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

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16. Abstract

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, $\frac{100,000}{16} \int_{-0.15}^{1.0} \left(\frac{b}{D}\right) x^3 \, dx$
b	blade section width, ft
B	number of blades
C_{L_D}	blade section design lift coefficient
C_{L_i}	propeller blade integrated design lift coefficient $4 \int_{0.15}^{1.0} C_{L_D} x^3 \, dx$
C_P	power coefficient, $\frac{SHP\ (\rho_0/\rho)\ 10^{11}}{2N^3D^5}$
C_Q	torque coefficient for $J \leq 1.0$, $\frac{SHP\ (\rho_0/\rho)\ 10^{11}}{4\pi\ N^3D^5}$
C_T	thrust coefficient, $\frac{1.514 \times 10^6 T\ (\rho_0/\rho)}{N^2D^4}$
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	torque coefficient for $J > 1.0$, $\frac{SHP(\rho_o/\rho)\ 10^{11}}{4\pi\ N^3 D^5} \times \frac{1}{J^2}$
R	blade radius at propeller tip, ft
r	radius at blade element, ft
SHP	shaft horsepower
T	propeller thrust, pounds
T_C	thrust coefficient for $J > 1.0$, $\frac{1.514 \times 10^6\ T(\rho o/\rho)}{N^2 D^4} \times \frac{1}{J^2}$
V_K	freestream velocity, knots
x	fraction of propeller tip radius, r/R
$\beta_{3/4}$	propeller blade angle at 3/4 radius
ρ	density, lb sec^2/ft^4
ρ_o	density at sea level standard day, 0.002378 lb sec^2/ft^4
ρ_o/ρ	Θ/δ
Θ	ratio of absolute temperature to absolute temperature at sea level, T/T_o
δ	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_i}.

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

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.

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

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

$$J = \frac{101.4\ V_k}{ND}$$

where:

SHP - shaft horsepower

ρ_o/ρ - 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_{P_E} and effective thrust coefficient, C_{T_E} were introduced. The effective power and thrust coefficients are defined as follows:

$$C_{P_E} = C_P \times P_{AF} \times PC_{L_i}$$

$$C_{T_E} = C_T \times T_{AF} \times TC_{L_i}$$

where:

C_P - power coefficient

P_{AF} - activity factor adjustment to power coefficient (ref. 1, fig. 3A)

PC_{L_i} - integrated design lift coefficient adjustment factor to power coefficient (ref. 2, fig. 4)

C_T - thrust coefficient

T_{AF} - activity factor adjustment factor to thrust coefficient (ref. 1, fig. 3A)

TC_{L_i} - integrated design lift coefficient adjustment factor to thrust coefficient (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:

$$J = \frac{101.4\, V_K}{ND}$$

$$C_Q = \frac{10^{11}\, SHP\, (\rho_o/\rho)}{4\pi N^3 D^5} \qquad \text{for } J \le 1.0$$

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

$$C_T = \frac{1.514 \times 10^6\, T(\rho_o/\rho)}{N^2 D^4} \qquad \text{for } J \le 1.0$$

$$T_C = \frac{1.514 \times 10^6\, T(\rho_o/\rho)}{N^2 D^4} \times \frac{1}{J^2} \qquad \text{for } J > 1.0$$

where:

SHP - shaft horsepower

ρ_o/ρ - 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_{L_i} propeller. The term effective torque coefficient, C_{Q_E} or Q_{C_E}, and effective thrust coefficient, C_{T_E} or T_{C_E}, are used. As with the forward flight generalization, these base curves with appropriate adjustments for AF, C_{L_i} and number of blades can be used in predicting reverse thrust characteristics for the family of propellers spanning 2 to 8 number of blades, 80-200 AF, and 0.3 to 0.8 C_{L_i}. The effective torque coefficients and thrust coefficients are defined as follows:

$$C_{Q_E} = \left[C_Q \times (3/B)^{0.83} \times Q_{AF} \right] - \Delta C_{Q_{E2}}\ (PCR/100) \qquad \text{for } J \le 1.0$$

$$Q_{C_E} = \left[Q_C \times (3/B)^{0.83} \times Q_{AF} \right] - \Delta Q_{C_{E2}}\ (PCR/100) \qquad \text{for } J > 1.0$$

$$C_{T_E} = \left[C_T \times (3/B)^{0.83} \times T_{AF} \right] - \Delta C_{T_{E2}}\ (PCR/100) \qquad \text{for } J \le 1.0$$

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

where:

C_Q - torque coefficient for $J \le 1.0$

$(3/B)^{0.83}$ - 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 C_P and C_T curves (fig. 1 and 2). It is recommended that propellers be selected to operate to the left of the indicated 50% stall line. The detailed procedure is explained in APPENDIX B of reference 1.

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

Propeller Weight Generalization

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

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

Propeller Cost Generalization

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

$$C = ZF\,(3B^{0.75} + E)$$

$$C_1 = F\,(3B^{0.75} + E)$$

where:

C - average original equipment manufacturer, O.E.M. propeller cost for a number of units/year, \$/lb.

C_1 - single unit O.E.M. propeller cost \$/lb.

Z - $\frac{LF}{LF_1}$

LF - learning curve factor for a number of units/year

LF_1 - learning curve factor for a single unit

B - number of blades

F - single unit cost factor

E - empirical factor

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

	1969			1980		
Category	F	E	Quantity	F	E	Quantity
I	3.5	1.0	1910	3.5	1.0	2230
II	3.7	1.5	2810	3.7	1.5	5470
III	3.2	3.5	1030	3.2	3.5	1990
IV	2.6	3.5	295	3.5	3.5	680
V	2.0	3.5	65	3.4	3.5	368

Computer Program

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

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

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

Propeller

1. Diameter range

2. Number of blades range (2-8)

3. AF range (80-200)

4. C_{L_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, C_1. - If a revision in unit cost is required, code as follows:

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

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

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

9. Initial quantity to be used

10. Increment to quantity

11. Number of different quantities

Card 4 contains the following input data in an (I3, 3X, 9F6.0) format where:

1. Card number

2. Initial diameter

3. Increment in diameter if a range of diameters are to be computed

4. Number of diameters

5. Initial activity factor (80-200 AF)

6. Increment of activity factor if a range of AF is to be computed

7. Number of activity factors

8. Initial number of blades (2-8 blades)

9. Increment in number of blades, if a range of blades is to be computed

10. Number of number of blades

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

1. Card number

2. Number of operating conditions with a maximum of 10

3. Initial integrated design lift coefficient (0.3 to 0.8 C_{L_i})

4. Increment of integrated design lift coefficient if a range of C_{L_i} is to be computed

5. Number of C_{L_i}'s

6. For reverse thrust calculation option if blade angle $\beta_{3/4}$ radius is given, code 2. If $\beta_{3/4}$ radius is to be computed, code 1.

7. For reverse thrust calculation option, code 1. for turbine engines and 2. for reciprocating engines.

Subsequent cards are coded as follows with (3X, 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 $= \frac{SHP\ (\rho_o/\rho)\ 10^{11}}{2\ N^3 D^5}$

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. C_L = F8.1' - the input C_{L_i} exceeds the permissible range of 0.3 to 0.8 C_{L_i}.

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

1. Worobel, R. and Mayo, M.: Advanced General Aviation Propeller Study. NASA Report CR 114289, April 1971.

2. Worobel, R. and Mayo, M.: Advanced General Aviation Propeller Study. NASA Report CR 114399, Jan . 1972.

TABLE I

ADVANCED GENERAL AVIATION PROPELLER STUDY

AIRCRAFT CLASSIFICATION

Aircraft Class	Seats	Cruise Vel., MPH	Engine Power	Propeller Type	Application	Gross Weight, lbs.	Price Range	Example Aircraft
I. Single Eng. Trainer Fixed Gear	2-4	100-160	100-200 Recip DD	Fixed Pitch 2 Blades	Trainer, Private Rental, Aerobatic	1000-2500	$8-25K	CESSNA 150, 172, Skyhawk BEECH Musketeer A23-19 PIPER Super Cub, Cherokee
II. Single Eng. Adv. Trainer Retract Gear IFR Equip.	4-6	120-150	150-300 Recip DD & Geared Some Small Turboprops	Constant Speed 2 Blades, Some 3 Blades	Adv. Trainer Private (Family) Survey, Business	2000-4000	$20-50K	CESSNA Skywagon 180, 206, 207, 210 BEECH Bonanza, Musketeer Super 300 PIPER Comanche C, Cherokee Arrow MOONEY M20F
III. Light Twins Retract Gear IFR Equip.	4-6	150-300	150-300 Recip DD & Geared Some Small Turboprops	Constant Speed 2 Blades Some 3 Blades Deicing	Private (Family) Survey, Business	3500-6000	$40-120K	CESSNA Super Skymaster, 310Q BEECH Turbobaron, Barron 55 PIPER Twin Comanche C, Aztec D MOONEY Aerostar
IV. Medium Twins Retract Gear IFR Equip.	6-11	150-300	250-450 Turboprops, Recip DD & Geared	Constant Speed Full Feather Deicing 3 Blades	Executive Charter Air Taxi	6000-8000	$100-200K	CESSNA 401B, 402B, 414, 421 BEECH Queen Air Duke PIPER Navajo 300, Turbo Navajo NORTH AMERICAN ROCKWELL-Shrike Commander BRITTEN-NORMAN ISLANDER, Helio Twin Stallion
V. Heavy Twins Retract Gear IFR Equip.	11 & Up	175-400	600-1500 Turbines	Constant Speed Full Feather Deicing, Reverse 3 and 4 Blades	Large Executive Charter, Third Tier Air Liners	8000-12,500	$400-600K	DEHAVILLAND Twin Otter MOONEY MU-2G NORTH AMERICAN ROCKWELL Hawk Commander BEECH King Air HANDLEY PAGE Jetstream

TABLE II

GENERAL AVIATION

Generalized Propeller Weight Equation:

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

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)

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

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

Aircraft Class	Technology 1970	Technology 1980
I	(1)	(1)
II	(2)	(2)
III	(3)	(3)
IV	(3)	(4)
V	(3)	(5)

	K_W	u	v	y
(1)	170	0.9	0.35	0
(2)	200	0.9	0.35	0
(3)	220	0.7	0.40	5.0
(4)	190	0.7	0.40	3.5
(5)	190	0.7	0.30	0

