr>
<tr>
<td>77. 1036. 302. 2010.</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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

YES

IS
NOISE
REQD?

CALCULATES
NOISE

NO

ARE
WEIGHT
& COST
REQD?

YES

CALCULATES
WEIGHT

NO

CALCULATES
COST

(WAIT)

PRINT
RESULTS

HAVE ALL
CONDITIONS FOR
THIS CASE
BEEN COMPUTED

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
DIMENSION FC(10), ALPRR(11), PRESRR(11), RORD(10), ZMS(2)

DIMENSION DIST(10), CQUN(2,11), COSTO(10), COST8(10)

DIMENSION BHPG(10), THRSTG(10), TIPSDG(11)

COMMON /ZINPUT/
BHP(10), THUSTR(10), ALT(10), VKTAS(10), T(10), TS(10)
L, IWIC(10), NOF, DO, DD, ND, AF, DAF, NAF, BLAD, DBLAD, NBL, DTS(10), NDTS(11)
2, DIST, XNOE, TC, ZMWT, STALIT(10), CLEI, CLF, CK70, CK80, CAMT, DMT, NMT
3, DCOSTO(10), CLI, DCLI, ZNCLI, RTC, ROT, PCPW(10), NPCPW(10), BETA(10),
4DCPCPW(10), RMCIC(10), ANDV(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 /

REAL*8 BLANK
COnHOH/AFCOR/AFCPE,AFCTE,XFT
COMHON/ASTRK/CPAST/CAST/ASTERK
COMHON/CPECTE/CPXCTE,BLLL

701 CONTINUE
WRITE (6,1)
FORMAT ('1',19X'HAMILTON  STANDARD  COMPUTER  DECK NO. H432'/17X*COMP
LUTES PERFORMANCE,NOISE,WEIGHT,AND COST FOR'/26X*GENERAL  AVIATION P
ZROPELLERS*)

1 FORMAT (*1,19X'HAMILTON STANDARD COMPUTER DECK NO. H432'/17X*COMP
LUTES PERFORMANCE,NOISE,WEIGHT,AND COST FOR'/26X*GENERAL  AVIATION P
ZROPELLERS*)

CALL INPUT
DO 700 IC=1,NOF
NCOST=DCOSTO(ICI)+.01
IF (STALLT(ICI,LE.50) GO TO 710
702 CONTINUE
C COMPUTATION
OF DENSITY
RATIO
IF (IC))100~100~160
100 IF (ALT(ICI)-36000~)120sl20~140
120 T( 16)~518.688-.00356+ALT(ICI)
GO TO 180
140 T(ICI)=389.988
GO TO 180
160 TO=518.69
180 TO=T(ICI)+459.69
TOT=TO/T(ICI)
FC(ICI)=SORTI  TOT)
RORO(ICI)=l.O/IPOP*TOT)
CALL UNINT(ll*ALTPRvPRESSR,ALT(ICI)*POPILIMIT)

C AF LOOP
AFT=AF-DAF
IF (IW.EQ.3) GO TO 7000
WRITE (6,706)
706 FORMAT (*0,18X*OPERATING CONDITION*)
FORTRAN IV G LEVEL 20.1  MAIN  DATE = 72034  10/08/04

0046  200  IENT=1
0047  CALL COST (WTCON,BLADT,CLFL,CLFC,CK70,CK80,AMT,AMT,NAMT,CQUNA(1,1
1,WT70,WT80,COST70,COST80,CCLFL,CCLFC,CK70,CK80,IENT)
0048  GO TO (210,230),1W
0049  210  WRITE (6,220) BHP(IC),XNOE,CLFL
0050  220  FORMAT( ' SHP =F7.0,9X*NO. OF ENGINES =F5.0,9X*UNIT FACTOR
1L,C. =F5.2)
0051  GO TO 250
0052  240  FORMAT( ' THRUST =F7.0,9X*NO. OF ENGINES =F5.0,9X*UNIT FACTOR
1L,C. =F5.2)
0053  230  WRITE (6,240) THRUST(IC),XNOE,CLFL
0054  250  IF(CK70.0. OR.CK80.0.) GO TO 255
0055  255  WRITE (6,252) ALT(IC),ZMWT,CLFL,VTAS(IC),WTCON,T(IDC),DIST(IDC)
0056  252  FORMAT( ' ALT-FT =F7.0,9X*DESIGN FLIGHT M. =F5.3,9X*1000 FACTO
1R L.C. =F5.2/1 V-KTAS =F7.1,9X*CLASSIFICATION =F5.0/1 TE
2MP R =F7.0,9X*FIELD POINT FT. =F5.0)
0057  GO TO 270
0058  255  WRITE (6,260) ALT(IC),ZMWT,CLFL,VTAS(IC),WTCON,CK70,T(IDC),
1DIST(IDC),CK80
0059  260  FORMAT( ' ALT-FT =F7.0,9X*DESIGN FLIGHT M. =F5.3,9X*1000 FACTO
1R L.C. =F5.2/1 V-KTAS =F7.1,9X*CLASSIFICATION =F5.0/1 TE
2UNIT COST 1970 =*F5.1/1 TEMP R =F7.0,9X*FIELD POINT FT. =
3*F5.0,9X*UNIT COST 1980 =F5.1)
0060  GO TO 270
0061  290  GO TO (10,12),1W
0062  10  WRITE (6,11) BHP(IC),XNOE
0063  11  FORMAT( ' SHP =F7.0,23X*NO. OF ENGINES =F5.0)
0064  GO TO 14
0065  12  WRITE (6,13) THRUST(IC),XNOE
0066  13  FORMAT( ' THRUST =F7.0,23X*NO. OF ENGINES =F5.0)
0067  14  WRITE (6,15) ALT(IC),ZMWT,VTAS(IC),WTCON,T(IDC),DIST(IDC)
0068  15  FORMAT( ' ALT-FT =F7.0,23X*DESIGN FLIGHT M. =F5.3/1 V-KTAS =F7
1.1,23X*CLASSIFICATION =F5.0/1 TEMP R =F7.0,23X*FIELD POINT
2 FT =F5.2)
0069  GO TO 270
0070  2000  WRITE (6,2100)
0071  2100  FORMAT( 'REVERSE THRUST COMPUTATION//'1)
0072  IF (ROT.EQ.1.) GO TO 2300
0073  WRITE (6,2200)
0074  2200  FORMAT( 'RECIPROCATING ENGINE//'1)
0075  GO TO 2400
0076  2300  WRITE(6,2350)
0077  2350  FORMAT( 'TURBINE ENGINE//'1)
0078  2400  WRITE (6,2500) BHP(IC),RPMC(IDC),ANDVK(IDC),ALT(IDC),T(IDC)
0079  2500  FORMAT( 'FULL THROTTLE RPM =F6.0/22X*FULL THROTTLE RPM =
1*F6.0/22X*FULL THROTTLE RPM =F6.0/22X*TEMPERATURE RANKINE =F
0.0/)
0080  270  DD 1200 IAF=1,NAF
0081  270  AFT=AFT+DAF
0082  IF(AFT.LT.200..AND.AFT.GE.80.) GO TO 182
0083  WRITE(6,181) AFT
0084  181  FORMAT( 'ILLEGAL ACTIVITY FACTOR =F8.1)
0085  GO TO 1200
0086  182  CONTINUE
0087  C INTEGRATED DESIGN CL LOOP
0088  NCL1=2,NCL1=1
0089  CL1=CL1-DCLI
0090  DO 1001 ICL=1,NCL1

FIGURE 3A. FORTRAN IV LISTING (CONTINUED)
CL1 = CL1 + DCLI
IF (CL1 .LE. 0.80001 .AND. CL1 .GE. 29999) GO TO 875
WRITE (6, 870) CL1
870 FORMAT (* ILLEGAL INTEGRATED DESIGN CL = ' , F5.3)
GO TO 1001
875 CONTINUE

C NO. OF BLADES LOOP
BLADT = BLADN - OBLAD
DO 1000 IB = 1, NBL
BLADT = BLADT + DRLAD
IF (BLADT .LE .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, CL1
2650 FORMAT ('O', *NUMBER OF BLADES = ' , F3.0, * ACTIVITY FACTOR = ' , F4.0, '
INTEGRATED DESIGN CL = ' , F4.3)
WRITE (6, 2660)
2660 FORMAT ('O', 'THROTTLE REVERSE', 'REV', 'DIA. FT SETTING A
INGLE V-KNOTS THRUST SHP RPM/')
GO TO 30
2700 WRITE (6, 21) BLADT, AFT, CL1
21 FORMAT ('O', *DIA. FT. T.S. FPS THRUST PNL ANGLE FT M
CP CT')
GO TO 30
24 WRITE (6, 25)
25 FORMAT ('O', 'DIA. FT. T.S. FPS SHP PNL ANGLE FT M
1 J CP CT')
GO TO 30
500 WRITE (6, 510)
510 FORMAT ('O', '1970 TECHNOLOGY *** 1980 TECHNOLOGY ***
1970 TECHNOLOGY *** 1980 TECHNOLOGY ***
1', 'DIA. FT. T.S. FPS THRUST PNL QUANTITY WT-LBS $COST QUANTITY
1', 'WT-LBS $COST ANGLE FT M J CP CT')
GO TO 30
550 WRITE (6, 560)
560 FORMAT ('O', '1970 TECHNOLOGY *** 1980 TECHNOLOGY ***
1970 TECHNOLOGY *** 1980 TECHNOLOGY ***
1', 'DIA. FT. T.S. FPS SHP PNL QUANTITY WT-LBS $COST QUANTITY
1', 'WT-LBS $COST ANGLE FT M J CP CT')
GO TO 30
30 CONTINUE

C DIAMETER LOOP
DIA = D - DD
DO 800 ID = 1, ND
800 DIA = DIA + DD
IF (IW .EQ. 3) GO TO 3000

C TIPSPEED LOOP
IF (STALETIC .LE. 50) GO TO 310
DTS (IC) = 0.
TRIG = 0.

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

ZMS(1) = .001512*VKTAS(IC)*FC(IC)
ZMS(2) = TIPSPO*FC(IC)/1120.
ZM1 = ZMS(1)
ZM2 = TIPSPO*FC(IC)/1120.