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

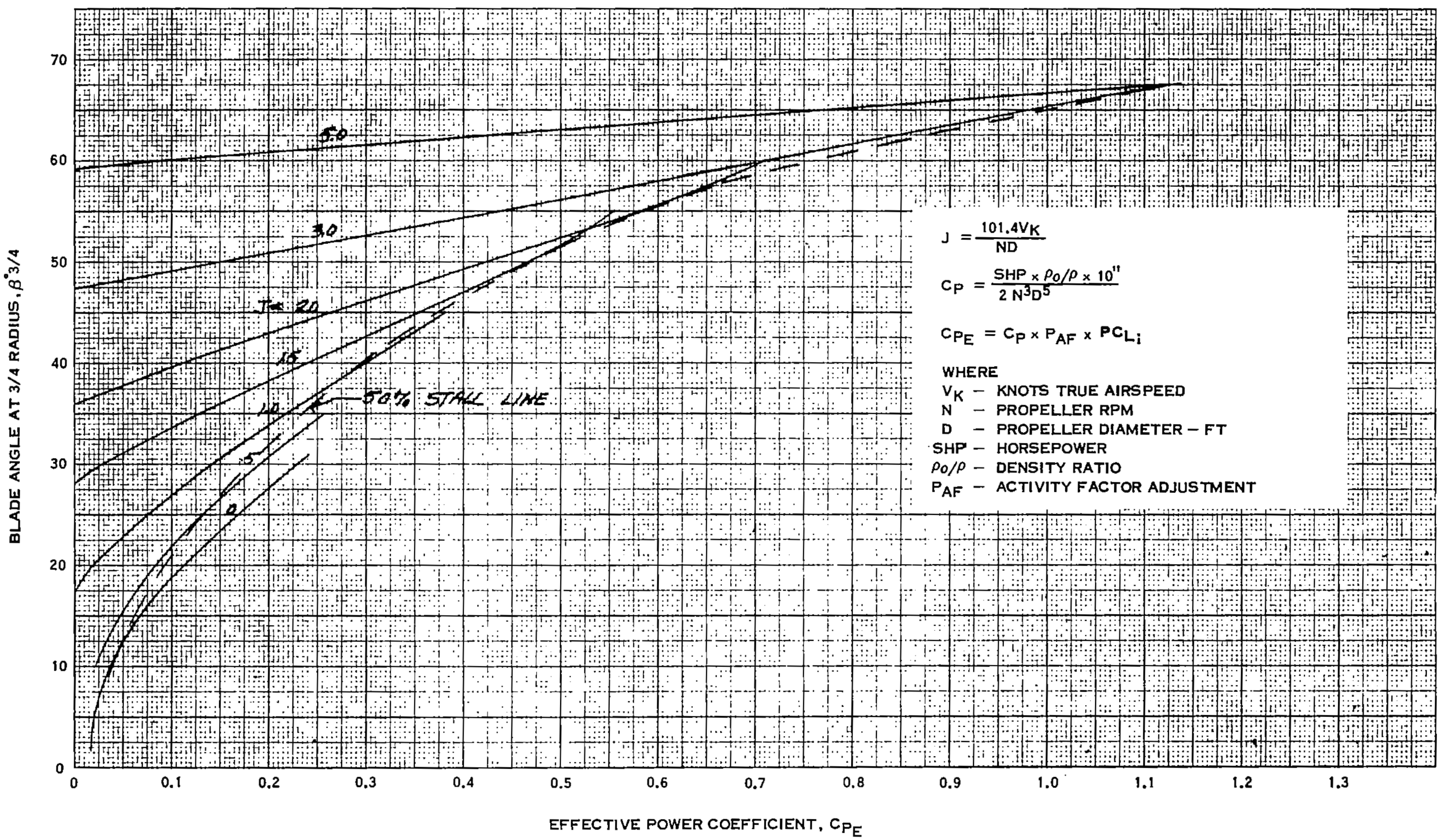

FIGURE 1. POWER COEFFICIENT CHART FOR A 2 BLADED, 150 ACTIVITY FACTOR, 0.500 INTEGRATED DESIGN C_{L_i} PROPELLER

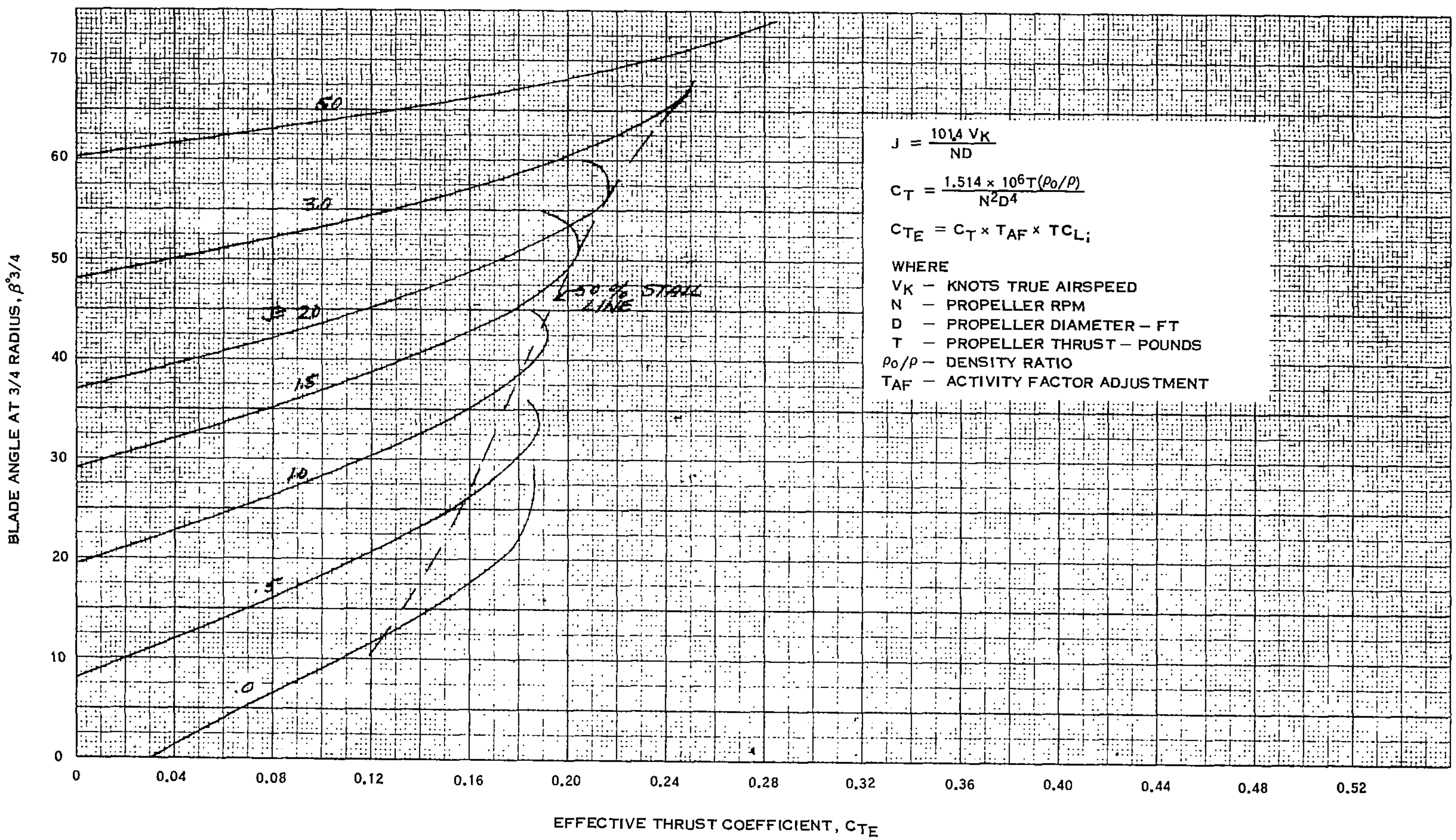

FIGURE 2. THRUST COEFFICIENT CHART FOR A 2 BLADED, 150 ACTIVITY FACTOR, 0.500 INTEGRATED DESIGN C_{L_i} PROPELLER

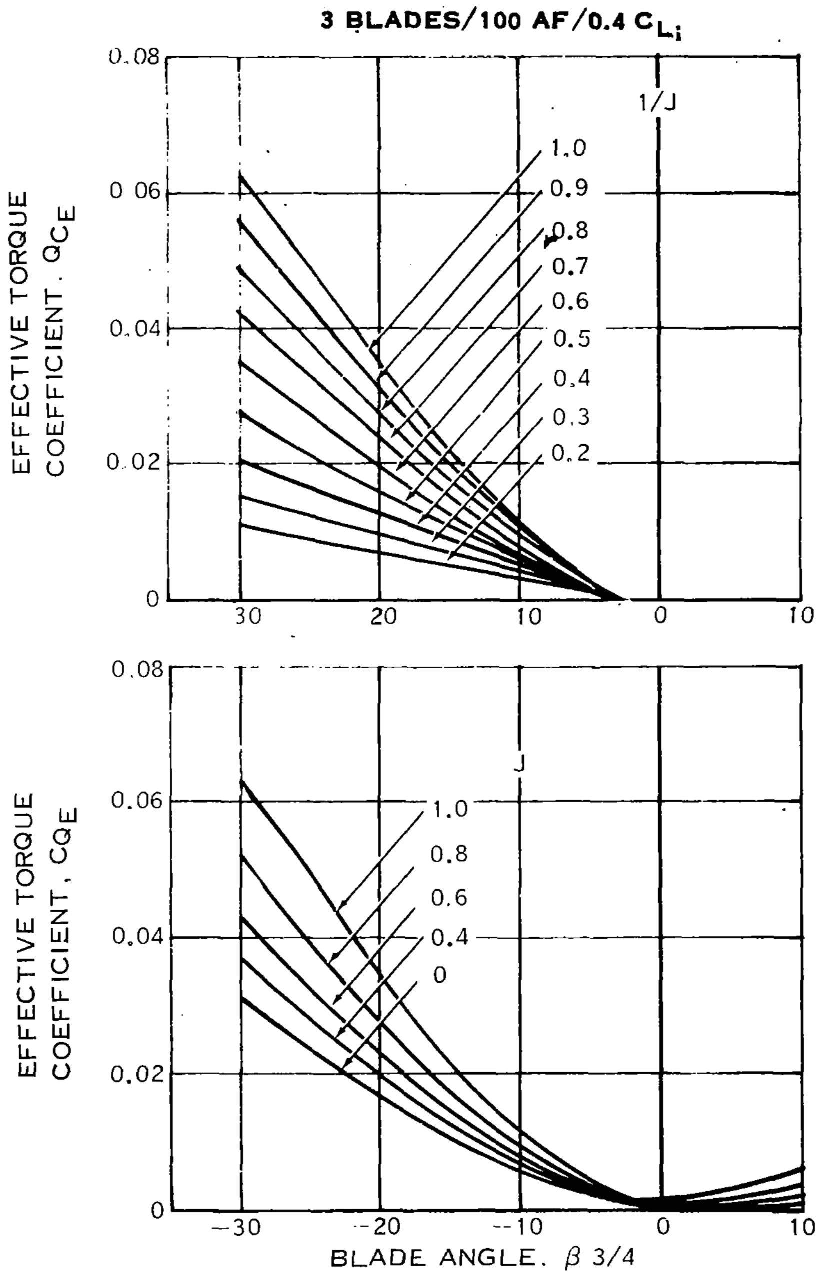

FIGURE 3. BASIC PERFORMANCE CURVE VARIATION OF EFFECTIVE TORQUE COEFFICIENT WITH ADVANCE RATIO & BLADE ANGLE

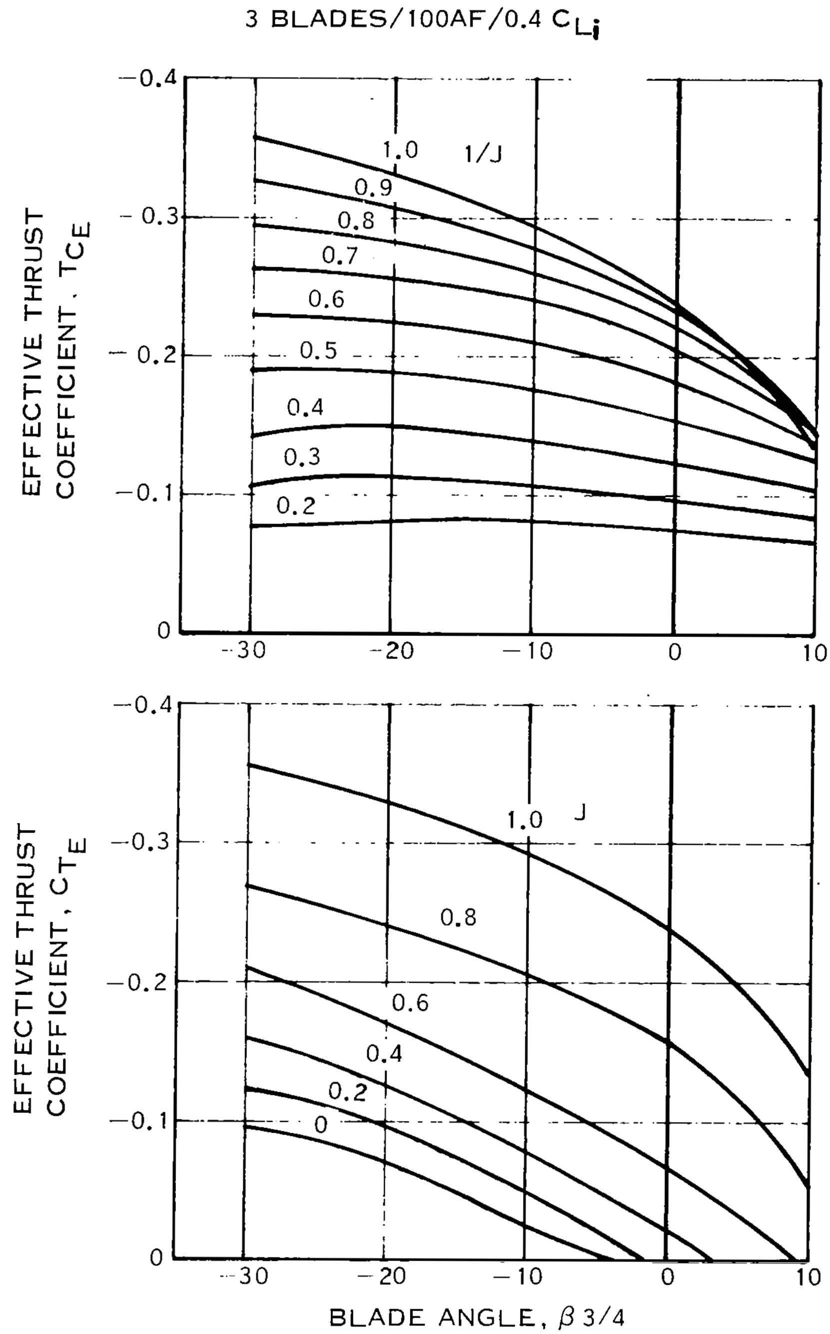

FIGURE 4. BASIC PERFORMANCE CURVE VARIATION OF EFFECTIVE THRUST COEFFICIENT WITH ADVANCE RATIO & BLADE ANGLE

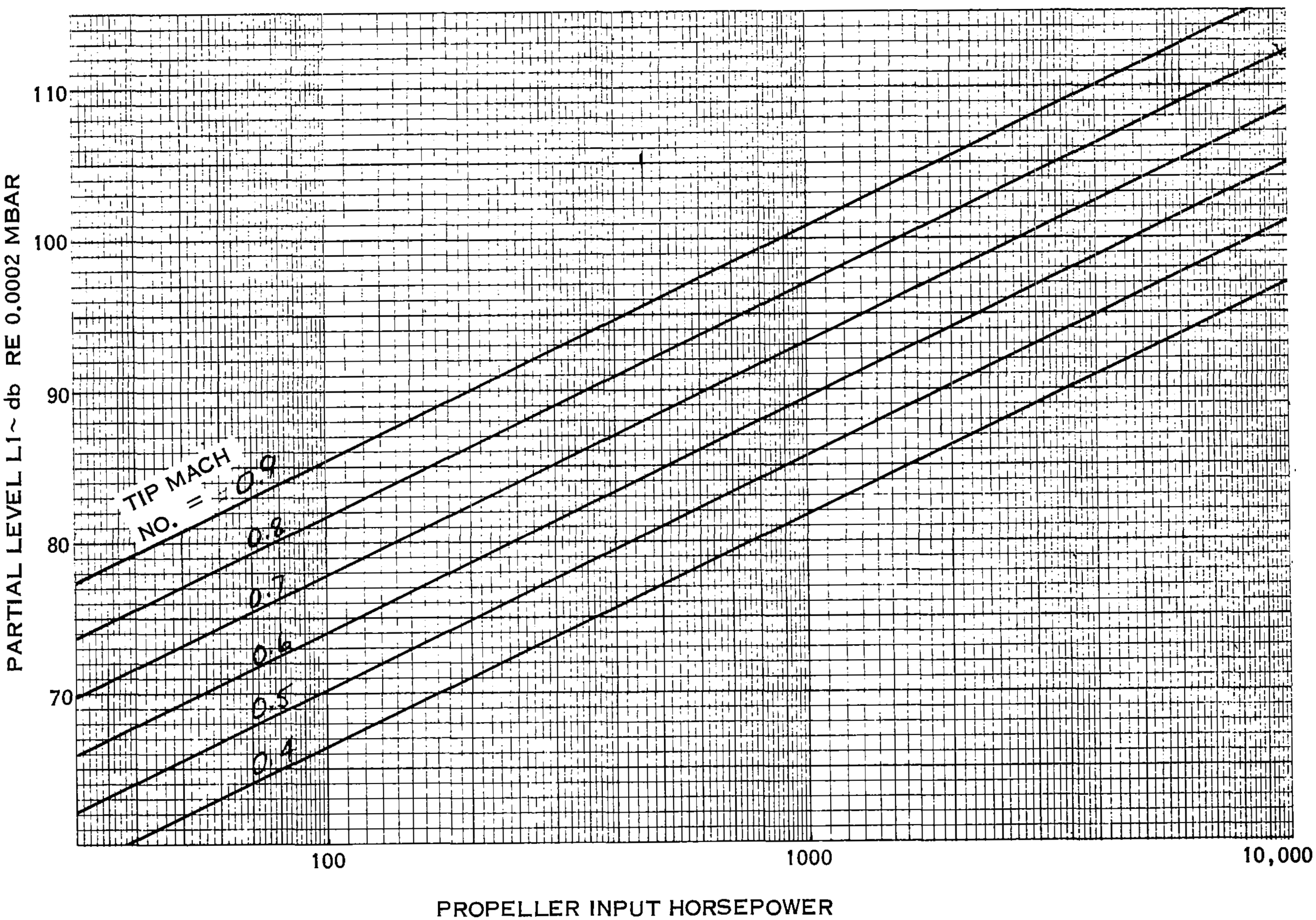

FIGURE 5. BASIC NOISE CURVE

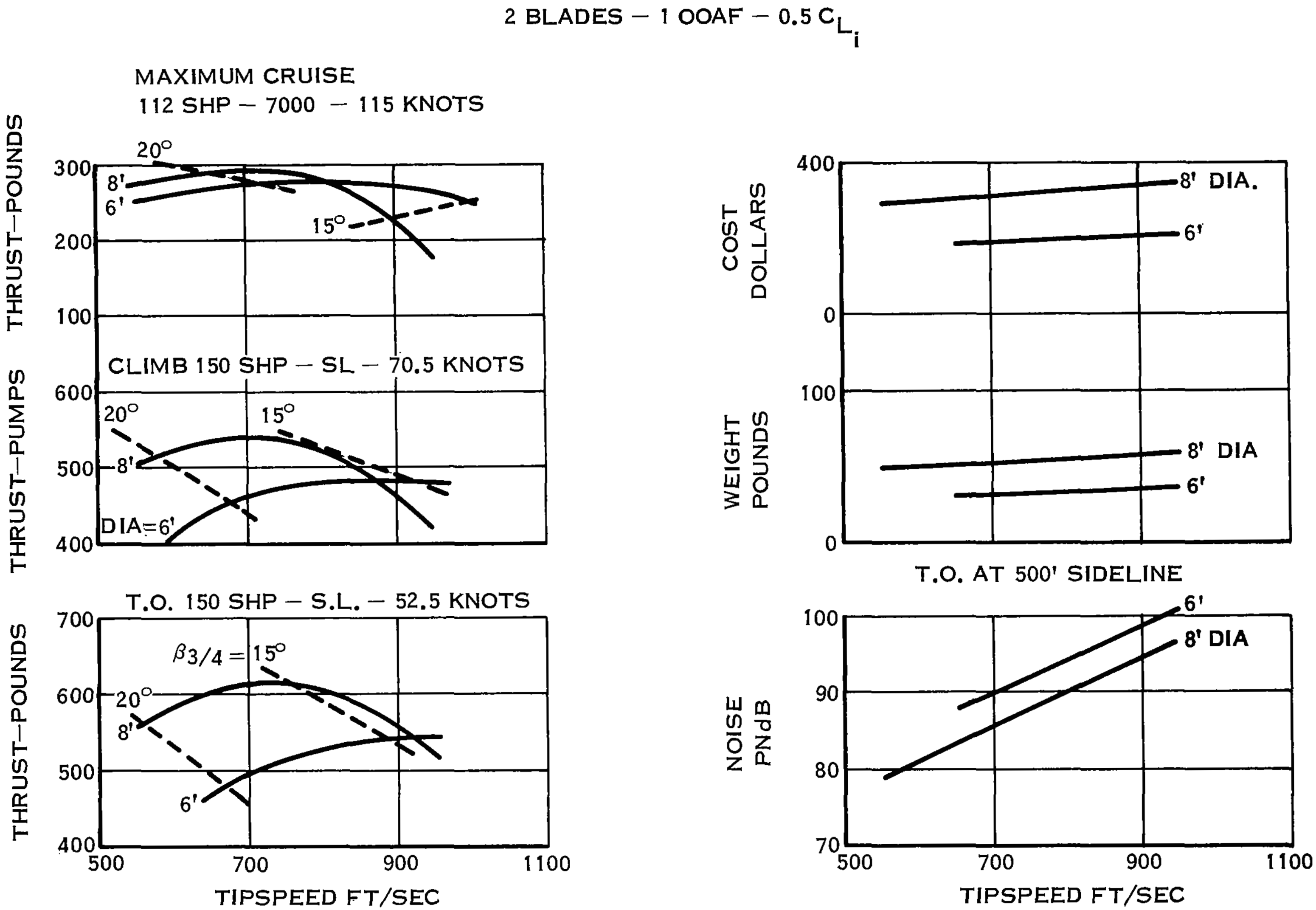

FIGURE 6. CATEGORY I PARAMETRIC STUDY

4 BLADES — 150 AF — 0.5 C_{L_i}

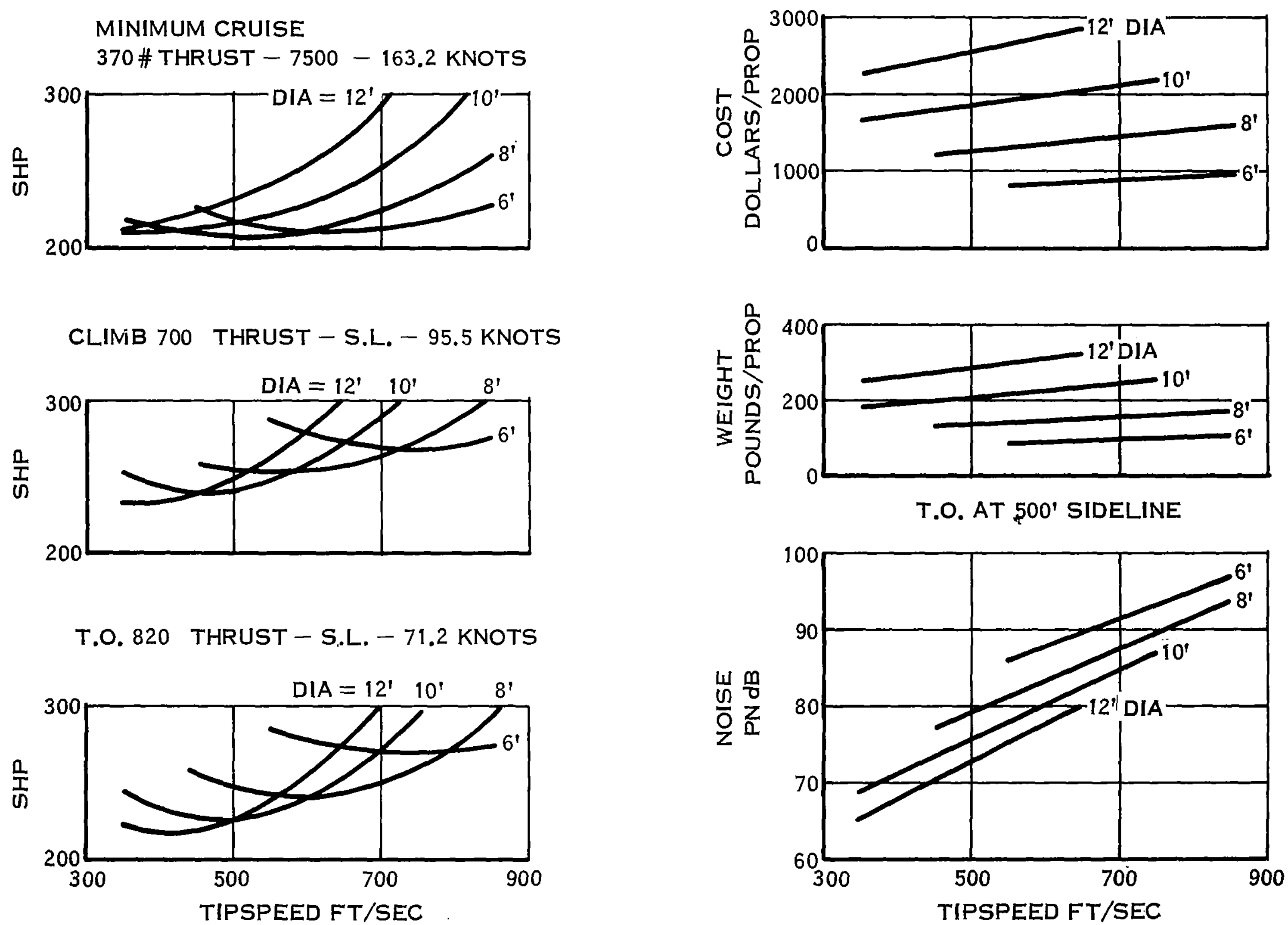

FIGURE 7. CATEGORY II PARAMETRIC STUDY

4 BLADES — 0.6 C_{L_i}

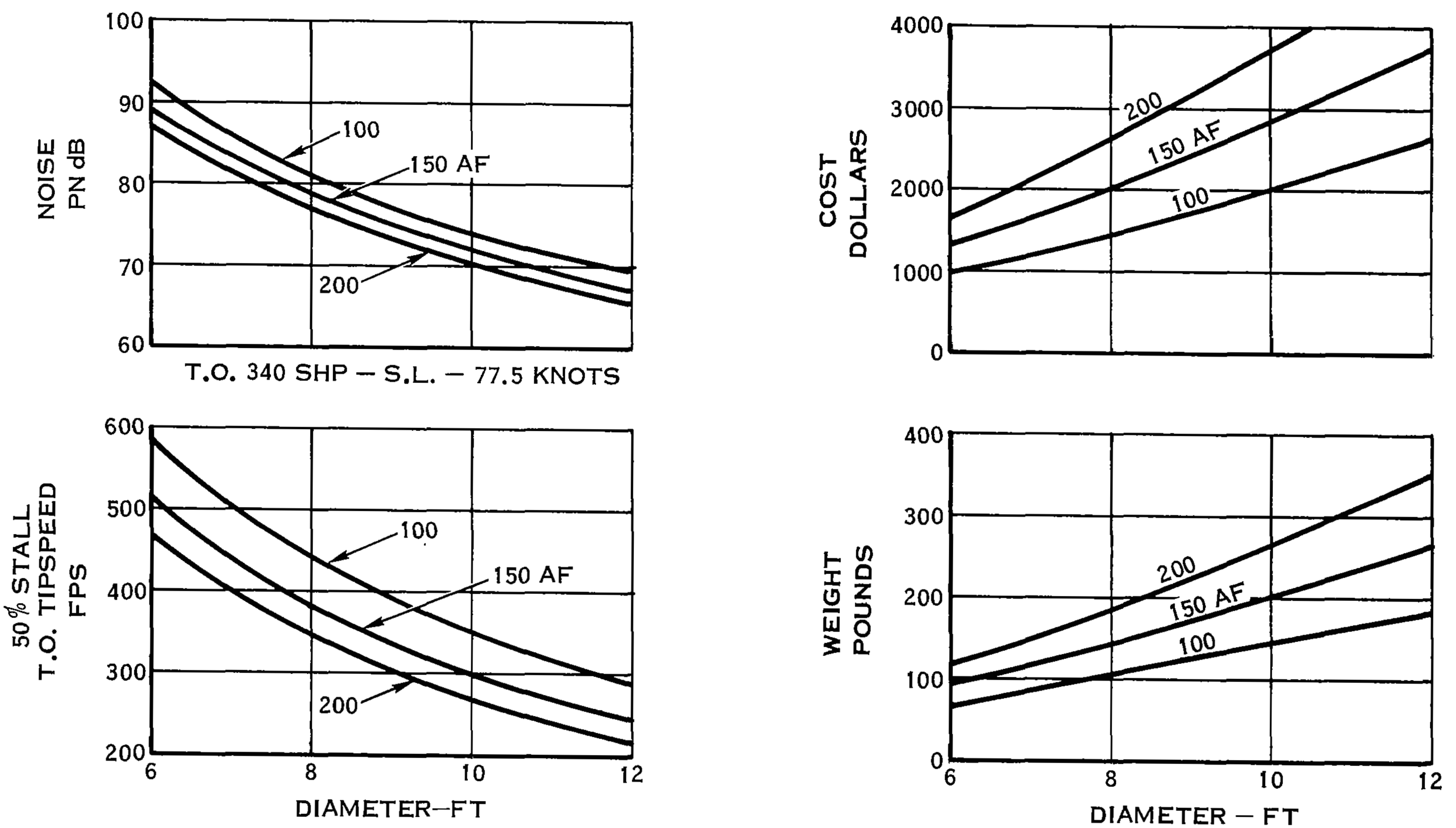

FIGURE 8. CATEGORY IV PARAMETRIC STUDY

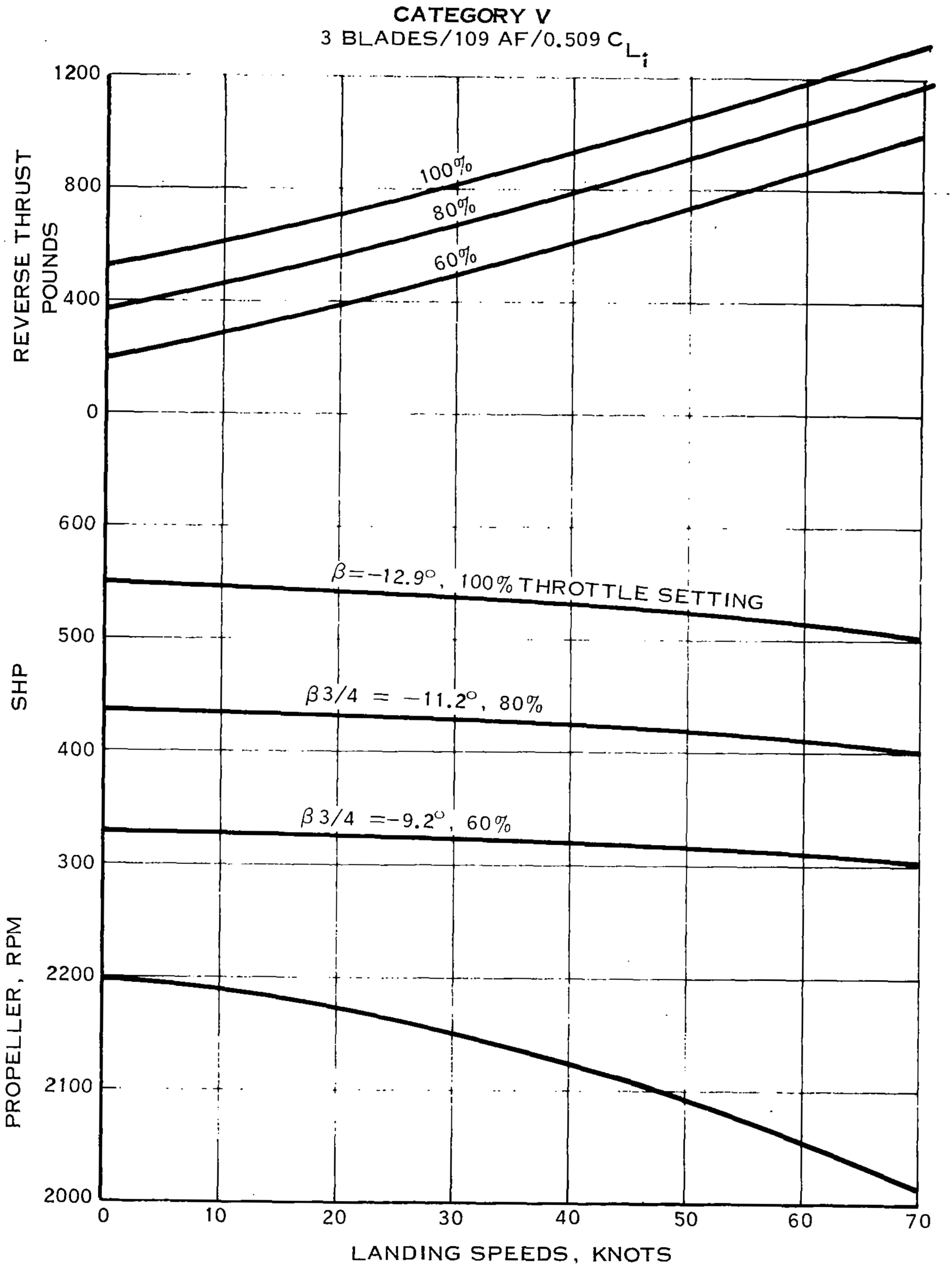