ZJI = 5.309*VKTAS/IC/TIPSPO

IF(ZJI .EQ. 0.) ZM1 = ZMS(2)
IF(STALIT(IC).LE..50..AND.ZJI.LE.5.0) GO TO 342
IF(STALIT(IC).GT..50..AND.ZJI.LE.3.0) GO TO 342
WRITE(6,341)

341 FORMAT(' ADVANCE RATIO TOO HIGH = ', F8.4)
GO TO 600

342 CONTINUE

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

IF(IN=0)
IF(STALIT(IC).LE..50.) GO TO 399
JWSV = 1W
I = 3
CALL PERF (3,CP,ZJI,AFT,BLADT,CI,CT,ZMS,7710)
IWSV = IWSV
IF(IW.EQ.0.) GO TO 712

711 BHPG(ITS) = 2.0*TIPSPO(ITS)**3*DIA**2*6966.*CP/(10.E10*RORO(IC))
IF(ABS(BHPG(ITS)-BHPG(ITS)).GE..005*BHPG(ITS)) GO TO 705
THUST(IC) = CT*TIPSPO**2*DIA**2/(1.515E06*RROO(IC))*364.76
TRIG = 1.
GO TO 720

705 IF(ITS.EQ.1) GO TO 7000
TIPS(ITS+1) = ALOG(BHPG(ITS))-ALOG(BHPG(ITS-1))
TIPS(ITS-1) = ALOG(BHPG(ITS-1))-ALOG(BHPG(ITS-1))
TIPS(ITS) = TIPS(ITS+1) + TIPS(ITS-1)
GO TO 700

700 TIPSPO = TIPS(ITS+1)
TIPSPO = TIPS(ITS+1)
TIPSPO = TIPS(ITS+1)
GO TO 600

THRG(ITS) = TIPS(ITS+2)*DIA**2*364.76*CT/(1.515E06*RROO(IC))
IF(ABS(THRG(ITS)-THRG(ITS)).GE..005*THRG(ITS)) GO TO 722
TIPSPO = TIPS(ITS)
BHPG(ITS) = CP*2.0*TIPSPO**3*DIA**2/(10.E10*RROO(IC))*6966.
TRIG = 1.
GO TO 720

722 IF(ITS.EQ.1) GO TO 7000
TIPS(ITS+1) = ALOG(THRSTG(ITS))-ALOG(THRSTG(ITS-1))
TIPS(ITS-1) = ALOG(THRSTG(ITS-1))-ALOG(THRSTG(ITS-1))
TIPS(ITS) = TIPS(ITS+1) + TIPS(ITS-2)

709 TIPSPO = TIPS(ITS+1)
IF(NTS.NE.ITS) GO TO 600
WRITE (6,598)

598 FORMAT(' FAILED STALL ITERATION USE 400% STALL')
GO TO 700

C END OF TIPSPO ITERATION 50 PERCENT STALL

C CALCULATION OF REQUIRED CP OR CT

399 IF(IW.EQ.0) WRITE 1,6,598

FIGURE 3A. FORTRAN IV LISTING (CONTINUED)
FIGURE 3A. FORTRAN IV LISTING (CONTINUED)
FORTRAN IV G LEVEL 20.1  MAIN  DATE = 72034  10/08/04

0238  588  CONTINUE
0239  GO TO 40
0240  730  GO TO (31,34),1W
0241  31  WRITE(6,32) DIA,TIPSPD,THRUST(IC),PNL,BLLL,L,XFT,ZM1,ZJI,CP,CT
0242  32  FORMAT(F7.2,F7.0,F9.0,F6.0,F6.1,F8.3,F7.4,F8.3,2F8.4)
0243  GO TO 40
0244  34  WRITE(6,32) DIA,TIPSPD,BHP(IC),PNL,BLLL,L,XFT,ZM1,ZJI,CP,CT
0245  40  IF(TRIG,EQ.1.) GO TO 750
0246  IF(ISTALL,EQ.2) GO TO 800
0247  IF(IFIN,EQ.7710) GO TO 800
0248  600  CONTINUE
0249  IF (W.LT.3) GO TO 750
C REVERSE THRUST CALCULATION
0250  3000  IRT=NCPW(IC)
0251  PCPW=PCPW(IC)
0252  DO 3900 I=1,IRT
0253  IF (RTC-1.) 3200,3100,3200
0254  3100  CP=BHP(IC)*PCPW*RORO(IC)*10.E10/(2.0*RPMC(IC)**3*DIAS**5*100.)
0255  3200  CALL REVTHRT (RTC,ROT,AFT,CLI,BLADT,DIA,CP,BETA(IC),RPOD(IC),
1  BHP(IC),RPMC(IC),PCPW,ANDV(K(IC))
0256  PCPW=PCPW+DPCPW(IC)
0257  3900  CONTINUE
0258  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)
FORTRAN IV G LEVEL 20.1

PERFM

DATE = 72034 10/08/04

X 1560., 2249., 3108., 4026.,
X 4900.,
X 5066., 7227., 20.00,

0017
DATA CPCLI/0.114, 0.294, 0.491, 0.698, 0.913, 1.486, 2.110, 2.802, 3.589,
1.4443, 5.368, 6.255, 0., 0.,
2.0294, 0.478, 0.678, 0.893, 1.118, 1.702, 2.355, 3.018, 3.775, 4.610, 5.505,
3.6331, 0.001,
4.0270, 0.324, 0.486, 0.671, 0.875, 1.094, 1.326, 1.935, 2.576, 3.259, 3.990,
5.4805, 5.664, 6.438,
6.0490, 0.524, 0.684, 0.868, 1.074, 1.298, 1.537, 2.169, 2.827, 3.512, 4.235,
7.5025, 5.848, 6.605,
8.0705, 0.743, 0.891, 1.074, 1.281, 1.509, 1.753, 2.407, 3.093, 3.775, 4.496,
9.5265, 6.065, 6.826,
A.0915, 0.973, 1.114, 1.290, 1.494, 1.723, 1.972, 2.646, 3.345, 4.047, 4.772,
B.5352, 6.307, 7.092,