FIGURE 9. EXAMPLE REVERSE THRUST VARIATION WITH LANDING SPEED AND POWER SETTING

UAC CODING FORM # 3

ENGINEER: ROSE WOROBEL MAIL ADDRESS: AERODYNAMICS EXTENSION: 306

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

JOB NO.: ACCT. NO.: W.O. NO.:

SAMPLE CASE #1

Col 2	Col 6	7–12	13–18	19–24	25–30	31–36	37–42	43–48	49–54	55–60	61–66
1		AIRPLANE IN CATEGORY I							SAMPLE CASE I		
2		SHP INPUT-TIPSPEED AND DIAMETER VARIATION-COST AND WEIGHT									
3		1.	1.	.187							
4		6.	2.	2.	100.	0.	1.	2.	0.	1.	
5	2	.5	.0	1.							
	1	150.	0.	52.5	0.	950.	-100.	5.	500.	0.	1.
	1	112.	7000.	115.	0.	950.	-100.	5.			

SAMPLE CASE #2

Col 2	Col 6	7–12	13–18	19–24	25–30	31–36	37–42	43–48	49–54	55–60	61–66
1		AIRPLANE IN CATEGORY II							SAMPLE CASE 2		
2		THRUST INPUT-TIPSPEED AND DIAMETER VAR. - COST AND WEIGHT									
3		1.	2.	.262							
4		6.	2.	2.	150.	0.	1.	4.	0.	1.	
5	2	.5	.0	1.							
	2	820.	0.	71.2	0.	850.	-100.	4.	500.	0.	1.
	2	370.	7500.	163.2	0.	850.	-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

JOB NO.: ACCT. NO.: W.O. NO.:

SAMPLE CASE #3

```
  1  AIRPLANE IN CATEGORY IV                            SAMPLE CASE 3
  2  SHP INPUT-CALC TIPSPEED FOR 50PERCENT STALL-COST FOR RANGE QUANT.
  3  2.    4.    .327  .0    .0    .0    .0    1.    1000. 5.
  4  8.    0.    1.    200.  0.    1.    4.    2.    2.
  5 1.6    .0    1.
    1340.  0.    77.5  0.                      500.  1.    1.
```

SAMPLE CASE #4

```
  1  AIRPLANE IN CATEGORY V                             SAMPLE CASE 4
  2  REVERSE THRUST OPTION
  3  2.    5.    .274
  4  8.5   0.    1.    109.  0.    1.    3.    0.    1.
  5 1.509  .0    1.    1.    2.
    3550.  0.    72.   0.    2200. 100.  -20.  3.
```

FIGURE 10 (CONTINUED). SAMPLE INPUT CODING

HAMILTON STANDARD COMPUTER DECK NO. H432
COMPUTES PERFORMANCE,NOISE,WEIGHT,AND COST FOR
GENERAL AVIATION PROPELLERS

1 AIRPLANE IN CATEGORY I SAMPLE CASE I

2 SHP INPUT-TIPSPEED AND DIAMETER VARIATION-COST AND WEIGHT

OPERATING CONDITION

SHP = 150. NO. OF ENGINES = 1. UNIT FACTOR L.C. = 3.22
ALT-FT = 0. DESIGN FLIGHT M.=0.187 1000 FACTOR L.C. = 1.02
V-KTAS = 52.5 CLASSIFICATION = 1.
TEMP R = 519. FIELD POINT FT. = 500.