0018
DATA CPEC /0.01, 0.02, 0.03, 0.04, 0.05, 0.06, 0.08, 0.10, 0.15, 0.20, 0.25,
1.30, 3.5, 40,

0019
DATA CTNG /0.030, 0.044, 0.058, 0.074, 0.105, 0.136,
X 1608., 1767., 1848., 1858.,
X 4900.,
X 1864., 1905., 20.00,
X 2070., 2045., 20.00,
X 2150., 30.00,
X 1964., 2213., 2414., 2505.,
X 4900.,
X 2678., 3071., 3318., 3416.,
X 4900.,
X 3487., 3596., 20.00,

0020
DATA CPSIAL /0.05, 0.12, 0.22, 0.35, 0.49, 0.65, 0.82, 1.01, 1.19,
2.16, 2.49, 0.75, 1.05, 1.37, 1.74, 2.13, 2.53,
3.30, 4.71, 7.51, 1.1, 1.51, 1.96, 2.41, 2.86, 3.30,
4.45, 7.1, 1.03, 1.40, 1.89, 2.45, 2.96, 3.55, 4.1,

0021
DATA CYCL /0.001, 0.021, 0.040, 0.060, 0.089, 0.125, 0.170, 0.217, 0.2501,
1.2490, 3.148, 3.316, 0.00,
2.0158, 0.0362, 0.0563, 0.0761, 0.0954, 0.419, 0.186, 0.2287, 0.2869, 0.3013, 3.317,
3.3460, 0.00,
4.0, 0.0083, 0.0297, 0.5070, 0.713, 0.916, 0.0114, 0.1585, 0.2032, 0.2456, 0.2834,
5.3191, 3.3487, 3.3626,
6.0130, 0.208, 0.0428, 0.0645, 0.0857, 0.1064, 0.1267, 0.1478, 0.2195, 0.2619, 0.2995,
7.3350, 3.647, 3.802,
8.026, 0.301, 0.0552, 0.0776, 0.0994, 0.1207, 0.1415, 0.1907, 0.2357, 0.2778, 0.3156,
9.3505, 3.808, 3.990,
A.0365, 0.0449, 0.0612, 0.0899, 0.1125, 0.1344, 0.1556, 0.2061, 0.2517, 0.2937, 0.3315,
B.3656, 3.963, 4.186,

0022
DATA CTEC /0.01, 0.03, 0.05, 0.07, 0.09, 0.12, 0.16, 0.20, 0.24, 0.28, 0.32, 0.36, 0.4,
1.44,

FIGURE 3A. FORTRAN IV LISTING (CONTINUED)
FIGURE 3A. FORTRAN IV LISTING (CONTINUED)
FIGURE 3A. FORTRAN IV LISTING (CONTINUED)
FORETRAN IV GLEVEL 20.1

PERFM.

DATE = 72035

0042  KK=1
0043  'ASTERK=999999

C AN ADJUSTMENT FOR CP AND CT FOR AF

DO 120 K=1,2
0045  CALL UNINT(6.,AFVAL(1),AFCP(C(1),K),AFT,AFCP(K),LIMIT)
0046  CALL UNINT(6.,AFVAL(1),AFCT(1),K),AFT,AFCT(K),LIMIT)
0047  120 CONTINUE
DO 100 K=3,7
0048  AFCP(K)=AFCP(2)
0049  AFT(C(K)=AFT(2)
0050  100 AFCT(K)=AFCT(2)
0051  IF(ZJI.GT.5) GO TO 105
0052  AFCE=2.*ZJI*AFCP(2)-AFCP(1)+AFCP(1)
0053  AFCT(K)=AFCT(2)
0054  GO TO 110
0055  105 AFCE=AFCP(2)
0056  AFCTE=AFCT(2)
0057  110 IF(ZJI.GT.1.0) GO TO 140
0058  NBEG=1
0059  NEND=4
0060  GO TO 148
0061  140 IF(ZJI.GT.1.5) GO TO 142
0062  NBEG=2
0063  NEND=5
0064  GO TO 148
0065  142 IF(ZJI.GT.2.0.AND.IW.LT.3) GO TO 147
0066  NBEG=3
0067  NEND=6
0068  GO TO 148
0069  147 NBEG=4
0070  NEND=7
0071  148 CONTINUE
0072  NCL=0
0073  DO 130 II=1,6
0074  IZ=II
0075  IF(ABS(CLI-CCL1(II)).LT.0009) GO TO 135
0076  130 CONTINUE
0077  IF(CLI.GT.6) GO TO 131
0078  NCL=1
0079  NCLT=4
0080  GO TO 119
0081  131 IF(CLI.GT.7)GO TO 132
0082  NCL=2
0083  NCLT=5
0084  GO TO 119
0085  132 NCL=3
0086  NCLT=6
0087  GO TO 119
0088  135 NCLT=1Z
0089  NCL=1
0090  NCLT=1Z
0091  119 CONTINUE
0092  NB=BLADT+1
0093  LMOD=MOD(NB,2)+1

FIGURE 3A. FORTRAN IV LISTING (CONTINUED)
GO TO (160,180),LMOD
160 NBB=1
L=BLADT/2.+1
GO TO 200
180 NBB=4
L=1
200 DO 500 IBB=1,NBB
C J INTERPOLATION
DO 300 K=NBEG,NEND
208 GO TO (210,250,212),IW
212 CALL UNINT (9,ZJSTAL,CTSTAL(1,L),ZJJ(K),CTT(K),LIMIT)
214 CALL UNINT (9,ZJSTAL,CPSTAL(1,L),ZJJ(K),CPP(K),LIMIT)
216 CALL UNINT (INN(K),CPANG(1,K,L),BLDANG(1,K),CPP(K),BLL(K),LIMIT)
218 CPE=CPE*AFCP(K)
219 CALL UNINT (14,CPEC(1),BLDCR(1,L),CPE,PBL,IMIT)
220 CPE=CPE*PBL*PFCLI(K)
221 NNCLT=NNCLT+1
222 CALL UNINT (NCLX(NNCLT),CPCLI(1,NNCLT),XPCLI(1,NNCLT),CPE,PKCLI
1(KL),IMIT)
223 IF (IMIT.EQ.1) GO TO 591
224 IF (INCL.EQ.1) GO TO 220
225 CALL UNINT (4,CCLI(NNCLT),PCLI(NNCLT),CPE,PKCLI,IMIT)
226 GO TO 221
227 PCLI=PKCLI(NNCLT)
228 CONTINUE
CPE=CPE*PKCLI
229 CALL UNINT (INN(K),CPANG(1,K,L),BLDANG(1,K),CPE,BLL(K),LIMIT)
230 CALL UNINT (INN(K),BLDANG(1,K),CTANG(1,K,L),BLL(K),CTT(K),LIMIT)
231 IF (IMIT.EQ.1) GO TO 221
232 GO TO 2501
233 CONTINUE
234 GO TO 2501
235 NNCLT=NNCLT+1
236 Dn
237 2200 DO 260 KL=NNCLT,NCLTT
238 CTA(1)=CT
239 CTA(2)=1.5*CT
240 DO 2600 KJ=1,5
241 NFXT=KJ
242 CTE=CTA(KJ)*AFCT(K)
243 CALL UNINT (14,CTE(1),BDCR(1,L),CTE,TFCLI,IMIT)
244 CTE=CTE*TFCLI(KL)
245 CALL UNINT (NCLX(NNCLT),CTCLI(1,NNCLT),XTCLI(1,NNCLT),CTE,TXCLI
1(KL),IMIT)
246 IF (IMIT.EQ.1) GO TO 591
247 9998 IF(ZIJ(K),EQ.0.) GO TO 40CO
248 CALL UNINT (11,ZJCLL(1),ZMCRL(1,NNCLT),ZJJ(K),ZMCRT,IMIT)
249 9999 DMN=ZMS(1)-ZMCRT
250 GO TO 4050
251 ZMCRT=ZMCRL(NNCLT)
252 DMN=ZMS(2)-ZMCRT
253 4050 XFFT(KL)=1.0
254 IF(DMN) 2300,2300,252
255 CTE2=CTE1*TXCLI(KL)/TFCLI(K)
256 CALL BIQUAD (ZMMCG,1,DMN,CTE2,XFFT(KL),IMIT)
257 CONTINUE
258 GO TO 4050
259 CONTINUE
260 DMN=ZMS(2)-ZMCRT
261 4050 XFFT(KL)=1.0
262 IF(DMN) 2300,2300,252
263 CTE2=CTE1*TXCLI(KL)/TFCLI(K)
264 CALL BIQUAD (ZMMCG,1,DMN,CTE2,XFFT(KL),IMIT)
265 CONTINUE
266 GO TO 4050
267 CONTINUE
268 IF (ICTA1(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(XCTA(KJ-1)-XCTA(KJ))/XCTA.KJ.LE.0.001) GO TO 2700
XCTA(KJ+1)=XCTA(KJ-1)*(XCTA(KJ)-XCTA(KJ-1))/((XCTA(KJ)-XCTA(KJ-1))+
1.0)

2600 CONTINUE
WRITE (6,391)
2700 CTK(KL)=CTA(NFTX)/XFT(KL)

320 NNCLT=NNCLT+1
IF(NNCLT.LE.1) GO TO 2700
CALL UNINT(4,NCL(NNCLT),XCL(NNCLT),CLI,CTK,LIMIT)
CALL UNINT(4,NCL(NNCLT),XFT(NNCLT),CLI,XFT(KL),LIMIT)
GO TO 271
270 TCL=TXCLI(NNCLT)
XFT(KL)=XFT(NNCLT)
CTK(KL)=CTN(NNCLT)

271 CTE=CTT(KL)*AFCT(KL)*TCLI
CALL UNINT(INN(KL),CTANG(KL),BLDANG1(KL),CTE,BLL(KL),LIMIT)
CALL UNINT(INN(KL),CTANG1(KL),CPANG(KL),BLD(KL),CPP(KL),LIMIT)
IF(LIMIT.EQ.0) GO TO 2501
GO TO 591

2501 CONTINUE

300 CONTINUE
CALL UNINT(4,ZJJ(NBEG),BLL(NBEG),ZJI,BLL(KL),LIMIT)
BLLL=BLL(KL)
GO TO (310,350,310)
310 CALL UNINT(4,ZJJ(NBEG),CTT(NBEG),ZJI,CTT(KL),LIMIT)
CTG(1)=.100
CTG(2)=.200
CALL UNINT(7,ZJJ(1),TFCLI(1),ZJI,TFCLI(1),LIMIT)
DO 390 IL=1,5
CT=CTG(IL)
CTE=CTG(IL)*AFCTE
CALL UNINT(14,CTEG(IL),BTDCR(IL),CTE,TBL,LIMIT)
CTE=CTE*TBL*TFCLI
390 CONTINUE