NUMBER OF BLADES= 2. ACTIVITY FACTOR=100. INTEGRATED DESIGN CL =.500

				*** 1970 TECHNOLOGY ***			*** 1980 TECHNOLOGY ***								
DIA.FT.	T.S.FPS	THRUST	PNL	QUANTITY	WT-LBS	$COST	QUANTITY	WT-LBS	$COST	ANGLE	FT	M	J	CP	CT
6.	950.	543.	101.	1910.	36.	215.	2230.	36.	210.	13.3	1.000	0.0794	0.293	0.0349	0.0694
6.	850.	540.	97.	1910.	34.	207.	2230.	34.	202.	16.5	1.000	0.0794	0.328	0.0487	0.0863
6.	750.	514.	92.	1910.	33.	198.	2230.	33.	193.	20.4	1.000	0.0794	0.372	0.0709	0.1055
6.	650.	470.	******	1910.	31.	188.	2230.	31.	184.	25.8	1.000	0.0794	0.429	0.1089	0.1283
6.	550.	377.	******	1910.	29.	178.	2230.	29.	173.	33.8	1.000	0.0794	0.507	0.1798	0.1440
8.	950.	524.	97.	1910.	59.	357.	2230.	59.	348.	8.8	1.000	0.0794	0.293	0.0196	0.0377
8.	850.	583.	92.	1910.	57.	343.	2230.	57.	335.	11.5	1.000	0.0794	0.328	0.0274	0.0524
8.	750.	618.	88.	1910.	55.	329.	2230.	55.	320.	15.0	1.000	0.0794	0.372	0.0399	0.0713
8.	650.	601.	84.	1910.	52.	312.	2230.	52.	305.	19.3	1.000	0.0794	0.429	0.0613	0.0923
8.	550.	559.	79.	1910.	49.	295.	2230.	49.	287.	25.4	1.000	0.0794	0.507	0.1011	0.1200

OPERATING CONDITION

SHP = 112. NO. OF ENGINES = 1.
ALT-FT = 7000. DESIGN FLIGHT M.=0.187
V-KTAS = 115.0 CLASSIFICATION = 1.
TEMP R = 494. FIELD POINT FT = 0.

NUMBER OF BLADES= 2. ACTIVITY FACTOR=100. INTEGRATED DESIGN CL =.500

DIA.FT.	T.S.FPS	THRUST	PNL	ANGLE	FT	M	J	CP	CT
6.00	950.	267.	0.	16.4	1.000	0.1782	0.643	0.0321	0.0421
6.00	850.	280.	0.	19.8	1.000	0.1782	0.718	0.0448	0.0550
6.00	750.	275.	0.	23.7	1.000	0.1782	0.814	0.0652	0.0695
6.00	650.	265.	0.	28.8	1.000	0.1782	0.939	0.1002	0.0892
6.00	550.	252.	0.	35.9	1.000	0.1782	1.110	0.1654	0.1184
8.00	950.	179.	0.	13.1	1.000	0.1782	0.643	0.0181	0.0159
8.00	850.	256.	0.	16.4	1.000	0.1782	0.718	0.0252	0.0283
8.00	750.	292.	0.	20.1	1.000	0.1782	0.814	0.0367	0.0415
8.00	650.	282.	0.	24.2	1.000	0.1782	0.939	0.0564	0.0534
8.00	550.	280.	0.	30.0	1.000	0.1782	1.110	0.0930	0.0741

FIGURE 11. SAMPLE OUTPUT – SHP OPTION

HAMILTON STANDARD COMPUTER DECK NO. H432
COMPUTES PERFORMANCE,NOISE,WEIGHT,AND COST FOR
GENERAL AVIATION PROPELLERS

1 AIRPLANE IN CATEGORY 11 SAMPLE CASE 2

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

OPERATING CONDITION

THRUST = 820. NO. OF ENGINES = 1. UNIT FACTOR L.C. = 3.22
ALT-FT = 0. DESIGN FLIGHT M.=0.262 1000 FACTOR L.C. = 1.02
V-KTAS = 71.2 CLASSIFICATION = 2.
TEMP R = 519. FIELD POINT FT. = 500.

NUMBER OF BLADES= 4. ACTIVITY FACTOR=150. INTEGRATED DESIGN CL =.500

				*** 1970 TECHNOLOGY ***			*** 1980 TECHNOLOGY XXX								
DIA.FT.	T.S.FPS	SHP	PNL	QUANTITY	WT-LBS	$COST	QUANTITY	WT-LBS	$COST	ANGLE	FT	M	J	CP	CT
6.	850.	274.	97.	2810.	105.	1033.	5470.	105.	925.	15.2	1.000	0.1077	0.445	0.0888	0.1309
6.	750.	270.	93.	2810.	100.	988.	5470.	100.	884.	18.6	1.000	0.1077	0.504	0.1276	0.1682
6.	650.	275.	90.	2810.	95.	941.	5470.	95.	843.	23.6	1.000	0.1077	0.582	0.1993	0.2239
6.	550.	273.	86.	2810.	90.	987.	5470.	90.	794.	30.3	1.000	0.1077	0.687	0.3268	0.3127
8.	850.	293.	94.	2810.	175.	1729.	5470.	175.	1548.	11.5	1.000	0.1077	0.445	0.0535	0.0737
8.	750.	260.	89.	2810.	165.	1631.	5470.	165.	1460.	14.0	1.000	0.1077	0.504	0.0690	0.0946
8.	650.	243.	85.	2810.	156.	1539.	5470.	156.	1378.	17.5	1.000	0.1077	0.582	0.0992	0.1260
8.	550.	242.	91.	2810.	147.	1451.	5470.	147.	1299.	22.5	1.000	0.1077	0.687	0.1634	0.1759

OPERATING CONDITION

THRUST = 370. NO. OF ENGINES = 1.
ALT-FT = 7500. DESIGN FLIGHT M.=0.262
V-KTAS = 163.2 CLASSIFICATION = 2.
TEMP R = 492. FIELD POINT FT = 0.

NUMBER OF BLADES= 4. ACTIVITY FACTOR=150. INTEGRATED DESIGN CL =.500

DIA.FT.	T.S.FPS	SHP	PNL	ANGLE	FT	M	J	CP	CT
6.00	850.	226.	0.	23.5	1.000	0.2534	1.019	0.0919	0.0739
6.00	750.	213.	0.	26.9	1.000	0.2534	1.155	0.1259	0.0950
6.00	650.	208.	0.	31.5	1.000	0.2534	1.333	0.1891	0.1264
6.00	550.	212.	0.	37.8	1.000	0.2534	1.575	0.3179	0.1766
8.00	850.	262.	0.	22.0	1.000	0.2534	1.019	0.0598	0.0416
8.00	750.	232.	0.	25.1	1.000	0.2534	1.155	0.0773	0.0534
8.00	650.	215.	0.	29.1	1.000	0.2534	1.333	0.1098	0.0711
8.00	550.	207.	0.	34.3	1.000	0.2534	1.575	0.1747	0.0993

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 1V SAMPLE CASE 3

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

OPERATING CONDITION

SHP = 340.	NO. OF ENGINES = 2.	UNIT FACTOR L.C. = 3.22	
ALT-FT = 0.	DESIGN FLIGHT M.=0.327	1000 FACTOR L.C. = 1.02	
V-KTAS = 77.5	CLASSIFICATION = 4.		
TEMP R = 519.	FIELD POINT FT. = 500.		

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

				*** 1970 TECHNOLOGY ***			*** 1980 TECHNOLOGY ***								
DIA.FT.	T.S.FPS	THRUST	PNL	QUANTITY	WT-LBS	$COST	QUANTITY	WT-LBS	$COST	ANGLE	FT	M	J	CP	CT
8.	345.	818.	77.	1.	228.	7106.	1.	185.	7770.	46.3	1.000	0.1172	1.194	0.9333	0.4473
				1001.	228.	2252.	1001.	185.	2463.						
				2001.	228.	2007.	2001.	185.	2195.						
				3001.	228.	1876.	3001.	185.	2052.						
				4001.	228.	1788.	4001.	185.	1956.						

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

				*** 1970 TECHNOLOGY ***			*** 1980 TECHNOLOGY ***								
DIA.FT.	T.S.FPS	THRUST	PNL	QUANTITY	WT-LBS	$COST	QUANTITY	WT-LBS	$COST	ANGLE	FT	M	J	CP	CT
8.	282.	828.	74.	1.	306.	11926.	1.	245.	12887.	51.2	1.000	0.1172	1.459	1.7021	0.6759
				1001.	306.	3780.	1001.	245.	4084.						
				2001.	306.	3368.	2001.	245.	3640.						
				3001.	306.	3149.	3001.	245.	3403.						
				4001.	306.	3002.	4001.	245.	3244.						

FIGURE 13. SAMPLE OPTION – 50% STALL OPTION

HAMILTON STANDARD COMPUTER DECK NO. H432
COMPUTES PERFORMANCE,NOISE,WEIGHT,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 RANKINE= 519.

NUMBER OF BLADES= 3. ACTIVITY FACTOR=100. INTEGRATED DESIGN CL=.509

DIA.FT	THROTTLE SETTING	REVERSE ANGLE	V-KNOTS	REVERSE THRUST	SHP	RPM
8.5	100.	-12.9	0.0	524.	550.	2199.
			10.0	615.	547.	2188.
			20.0	714.	543.	2172.
			30.0	822.	538.	2151.
			40.0	938.	531.	2124.
			50.0	1059.	523.	2092.
			60.0	1179.	514.	2056.
			70.0	1313.	503.	2013.
			72.0	1342.	501.	2004.
8.5	80.	-11.2	0.0	380.	440.	2199.
			10.0	468.	437.	2187.
			20.0	565.	434.	2170.
			30.0	673.	430.	2149.
			40.0	790.	425.	2124.
			50.0	913.	419.	2093.
			60.0	1035.	412.	2059.
			70.0	1173.	404.	2019.
			72.0	1204.	402.	2010.
8.5	60.	-9.2	0.0	208.	330.	2200.
			10.0	293.	328.	2184.
			20.0	388.	325.	2165.
			30.0	495.	321.	2143.
			40.0	612.	318.	2117.
			50.0	737.	313.	2087.
			60.0	861.	308.	2054.
			70.0	1002.	303.	2018.
			72.0	1035.	302.	2010.

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 computers 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.

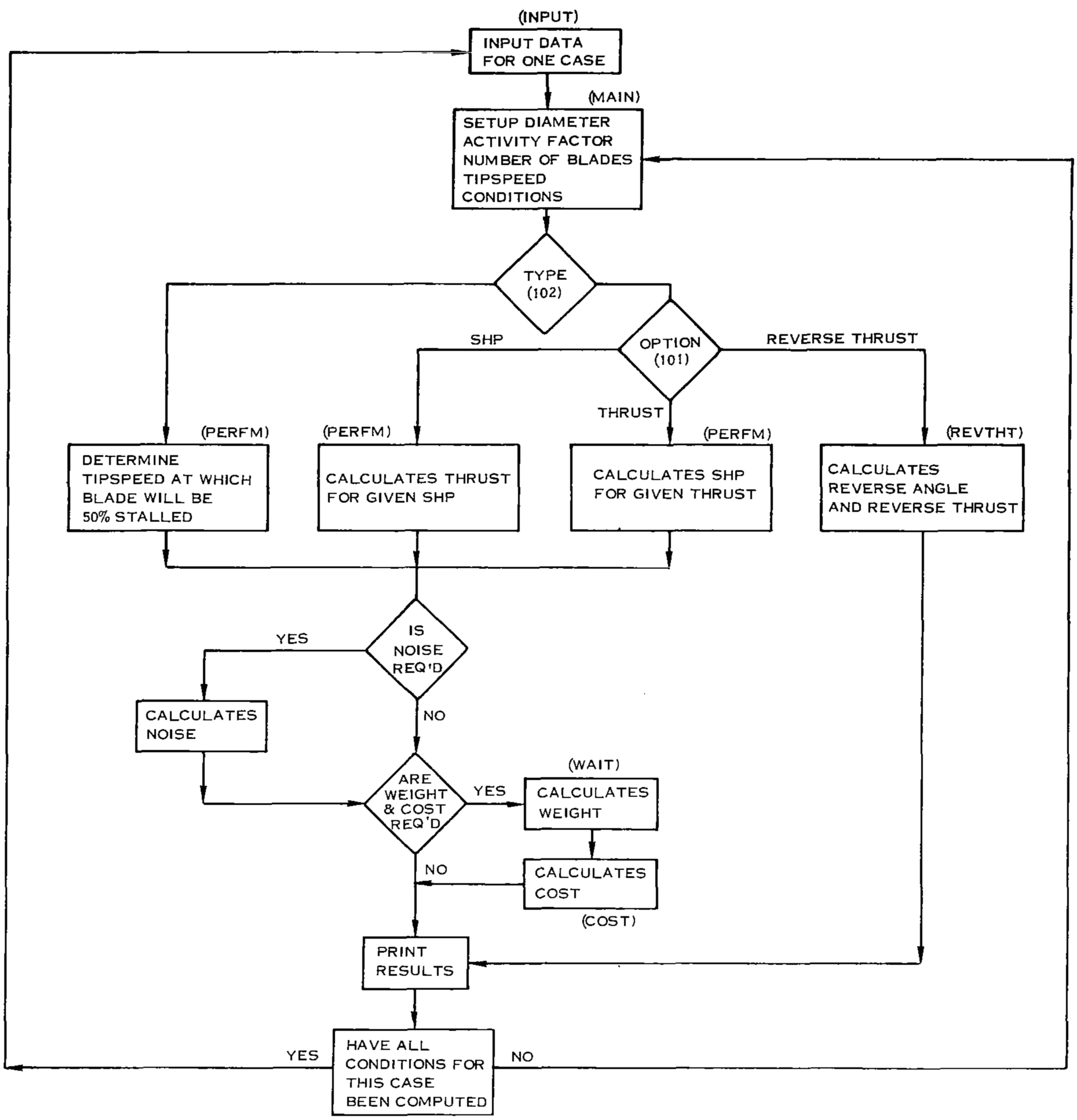

FIGURE 1A COMPUTER PROGRAM FLOW CHART

HAMILTON STANDARD DECK H432

Computer Program for Advanced General Aviation Propeller Studies

MAIN
INPUT
PERFM
ZNOISE
WAIT
COST
REVTHT
UNINT
BIQUAD

Figure 2A LIST OF SUBROUTINES

```
              REAL*8  BLANK
              COMMON/AFCOR/AFCPE,AFCTE,XFT
              COMMON/ASTRK/CPAST,CTAST,ASTERK
              COMMON/CPECTE/CPE,CTE,BLLLL
              DIMENSION FC(10),ALTPR(11),PRESSR(11),RORO(10),ZMS(2)
              DIMENSION DIST(10),CQUAN(2,11),COST70(10),COST80(10)
              DIMENSION BHPG(10),THRSTG(10),TIPSDG(11)
              COMMON /ZINPUT/ BHP(10),THRUST(10),ALT(10),VKTAS(10),T(10),TS(10)
             1,IWIC(10),NOF,D,DD,ND,AF,DAF,NAF,BLADN,DBLAD, NBL,DTS(10),NDTS(10)
             2,DIST,XNOE,WTCON,ZMWT,STALIT(10),CLF1,CLF,CK70,CK80,CAMT,DAMT,NAMT
             3,DCOST(10),CLII,DCLI,ZNCLI,RTC,ROT,PCPW(10),NPCPW(10),BETA(10),
             4DPCPW(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      /
              CBRT(X)= X**(1./3.)
          701 CONTINUE
              WRITE (6,1)
            1 FORMAT ('1',19X'HAMILTON STANDARD COMPUTER DECK NO. H432'/17X'COMP
             1UTES PERFORMANCE,NOISE,WEIGHT,AND COST FOR'/26X'GENERAL AVIATION P
             2ROPELLERS')
              CALL INPUT
              DO 700 IC=1,NOF
              NCOST=DCOST(IC)+.01
              IF (STALIT(IC).LE..50) GO TO 710
              NDTS(IC)=10
              DTS(IC)=0.0
          710 CONTINUE
              IW= IWIC(IC)
        C IW=1   HP INPUT
        C IW=2   THRUST INPUT
        C     IW=3   REVERSE THRUST
              IF (IW.LE.3) GO TO 3
              WRITE (6,2) IW,IC
            2 FORMAT ( ' INPUT ERROR, IW= ',I2,' IC= ',I2 )
              GO TO 700
            3 CONTINUE
        C     COMPUTATION OF DENSITY RATIO
              IF(T(IC))100,100,160
          100 IF(ALT(IC)-36000.)120,120,140
          120 T(IC)=518.688-.00356*ALT(IC)
              GO TO 180
          140 T(IC)=389.988
              GO TO 180
          160 T(I)=T(IC)+459.69
          180 TO=518.69
              TOT=TO/T(IC)
              FC(IC)=SQRT(TOT)
              CALL UNINT (11,ALTPR,PRESSR,ALT(IC),POP,LIMIT)
              RORO(IC)=1.0/(POP*TOT)
        C     AF LOOP
              AFT=AF-DAF
              IF (IW.EQ.3) GO TO 2000
              WRITE (6,706)
          706 FORMAT ('0',18X'OPERATING CONDITION'/)
              IF(NCOST-1)290,200,290
```

FIGURE 3A. FORTRAN IV LISTING

```
0046        200 IENT=1
0047            CALL COST (WTCON,BLADT,CLF1,CLF,CK70,CK80,CAMT,DAMT,NAMT,CQUAN(1,1
               1),WT70,WT80,COST70,COST80,CCLF1,CCLF,CCK70,CCK80,IENT)
0048            GO TO (210,230),IW
0049        210 WRITE (6,220) BHP(IC),XNOE,CCLF1
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,CCLF1
0054        250 IF(CK70.GT.0..OR.CK80.GT.0.) GO TO 255
0055            WRITE (6,252) ALT(IC),ZMWT,CCLF,VKTAS(IC),WTCON,T(IC),DIST(IC)
0056        252 FORMAT(' ALT-FT =',F7.0,9X,'DESIGN FLIGHT M.=',F5.3,9X,'1000 FACTO
               1R L.C.    =',F5.2/' V-KTAS =',F7.1,9X,'CLASSIFICATION  =',F5.0/' TE
               2MP R =',F7.0,9X,'FIELD POINT FT. =',F5.0)
0057            GO TO 270
0058        255 WRITE (6,260) ALT(IC),ZMWT    ,CCLF,VKTAS(IC),WTCON, CK70,T(IC),
               1DIST(IC), CK80
0059        260 FORMAT( ' ALT-FT =',F7.0,9X,'DESIGN FLIGHT M.=',F5.3,9X,'1000 FACT
               1OR L.C.    =',F5.2/' V-KTAS =',F7.1,9X,'CLASSIFICATION  =',F5.0,9X,
               2'UNIT COST 1970     =',F5.1/' 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),IW
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 =',F7.0,22X'NO. OF ENGINES  =',F5.0)
0067         14 WRITE (6,15) ALT(IC),ZMWT,VKTAS(IC),WTCON,T(IC),DIST(IC)
0068         15 FORMAT(' ALT-FT =',F7.0,23X'DESIGN FLIGHT M.=',F5.3/' V-KTAS =',
               1F7.1,23X'CLASSIFICATION  =',F5.0/' TEMP R =',F7.0,23X'FIELD POINT
               2 FT =',F5.0)
0069            GO TO 270
0070       2000 WRITE (6,2100)
0071       2100 FORMAT ('0',21X,'REVERSE THRUST COMPUTATION'//)
0072            IF (ROT.EQ.1.) GO TO 2300
C073            WRITE (6,2200)
0074       2200 FORMAT(24X,'RECIPROCATING ENGINE'//)
0075            GO TO 2400
0076       2300 WRITE(6,2350)
0077       2350 FORMAT (27X,'TURBINE ENGINE'//)
0078       2400 WRITE (6,2500)BHP(IC),RPMC(IC),ANDVK(IC),ALT(IC),T(IC)
0079       2500 FORMAT (22X,'FULL THROTTLE SHP  =', F6.0/22X,'FULL THROTTLE RPM  =
               1',F6.0/22X,'TOUCH DOWN V-KNOTS =',F6.0/22X,'ALTITUDE FEET      =',
               2F6.0/22X,'TEMPERATURE RANKINE=',F6.0//)
0C80       270  DO 1200 IAF=1,NAF
0081            AFT=AFT+DAF
0C82            IF(AFT.LE.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
0C86        182 CONTINUE
          C     INTEGRATED DESIGN CL LOOP
0087            NCLI=ZNCLI+.1
0088            CLI=CLII-DCLI
0089            DO 1001 ICL=1,NCLI
```

FIGURE 3A. FORTRAN IV LISTING (CONTINUED)

```
0090            CLI=CLI+DCLI
0091            IF(CLI.LE..80001.AND.CLI.GE..29999) GO TO 875
0092            WRITE (6,870) CLI
0093        870 FORMAT( ' ILLEGAL INTEGRATED DESIGN CL =',F5.3)
0094            GO TO 1001
0095        875 CONTINUE
          C     NO. OF BLADES LOOP
0096            BLADT=BLADN-DBLAD
0097            DO 1000 IB=1,NBL
0098            BLADT=BLADT+DBLAD
0099            IF(BLADT.LE.8..AND.BLADT.GE.2.) GO TO 888
0100            WRITE(6,887) BLADT
0101        887 FORMAT(' ILLEGAL NO. OF BLADES = ',F8.1)
0102            GO TO 1000
0103        888 CONTINUE
          C PRINT APPROPIATE HEADING
0104            IF (IW .LT.3) GO TO 2700
0105            WRITE (6,2650) BLADT,AFT,CLI
0106       2650 FORMAT ('0','NUMBER OF BLADES=',F3.0,'  ACTIVITY FACTOR=',F4.0,'
               1INTEGRATED DESIGN CL=',F4.3/)
0107            WRITE (6,2660)
0108       2660 FORMAT (13X,'THROTTLE REVERSE',8X,'REVERSE'/5X,'DIA.FT SETTING   A
               1NGLE  V-KNOTS THRUST     SHP    RPM'/)
0109            GO TO 30
0110       2700 WRITE (6,20) BLADT,AFT,CLI
0111         20 FORMAT('0',' NUMBER OF BLADES=',F3.0,18X'ACTIVITY FACTOR=',F4.0,
               X18X' INTEGRATED DESIGN CL =',F4.3)
0112            IF(NCOST.EQ.1) GO TO 500
0113            GO TO (21,24),IW
0114         21 WRITE (6,22)
0115         22 FORMAT('0',' DIA.FT. T.S.FPS THRUST  PNL   ANGLE   FT      M
               1 J      CP      CT'/)
0116            GO TO 30
0117       24   WRITE(6,25)
0118         25 FORMAT('0',' DIA.FT. T.S.FPS   SHP   PNL   ANGLE   FT      M
               1 J      CP      CT'/)
0119            GO TO 30
0120        500 GO TO (510,550),IW
0121        510 WRITE (6,520)
0122        520 FORMAT('0',30X'*** 1970 TECHNOLOGY ***  *** 1980 TECHNOLOGY ***'/
               1' DIA.FT. T.S.FPS THRUST  PNL  QUANTITY  WT-LBS  $COST   QUANTITY
               2 WT-LBS  $COST   ANGLE   FT     M       J      CP      CT'/)
0123            GO TO 30
0124        550 WRITE (6,560)
0125        560 FORMAT('0',30X'*** 1970 TECHNOLOGY ***  *** 1980 TECHNOLOGY XXX'/
               1' DIA.FT. T.S.FPS  SHP    PNL  QUANTITY  WT-LBS  $COST   QUANTITY
               2 WT-LBS  $COST   ANGLE   FT     M       J      CP      CT'/)
0126         30 CONTINUE
0127            ILINE=ILINE+6
          C     DIAMETER LOOP
0128            DIA=D-DD
0129            DO 800 ID=1,ND
0130            DIA=DIA+DD
0131            IF (IW.EQ.3) GO TO 3000
          C     TIPSPEED LOOP
0132            IF(STALIT(IC).LE..50)GO TO 310
0133            DTS(IC)=0.
0134            TRIG=0.
```