71 CTEZ=CTE*TCLI(KL)*TBL

396 XFT(KL)=1.0
IF (XFT.GT.1.0) XFT=1.0

GO TO 394
3000 ZMCR=ZMCR0(NNCLT)
3050 XFT(KL)=1.0
IF(DMN) 396,396,399
399 CTE2=CTE*XFTX(CL(KL))TBL
CALL BIQUEAD(ZMMC1,DMN,CTE2,XFTX(KL),LIMIT)
396 NNCLT=NNCLT+1
IF(NNCLT.LT.1) GO TO 395
CALL UNINT(4,NCL(NNCLT),XCL(NNCLT),CLI,CTK(LIMIT)
CALL UNINT(4,NCL(NNCLT),XFT(NNCLT),CLI,XFT(LIMIT)
IF(XFT.GT.1.0) XFT=1.0

FIGURE 3A. FORTRAN IV LISTING (CONTINUED)
394 CT=CTG(IL)
0205 CTE=CTG(IL)*AFCT*TCP
0206 CTG(IL)=CTE-CTT(IIBB)
0207 IF(ABS(CTG(IL)/CTT(IIBB)) .LT. 0.001) GO TO 392
0208 IF(IL.LE.1) GO TO 390
0209 CTG(IL+1)=-CTG(IL-1)*(CTG(IL)-CTG(IL-1))/(CTG(IL)-CTG(IL-1)) +
1*CTG(IL-1)
0210 390 CONTINUE
0211 391 FORMAT(1X,'INTEGRATED DESIGN CL ADJUSTMENT NOT WORKING PROPERLY FOR
0212 XR CT DEFINITION*)
0213 392 GO TO 360
0214 393 IF(XFT.GT.1.X) XFT=1.0
0215 CT(TT(IIBB)=CT
0216 CALL UNINT (4,ZJJ(NBEG),XFT1(NBEG),ZJI,XFT,LIMIT)
0217 IF(XFT1.GT.1.X) GO TO 360
0218 CALL UNINT (4,ZJJ(NBEG),CPP(NBEG),ZJI,CPPP(IIBB),LIMIT)
0219 CPG(II)=.150
0220 CPG(2)=.200
0221 CALL UNINT (4,ZJJ(NBEG),PFCLI(NBEG),ZJI,PFCLI,LIMIT)
0222 DO 290 IL=1,5
0223 CP=CPG(IL)
0224 CPE=CPG(IL)*AFCE
0225 CALL UNINT (14,CPEC(1),BLDCL(1,1),CPE,PBL,LIMIT)
0226 CPEL=CPE*PBL*PFCLI
0227 NNCLT=NNCLT
0228 DO 280 KL=NNCLT,NNCLT
0229 CALL UNINT (NNCLX(NNCLT),CPCLI(1,NNCLT),XPCLI(1,NNCLT),CPP1,CPCLI(1
1K),LIMIT)
0230 IF(LIMIT.EQ.1) GO TO 591
0231 280 NNCLT=NNCLT+1
0232 IF(NNCL.EQ.1) GO TO 282
0233 CALL UNINT (4,CPCLI(NNCLT),CPCLI(LIMIT)
0234 282 GO TO 284
0235 283 PCLI=PXCLI(NNCLT)
0236 284 CP=CPG(IL)
0237 CPE=CPG(IL)
0238 CPG(IL)=CPE-CPPP(IIBB)
0239 IF(ABS(CPG(IL)/CPPPP(IIBB)) .LE. 0.001) GO TO 287
0240 IF(IL.EQ.1) GO TO 290
0241 CPG(IL+1)=-CPG(IL-1)*(CPG(IL)-CPG(IL-1))/((CPG(IL)-CPG(IL-1))+
1CPG(IL-1)
0242 290 CONTINUE
0243 291 WRITE (*,285)
0244 285 FORMAT(1X,'INTEGRATED DESIGN CL ADJUSTMENT NOT WORKING PROPERLY FOR
0245 1CP DEFINITION*)
0246 287 CPPP(IIBB)=CP
0247 360 L=L+1
0248 500 CONTINUE
0249 IF(NBB-1) 510,590,510
0249 510 CALL UNINT (4,XXB1,I,BLLL1,BLADT,BLLL,LIMIT)
0250 GO TO 520,520,520
0251 520 CALL UNINT (4,XXBI1,CTT1,BLADT,CT,LIMIT)
0252 521 GO TO 590
0253 530 CALL UNINT (4,XXB1,CPPP1,BLADT,CP,LIMIT)
0254 590 CONTINUE
0255 591 CT=ASTEKR
0256 592 CP=ASTEKR
0257

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,TIPSPD,WT70,WT80)

IF(WTCON.LE.0.) RETURN
ZND=TIPSPD*60./3.14159
ZN=ZND/DIA
ZK2=(DIA/10.)**2
ZK3=(BLADT/4.)**.7
ZK4=AFT/100.
ZK5=ZN/20000.
ZK6=(BHP/10./DIA**2)**.12
ZK7=(ZMWT+1.0)**.5

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.*WTFAC*ZK4**.9*ZK5**.35
WT80=WT70
GO TO 60

20 WT70=200.*WTFAC*ZK4**.9*ZK5**.35
WT80=WT70
GO TO 60

30 WT70=220.*WTFAC*ZK4**.7*ZK5**.4+ZC*(5.0/3.5)
WT80=WT70
GO TO 60

40 WTFA=WTFA*ZK4**.7*ZK5**.4
WT70=220.*WTFA+ZC*(5.0/3.5)
WT80=190.*WTFAC+ZC
GO TO 60

50 WT70=220.*WTFA*ZK4**.7*ZK5**.4+ZC*(5.0/3.5)
WT80=190.*WTFA*ZK4**.7*ZK5**.3
60 RETURN

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

```
2.0107, 0.0089, 0.0689, 0.0649, 0.0300, 0.011, -0.004, -0.019, -0.033,
4.0202, 0.0167, -0.0212, 0.085, 0.049, 0.012, -0.020, -0.043, -0.072,
6.0353, 0.0272, 0.0195, 0.0128, 0.0070, 0.016, -0.030, -0.065, -0.093,
9.0491, 0.0379, 0.0278, 0.0180, 0.0091, 0.0075, -0.026, -0.062, -0.080,
1.0629, -0.0493, 0.0366, 0.0220, 0.0220, 0.0100, 0.0037, -0.012, -0.046, -0.062
0011 DATA GQGCZ/ 10.8, 0., 0.019, 0.028, 0.039, 0.056, 0.021, 0.017, 0.024,
1.731, -3.5, 6.3, -7.9, 10., -15., -20., -30. /
0012 DATA ASSJ / 0, 25, 50, 75, 100, 1.25, 1.50, 1.75, 2.00 /
0013 CORT(X)=ABS(X)**2/(.4/.3)*X/ABS(X).
0014 CALL BIQUAD (TAFU1,1,AFT,CLT1,TAF,LIMIT)
0015 CALL RIQUAD (QAFU1,1,AFT,CLT,QA1,LIMIT)
0016 IF (RTC-1) 20, 10, 70
0017 10 CPDP=CP/(6.2832*(3.0/BLADN)**.83)*QA1
0018 CALL BIQUAD (QCFCP1,1,ASSJ11,CLT1,DCFCP1,LIMIT)
0019 CPDP=CPDP-DCFCP1
0020 CALL BIQUAD (QCFCP1,1,CPQ,CPQ,THETA,LIMIT)
0021 20 DO 50 I=1,5
0022 CALL BIQUAD (QCFCP1,1,ASSJ11,THETA,CTP,LIMIT)
0023 CALL BIQUAD (TCP1,1,ASSJ11,THETA,CTP,LIMIT)
0024 CALL BIQUAD (CPHC1,1,ASSJ11,THETA,CPHC,LIMIT)
0025 IF(PCHC1.GT.1.) PCHC=1.
0026 CALL BIQUAD (QCFCP1,1,ASSJ11,CLT1,DCFCP1,LIMIT)
0027 DCTPP=.0975*CLT1-.039
0028 CT0=(CTP+CPHC1*DCFCP1)*.62832/(QA1*(3.0/BLADN)**.83)
0029 CT=(CTP+CPHC1*DCFCP1)/(TAFU1*(3.0/BLADN)**.83)
0030 IF(ROT.F0.1.) GO TO 30
0031 CONST=RHPI/RPMI*PCPW/100.
0032 RPMC(I)=SQRT(1.0+RORO*CONST/(2.0*DIA**5*CP))
0033 IF(RPMC(I).GT.RPMI) ANF.RTC.NF.2.) RPMC(I)=RPMI
0034 BHPC(I)=CONST*RPMC(I)
0035 GO TO 30
0036 30 BHPC(I)=BHPI*PCPW/100.
0037 CONST=10.0+10*BHPC(I)*RORO/(2.0*DIA**5*CP)
0038 RPMC(I)=CRCT(CONST)
0039 40 VKC(I)=ASSJ111*RPMC(I)/DIA101.4
0040 THRC(I)=CT0*RPMC1**2*1.5**4/(1.514*10.5*E5*ROR0)
0041 THRC(I)=ABS(THRC(I))
0042 50 CONTINUE
0043 NNJ=5
0044 IF (VKC(I).LT.GT.AN DKV) GO TO 90
0045 DO 80 I=6,9
0046 TJ=1./ASSJ11
0047 CALL BIQUAD (UCPC111,TJ,THETA,QCP,LIMIT)
0048 CALL RIQUAD (TCP111,TJ,THETA,TCP,LIMIT)
0049 CP=QCP(1)*6.2832/(QA1*(3.0/BLADN)**.83)/TJ**2
0050 CT=(TCP(1)/(TAFU1*(3.0/BLADN)**.83)/TJ**2
0051 IF (ROT.EQ.1.) GO TO 60
0052 CONST=RHPI/RPMI*PCPW/100.
0053 RPMC(I)=SQRT(1.0+RORO*CONST/(2.0*DIA**5*CP))
0054 BHPC(I)=CONST*RPMC(I)
0055 GO TO 30
0056 60 BHPC(I)=BHPI*PCPW/100.
0057 CONST=10.0+10*BHPC(I)*RORO/(2.0*DIA**5*CP)
0058 RPMC(I)=CRCT(CONST)
0059 70 VKC(I)=DIA**5*RPMC(I)/TJ**101.4
0060 THRC(I)=CT0*RPMC1**2*DIA**4/(1.514*10.5*E5*ROR0)
0061 THRC(I)=ABS(THRC(I))
0062 NNJ=NNJ+1
```
FIGURE 3A, FORTRAN IV LISTING (CONTINUED)
SUBROUTINE UNINT (N, XA, YA, X, Y, L)
C
REFORMED SEPTEMBER 18, 1967
C
UNIVARIATE TABLE ROUTINE WITH SEPARATE 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
C
DIMENSION XA(1), YA(1), D(4), P(5)
C
L=0
C
I=1
C
TEST FOR LOW END NO # YES
C
IF ( XA(1)-X ) 100, 150, 10
C
10  L=1
C
GO TO 150
C
100  NO 120 I=2,N
C
IF ( XA(I)-X ) 120, 150, 200
C
120  CONTINUE
C
OFF HIGH END
C
I = N
C
L= 2
C
150  Y= YA(I)
C
GO TO 999
C
TEST FOR FIRST INTERVAL
C
700  IF(I-1) 240, 220, 240
C
FIRST INTERVAL
C
220  JXI = 1
C
RA = 1.
C
GO TO 400
C
TEST FOR LAST INTERVAL
C
240  IF(I-N) 300, 250, 300
C
LAST INTERVAL
C
250  JXI = N-3
C
RA = 0.
C
400  GO TO 400
C
300  JXI = I-2
C
RA = (XA(I)-X) / (XA(I)-XA(I-1))
C
GET COEFFICIENTS AND RESULTS
C
0026  J = JXI
0027  DO 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(JXI) + RA/P(1) * D(2)/P(4) * D(3) +
1 YA(JXI+1) + (-RA/P(1) * D(1)/P(2) * D(3) + RB/P(2) * D(3)/P(5) -
2 *D(4)) + YA(JXI+2) *(RA/P(2) * D(1)/P(4) * D(2) - RB/P(2) -
3 *D(2)/P(3) * D(4)) + YA(JXI+3) * RB/P(5) * D(2)/P(3) * D(3)
C
999  RETURN
C
END
C
C
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.