FIGURE 3A. FORTRAN IV LISTING (CONTINUED)

```
0135          NTS=10
0136          TIPSDG(1)=700.
0137          TIPSPD=700.
0138          GO TO 320
0139      310 TIPSPD=TS(IC)-DTS(IC)
0140          NTS=NDTS(IC)
0141      320 DO 600 ITS=1,NTS
0142          TIPSPD=TIPSPD+DTS(IC)
        C     MACH NUMBER CALCULATION AND ADVANCE RATIO J
0143          ZMS(1)=.001512*VKTAS(IC)*FC(IC)
0144          ZMS(2)=TIPSPD*FC(IC)/1120.
0145          ZM1=ZMS(1)
0146      340 ZJI=5.309*VKTAS(IC)/TIPSPD
0147          IF(ZJI.EQ.0.) ZM1=ZMS(2)
0148          IF (STALIT(IC).LE..50.AND.ZJI.LE.5.0) GO TO 342
0149          IF(STALIT(IC).GT..50.AND.ZJI.LE.3.0) GO TO 342
0150          WRITE(6,341) ZJI
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          IFIN=0
0155          IF (STALIT(IC).LE..50) GO TO 399
0156          IWSV=IW
0157          IW=3
0158          CALL PERFM (3,CP,ZJI,AFT,BLADT,CLI,CT,ZMS,7710)
0159          IW=IWSV
0160          IF(IW.EQ.2) GO TO 712
0161      711 BHPG(ITS)=2.0*TIPSDG(ITS)**3*DIA**2*6966.*CP/(10.E10*RORO(IC))
0162          IF(ABS(BHP(IC)-BHPG(ITS)).GE..005*BHP(IC)) GO TO 705
0163          THRUST(IC)=CT*TIPSPD**2*DIA**2/(1.515E06*RORO(IC))*364.76
0164          TRIG=1.
0165          GO TO 720
0166      705 IF(ITS.EQ.1) GO TO 7000
0167          TIPSDG(ITS+1)=(ALOG(BHP(IC))-ALOG(BHPG(ITS-1)))*(TIPSDG(ITS)-
         1TIPSDG(ITS-1))/(ALOG(BHPG(ITS))-ALOG(BHPG(ITS-1)))+TIPSDG(ITS-1)
0168          GO TO 709
0169     7000 TIPSDG(2)=400.
0170          TIPSPD=TIPSDG(ITS+1)
0171          GO TO 600
0172      712 THRSTG(ITS)=TIPSDG(ITS)**2*DIA**2*364.76*CT/(1.515E06*RORO(IC))
0173          IF(ABS(THRUST(IC)-THRSTG(ITS)).GE..005*THRUST(IC)) GO TO722
0174          TIPSPD=TIPSDG(ITS)
0175          BHP(IC)=CP*2.0*TIPSPD**3*DIA**2/(10.E10*RORO(IC))*6966.
0176          TRIG=1.
0177          GO TO 720
0178      722 IF(ITS.EQ.1) GO TO 7000
0179          TIPSDG(ITS+1)=(ALOG(THRUST(IC))-ALOG(THRSTG(ITS-1)))*(TIPSDG(ITS)-
         1TIPSDG(ITS-1))/(ALOG(THRSTG(ITS))-ALOG(THRSTG(ITS-1)))+TIPSDG
         2(ITS-1)
0180      709 TIPSPD=TIPSDG(ITS+1)
0181          IF(NTS.NE.ITS) GO TO 600
0182          WRITE ( 6,598)
0183      598 FORMAT (//' FAILED STALL ITERATION '// )
0184          GO TO 700
        C   END OF TIPSPD ITERATION 50 PERCENT STALL
        C     CALCULATION OF REQUIRED CP OR CT
0185      399 IF(IW-1)400,400,430
```

FIGURE 3A. FORTRAN IV LISTING (CONTINUED)

```
      400 CP=BHP(IC)*10.E10*RORO(IC)/(2.0*TIPSPD**3*DIA**2*6966.)
          CALL PERFM (1,CP,ZJI,AFT,BLADT,CLI,CT,ZMS,LIMIT)
      420 THRUST(IC)=CT*TIPSPD**2*DIA**2/(1.515E06*RORO(IC))*364.76*XFT
          IF (CT.EQ.ASTERK) THRUST(IC)=9999999999.
          GO TO 460
      430 CT=THRUST(IC)*1.515E06*RORO(IC)/(TIPSPD**2*DIA**2*364.76)
          CALL PERFM (2,CP,ZJI,AFT,BLADT,CLI,CT,ZMS,LIMIT)
      450 BHP(IC)=CP*2.0*TIPSPD**3*DIA**2/(10.E10*RORO(IC))*6966.
          IF (CP.EQ.ASTERK) BHP(IC)=999999999.
      460 IF (CP.NE.ASTERK) GO TO 720
          PNL=99999999.
          WT70=99999.
          WT80=99999.
          COST70(1)=99999.
          COST80(1)=99999.
          GO TO 730
      720 PNL=0.0
          ISTALL=0
          IF(DIST(IC).LE.0.) GO TO 461
          CALL ZNOISE (BLADT,DIA,TIPSPD,VKTAS(IC),BHP(IC),DIST(IC),PNL,
         1FC(IC),XNOE)
          CPA=CP
          CTA=CT
          SBLLL=BLLLL
          SXFT=XFT
          IWSV=IW
          IW=3
          CALL PERFM(3,CP,ZJI,AFT,BLADT,CLI,CT,ZMS,7710)
          CPS=CP
          CP=CPA
          CT=CTA
          BLLLL=SBLLL
          XFT=SXFT
          IW=IWSV
          IF (CP.GT.CPS) PNL=99999999.
      461 CONTINUE
          WT70=99999.
          WT80=99999.
          COST70(1)=99999.
          COST80(1)=99999.
          IF (NCOST-1) 730,725,730
      725 IF(NCOST.EQ.1)CALL WAIT(WTCON,ZMWT,BHP(IC),DIA,AFT,BLADT,TIPSPD,
         1WT70,WT80)
          IENT=2
          CALL COST (WTCON,BLADT,CLF1,CLF,CK70,CK80,CAMT,DAMT,NAMT,CQUAN(1,1
         1),WT70,WT80,COST70,COST80,CCLF1,CCLF,CCK70,CCK80,IENT)
          GO TO (570,580),IW
      570 WRITE (6,575)DIA,TIPSPD,THRUST(IC),PNL,CQUAN(1,1),WT70,COST70(1),
         1CQUAN(2,1),WT80,COST80(1),BLLLL,XFT,ZM1,ZJI,CP,CT
      575 FORMAT(2F7.0,F9.0,F6.0,2F8.0,F9.0,2F8.0,F9.0,F9.1,F6.3,F7.4,F8.3,
         12F8.4)
          GO TO 585
      580 WRITE (6,575) DIA,TIPSPD,BHP(IC),PNL,CQUAN(1,1),WT70,COST70(1),
         1CQUAN(2,1),WT80,COST80(1),BLLLL,XFT,ZM1,ZJI,CP,CT
      585 IF(NAMT-1) 40,40,586
      586 DO 588 I=2,NAMT
          WRITE(6,587) CQUAN(1,I),WT70,COST70(I),CQUAN(2,I),WT80,COST80(I)
      587 FORMAT (29X,2F8.0,F9.0,2F8.0,F9.0)
```

FIGURE 3A. FORTRAN IV LISTING (CONTINUED)

```
0238        588  CONTINUE
0239             GO TO 40
0240        730  GO TO (31,34),IW
0241         31  WRITE(6,32) DIA,TIPSPD,THRUST(IC),PNL,BLLLL,XFT,ZM1,ZJI,CP,CT
0242          32 FORMAT(F7.2,F7.0,F9.0,F6.0,F6.1,F8.3,F7.4,F8.3,2F8.4)
0243             GO TO 40
0244         34  WRITE(6,32) DIA,TIPSPD,BHP(IC),PNL,BLLLL,XFT,ZM1,ZJI,CP,CT
0245          40 IF(TRIG.EQ.1.) GO TO 750
0246             IF(ISTALL.EC. 2) GO TO 800
0247             IF(IFIN.EQ.7710) GO TO 800
0248         600 CONTINUE
0249             IF (IW.LT.3) GO TO 750
           C     REVERSE THRUST CALCULATION
0250        3000 IRT=NPCPW(IC)
0251             PCPWC=PCPW(IC)
0252             DO 3900 I=1,IRT
0253             IF (RTC-1.) 3200,3100,3200
0254        3100 CP=BHP(IC)*PCPWC*RORO(IC)*10.E10/(2.0*RPMC(IC)**3*DIA**5*100.)
0255        3200 CALL REVTHT (RTC,ROT,AFT,CLI,BLADT,DIA,CP,BETA(IC),RORO(IC),
               1BHP(IC)       ,RPMC(IC),PCPWC,ANDVK(IC))
0256             PCPWC=PCPWC+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)

```
      SUBROUTINE INPUT
      REAL*8  TITLE
      DIMENSION DIST(10)
      DIMENSION  TITLE(14)
      COMMON /ZINPUT/ BHP(10),THRUST(10),ALT(10),VKTAS(10),T(10),TS(10)
     1,IWIC(10),NOF,D,DD,ND,AF,DAF,NAF,BLADN,DBLAD,NBL,DTS(10),NDTS(10)
     2,DIST,XNOF,WTCON,ZMWT,STALIT(10),CLF1,CLF,CK70,CK80,CAMT,DAMT,NAMT
     3,DCOST(10),CLII,DCLI,ZNCLI,RTC,ROT,PCPW(10),NPCPW(10),BETA(10),
     4DPCPW(10),RPMC(10),ANDVK(10)
      DO 3 I=1,2
      READ (5,1) TITLE
    1 FORMAT (13A6,A2)
      WRITE(6,2) TITLE
    2 FORMAT ('0',13A6,A2)
    3 CONTINUE
      READ (5,4) IDUM,XNOF,WTCON,ZMWT,CLF1,CLF,CK70,CK80,CAMT,DAMT,CNAMT
      IF(IDUM.EQ.99) GO TO 10
      READ (5,4)IDUM,D,DD,ZND,AF,DAF,ZAF,BLADN,DBLAD,ZNBL
      READ (5,4) NOF,CLII,DCLI,ZNCLI,RTC,ROT
    4 FORMAT(3XI3,12F6.1)
      ND = ZND+.01
      NAF= ZAF+.01
      NBL= ZNBL+.01
      NAMT=CNAMT+.01
      DO 6  IC=1,NOF
      IF (ROT.EQ.0.) GO TO 7
      READ (5,4) IWIC(IC),BHP(IC),ALT(IC),ANDVK(IC),T(IC),RPMC(IC),
     1PCPW(IC),DPCPW(IC),ZPCPW,BETA(IC)
      NPCPW(IC)=ZPCPW
      GO TO 5
    7 READ(5,4) IWIC(IC),BHP(IC),ALT(IC),VKTAS(IC),T(IC), TS(IC),
     1DTS(IC),ZNDTS,DIST(IC),STALIT(IC),DCOST(IC)
      NDTS(IC)= ZNDTS
      IF(IWIC(IC).EQ.1) GO TO 5
      THRUST(IC)= BHP(IC)
      BHP(IC)= 0.0
    5 CONTINUE
    6 CONTINUE
      RETURN
   10 CALL EXIT
      END
```

FIGURE 3A. FORTRAN IV LISTING (CONTINUED)