DIMENSION T(I), XI(4), YI(4), Z(4), D(I)
EQUVALENCE (XI(I), D(I))

C TABLE SET UP
C T<  # TABLE NUMBER
C T< # NUMBER OF "XX" VALUES
C T< # NUMBER OF "YY" VALUES. FOR UNIVARIATE TABLES
C T< # VALUES OF "XX" IN ASCENDING ORDER

NX = T(I+1)
NY = T(I+2)
JI = I+3
J2 = J1 + NX - 1
X = XI
SEARCH IN X SENSE
L = 0
GO TO 1000

C 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
X(J) = T(JX1)
110 JX1 = JX1 + 1
GET COEFF. IN X SENSE
GO TO 2000

C RETURN HERE WITH COEFF. TEST FOR UNIVARIATE OR BIVARIATE

200 IF (NY) 300,210,300
210 Z=0.
220 JY = JX + NY
230 Z = Z + (J(J))*T(JY)
240 JY = JY + 1
GO TO 250
C UNIVARIATE TABLE
300 L=1
310 X = YI
320 J1 = J2 + 1
330 J2 = J1 + NY - 1
SEARCH IN Y SENSE JX1 # SUBSCRIPT OF 1ST Y
GO TO 1000
350 K = K+3*XX
C INTERPOLATE IN X SENSE
C SUBSCRIPT = HASF NO. OF COL. NO. OF YS
JY = J2+1 + (JX-I-2)*NY + JX1-J1
370 M=1,4
380 JX = JY
390 Y(M) = 0.
400 JY = JY + 1
410 Y(M) = Y(JY) + (J(J))*T(JX)
GO TO 520
520 JX = JY + 1

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

RIQUAD

DATE = 72031

0038 550  JY = JY+1
C
C GET COEFF. IN Y SFNSE
0039 600   Z = 0.
0040 700   DO 700  J=1,4
0041 700   Z = Z + C(J)*Y(J)
0042 9999  RETURN
C
C SFARCH ROUTINE - INPUT J1,J2,X
C
C -OUTPUT RA,RR,KX,JX1
0044 1000  KX = 0
0045 1010   DO 1010  J=1010 J=J1,J2
0046 1010   IF (T(J)-X) 1010 1050 1050
0047 1010 CONTINUE
C
C OFF HIGH END
0048 1050  X = T(J2)
0049 1050  KX = 2
C
C USF LAST 4 POINTS AND CURVE B
0050 1060  JX1 = J2-3
0051 1060  RA = 0.
0052 1060  GO TO 1600
C
C TEST FOR -- OFF LOW END, FIRST INTERVAL, OTHER
0053 1080  IF(J-J1-1) 1080 1090 1090
0054 1080  IF(T(J)-X) 1080 1090 1090
0055 1082  KX = 1
0056 1090  X = T(J1)
0057 1090  JX1 = J1
0058 1090  RA = 1.
0059 1090  GO TO 1600
C
C TEST FOR LAST INTERVAL NO, YES, NO
0060 1100  IF (J - J2) 1100 1150 1150
0061 1150  JX1 = J2-3
0062 1150  RA = (T(J) - X)/(T(J) - T(J-1)
0063 1150  RB = 1. - RA
C
C RETURN BACK TO MAIN BODY
0064 1600  IF (L) 500, 100, 500
C
C COEFFICIENT ROUTINE - INPUT X, X1, X2, X3, X4, RA, RB
0065 2000  NO 2010  J=1,3
0066 2010  P(J) = XC(J+1)-XC(J)
0067 2030  P(4)=P(1)+P(2)
0068 2050  P(5)=P(2)+P(3)
0069 2070  NO 2080  J=1,4
0070 2080  P(D(J)) = X-XC(J)
0071 2090  C(1)=(RA/P(1) )*D(2)/P(4) *D(3)
0072 2090  C(2)=(-RA/P(1) )*D(1)/P(2) *D(3)+(RB/P(2))*D(3)/P(5)*D(4)
0073 2090  C(3)=((RA/P(2)))*D(1)/P(4)*D(2)-(RB/P(2))*(D(2)/P(3))*D(4)
0074 2090  C(4)=(RB/P(5))*(D(2)/P(3))*D(3)
C
C RETURN TO MAIN BODY
0075 600, 200, 600
0076

FIGURE 3A. FORTRAN IV LISTING (CONCLUDED)