```
0001        SUBROUTINE PERFM (IW,CP,ZJI,AFT,BLADT,CLI,CT,ZMS,KIMIT)
0002        COMMON/AFCOR/AFCPE,AFCTE,XFT
0003        COMMON/CPECTE/CPE,CTE,BLLLL
0004        COMMON/ASTRK/CPAST,CTAST,ASTERK
0005        DIMENSION  AFVAL(6),AFCPC(6,2),AFCTC(6,2),AFCP(7),AFCT(7),XLB(4),
           X        INN(7),ZJJ(7),CTT(7),CPP(7),CTTT(4),CPPP(4),CPANG(10,7,4),
           XCTANG(10,7,4),BLDANG(10,7),NJ(7),BLL(7),BLLL(7),CTEC(14),
           XPFCLI(7),TFCLI(7),CPCLI(14,6),CTCLI(14,6),XPCLI(14,6),XTCLI(14,6)
           X,CCLI(6),ZMCRL(11,6),ZJCL(11),CPEC(14),BLDCR(14,4),ZMMMC(93)
           X,NCLX(6),PXCLI(6),BTDCR(14,4),TXCLI(6),XFFT(6),XFT1(7)
           X,CPG(6),CPG1(6),CTG(6),CTG1(6),CTA(7),CTA1(7),CTN(7),ZMS(2)
0006        DIMENSION  DUM1(200), DUM2(200), DUM3(200), DUM4(200),ZMCRO(6)
0007        DIMENSION CTSTAL(9,4),CPSTAL(9,4),ZJSTAL(9)
0008        EQUIVALENCE  (CPANG(1,4,2),DUM1(1)), (CPANG(1,7,3),DUM2(1)),
           X (CTANG(1,4,2),DUM3(1)), (CTANG(1,7,3),DUM4(1))
0009        DATA   AFCPC           /1.67,1.37,1.165,1.0,.881,.81,
           X                        1.55,1.33,1.149,1.,.890,.82/
0010        DATA   AFCTC           /1.39,1.27,1.123,1.0,.915,.865,
           X                        1.46,1.29,1.143,1.0,.890,.84/
0011        DATA   AFVAL         /80.,100.,125.,150.,175.,200./
0012        DATA   BLDANG                /0.,2.,4.,6.,10.,14.,18.,22.,26.,30.,
           X                              10.,15.,20.,25.,30.,35.,4*0.,
           X                              10.,15.,20.,25.,30.,35.,40.,45.,2*0.,
           X                              20.,25.,30.,35.,40.,45.,50.,55.,2*0.,
           X                              30.,35.,40.,45.,50.,55.,60.,3*0.,
           X                               45.,47.5,50.,52.5,55.,57.5,60.,62.5,65.
           X,67.5,
           X                              57.5,60.,62.5,65.,67.5,70./
0013        DATA   BLDCR           /1.84,1.775,1.75,1.74,1.76,1.78,1.80,1.81,
           11.835,1.85,1.865,1.875,1.88,1.88,
           X                         1.,1.,1.,1.,1.,1.,1.,1.,1.,1.,1.,1.,1.
           1,
           X                         .585,.635,.675,.710,.738,.745,.758,.755,
           1.705,.735,.710,.725,.725,.725,
           X                         .415,.460,.505,.535,.560,.575,.600,.610,
           1.630,.630,.610,.605,.600,.600/
0014        DATA BTDCR /1.58,1.685,1.73,1.758,1.777,1.802,1.828,1.839,1.848,
           11.850,1.850,1.850,1.850,1.850,
           21.,1.,1.,1.,1.,1.,1.,1.,1.,1.,1.,1.,1.,1.,
           3.918,.874,.844,.821,.802,.781,.764,.752,.750,.750,.750,.750,.750,
           4.750,
           5.864,.797,.758,.728,.701,.677,.652,.640,.630,.622,.620,.620,.620,
           6.620/
0015        DATA CCLI /.3,.4,.5,.6,.7,.8/
0016        DATA   CPANG                 /.0158,.0165,.0188,.0230,.0369,.0588,
           X.0914,.1340,.1816,.2273,
           X                               .0215,.0459,.0829,.1305,.1906,.2554,
           X 4*0.,
           X                               -.0149,-.0088,.0173,.0744,.1414,.2177,
           X.3011,.3803,2*0.,
           X                              -.0670,-.0385,.0285,.1304,.2376,.3536,
           X.4674,.5535,2*0.,
           X                               -.1150,-.0281,.1086,.2646,.4213,.5860,
           X.7091    ,3*0.,
           X                                -.1151,.0070,.1436,.2910,.4345,.5744,
           X.7142,.8506,.9870,1.1175,
           X                           -.2427,.0782,.4242,.7770,1.1164,1.4443,
           X 4*0.,
```

FIGURE 3A. FORTRAN IV LISTING (CONTINUED)

```
                    X                        .0311,.0320,.0360,.0434,.0691,.1074,
                    X.1560,.2249,.3108,.4026,
                    X                       .0380,.0800,.1494,.2364,.3486,.4760,
                    X 4*0.,
                    X                       -.0228,-.0109,.0324,.1326,.2578,.399,
                    X.5664,.7227,2*0./
0017                 DATA CPCLI/.0114,.0294,.0491,.0698,.0913,.1486,.2110,.2802,.3589,
                    1.4443,.5368,.6255,0.,0.,
                    2.0294,.0478,.0678,.0893,.1118,.1702,.2335,.3018,.3775,.4610,.5505,
                    3.6331,0.,0.,
                    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,.0743,.0891,.1074,.1281,.1509,.1753,.2407,.3083,.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                  /.0303,.0444,.0586,.0743,.1065,.1369,
                    X.1608,.1767,.1848,.1858,
                    X                       .0205,.0691,.1141,.1529,.1785,.1860,
                    X 4*0.,
                    X                       -.0976,-.0566,.0055,.0645,.1156,.1589,
                    X.1864,.1905,2*0.,
                    X                      -.1133,-.0624,.0111,.0772,.1329,.1776,
                    X.202,.2045,2*0.,
                    X                       -.1132,-.0356,.0479,.1161,.1711,.2111,
                    X.2150    ,3*0.,
                    X                        -.0776,-.0159,.0391,.0868,.1279,.1646
                    X,.1964,.2213,.2414,.2505,
                    X                       -.1228,-.0221,.0633,.1309,.1858,.2314,
                    X 4*0.,
                    X                        .0426,.0633,.0853,.1101,.1649,.2204,
                    X.2678,.3071,.3318,.3416,
                    X                       .0318,.1116,.1909,.2650,.3241,.3423,
                    X 4*0.,
                    X                       -.1761,-.0960,.0083,.1114,.2032,.2834,
                    X.3487,.3596,2*0./
0020                 DATA CPSTAL/.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,.75,1.1,1.51,1.96,2.41,2.86,3.30,
                    4.45,.71,1.03,1.40,1.89,2.45,2.96,3.55,4.1/
0021                 DATA CTCLI/.0013,.0211,.0407,.0600,.0789,.1251,.1702,.2117,.2501,
                    1.2840,.3148,.3316,0.,0.,
                    2.0158,.0362,.0563,.0761,.0954,.0419,.1868,.2287,.2669,.3013,.3317,
                    3.3460,.0,.0,
                    4.0,.0083,.0297,.0507,.0713,.0916,.1114,.1585,.2032,.2456,.2834,
                    5.3191,.3487,.3626,
                    6.0130,.0208,.0428,.0645,.0857,.1064,.1267,.1748,.2195,.2619,.2995,
                    7.3350,.3647,.3802,
                    8.026,.0331,.0552,.0776,.0994,.1207,.1415,.1907,.2357,.2778,.3156,
                    9.3505,.3808,.3990,
                    A.0365,.0449,.0672,.0899,.1125,.1344,.1556,.2061,.2517,.2937,.3315,
                    B.3656,.3963,.4186/
0022                 DATA CTEC /.01,.03,.05,.07,.09,.12,.16,.20,.24,.28,.32,.36,.40,
                    1.44/
```

FIGURE 3A. FORTRAN IV LISTING (CONTINUED)

```
0023      DATA CTSTAL/.125,.151,.172,.187,.204,.218,.233,.243,.249,
         2.268,.309,.343,.369,.387,.404,.420,.435,.451,
         3.401,.457,.497,.529,.557,.582,.605,.629,.651,
         4.496,.577,.628,.665,.695,.720,.742,.764,.785/
0024      DATA  DUM1  /              -.1252,-.0661,.0535,.2388,.4396,.6554,
         X.8916,1.0753,2*0.,
         X                           -.2113,-.0480,.1993,.4901,.7884,1.099,
         X1.3707,3*0.,
         X                            -.2077,.0153,.2657,.5387,.8107,1.075,
         X1.3418,1.5989,1.8697,2.1238,
         X                           -.4508,.1426,.7858,1.448,2.0899,2.713,
         X 4*0.,
         X                            .0450,.0461,.0511,.0602,.0943,.1475,
         X.2138,.2969,.4015,.5237,
         X                           .0520,.1063,.2019,.3230,.4774,.6607,
         X 4*0.,
         X                           -.0168,-.0085,.0457,.1774,.3520,.5506,
         X.7833,1.0236,2*0.,
         X                          -.1678,-.0840,.0752,.3262,.6085,.9127,
         X1.2449,1.5430,2*0.,
         X                           -.2903,-.0603,.2746,.6803,1.0989,
         X1.5353,1.9747,3*0.,
         X                            -.2783,.0259,.3665,.7413,1.1215,
         X1.4923,1.8655,2.2375,2.6058,2.9831/
0025      DATA  DUM2  /              -.6181,.1946,1.0758,1.9951,2.8977,
         X3.7748,4*0.,
         X                            .0577,.0591,.0648,.0751,.1141,.1783,
         X.2599,.3551,.4682,.5952,
         X                           .0650,.1277,.2441,.3947,.5803,.8063,
         X 4*0.,
         X                           -.0079,-.0025,.0595,.2134,.4266,.6708,
         X.9519,1.2706,2*0.,
         X                          -.1894,-.0908,.0956,.3942,.7416,1.1207,
         X1.5308,1.9459,2*0.,
         X                           -.3390,-.0632,.3350,.8315,1.3494,
         X1.890,2.4565,3*0.,
         X                            -.3267,.0404,.4520,.9088,1.3783,
         X1.8424,2.306,2.7782,3.2292,3.7058,
         X                           -.7508,.2395,1.315,2.4469,3.5711,
         X4.6638,4*0./
0026      DATA  DUM3  /              -.2155,-.1129,.0188,.1420,.2401,.3231,
         X.3850,.3850,2*0.,
         X                           -.2137,-.0657,.0859,.2108,.3141,.3894,
         X.4095,3*0.,
         X                           -.1447,-.0314,.0698,.1577,.2342,.3013,
         X.3611,.4067,.4457,.4681,
         X                          -.2338,-.0471,.1108,.2357,.3357,.4174,
         X 4*0.,
         X                           .0488,.0732,.0999,.1301,.2005,.2731,
         X.3398,.3982,.4427,.4648,
         X                          .0375,.1393,.2448,.3457,.4356,.4931,
         X 4*0.,
         X                          -.2295,-.1240,.0087,.1443,.2687,.3808,
         X.4739,.5256,2*0.,
         X                          -.2999,-.1527,.0235,.1853,.3246,.4410,
         X.5290,.5467,2*0.,
         X                          -.3019,-.0907,.1154,.2871,.429,.5338,
         X.5954,3*0.,
```

FIGURE 3A. FORTRAN IV LISTING (CONTINUED)

```
                 X                                -.2012,-.0461,.0922,.2125,.3174,.4083,
                 X.4891,.5549,.6043,.6415/
0027              DATA  DUM4  /                  -.3307,-.0749,.1411,.3118,.4466,.5548,
                 X 4*0.,
                 X                                 .0534,.0795,.1084,.1421,.2221,.3054,
                 X.3831,.4508,.5035,.5392,
                 C                                 .0423,.1588,.2841,.4056,.5157,.6042,
                 X 4*0.,
                 X                                -.2606,-.1416,.0097,.1685,.3172,.4526,
                 X.5655,.6536,2*0.,
                 X                                -.3615,-.1804,.0267,.2193,.3870,.5312,
                 X.6410,.7032,2*0.,
                 X                                -.3674,-.1096,.1369,.3447,.5165,.6454,
                 X.7308,3*0.,
                 X                                 -.2473,-.0594,.1086,.2552,.3830,.4933,
                 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 / 12,12,14,14,14,14/
0030              DATA  NJ          /1,2,3,4,5,6,7/
0031              DATA PFCLI/1.68,1.405,1.0,.655,.442,.255,.102/
0032              DATA TFCLI/1.22,1.105,1.0,.882,.792,.665,.540/
0033              DATA XLB          /2.,4.,6.,8./
0034              DATA XPCLI/4.26,2.285,1.780,1.568,1.452,1.300,1.220,1.160,1.110,
                 11.085,1.054,1.048,0.,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.,1.,1.,1.,1.,1.,1.,1.,1.,1.,1.,1.,1.,1.,
                 5.551,.619,.712,.775,.815,.845,.865,.891,.910,.928,.941,.958,.970,
                 6.975,
                 7.382,.436,.545,.625,.682,.726,.755,.804,.835,.864,.889,.914,.935,
                 8.944,
                 9.293,.333,.436,.520,.585,.635,.670,.730,.770,.807,.835,.871,.897,
                 A.909/
0035              DATA XTCLI/22.85,2.40,1.75,1.529,1.412,1.268,1.191,1.158,1.130,
                 11.122,1.108,1.108,0.,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.,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.C,2.5,3.0,3.5,4.0,4.5,5.0/
0037              DATA ZJJ          /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 ZMCRL /.0,.151,.299,.415,.505,.578,.620,.630,.630,.630,.630,
                 1.0,.146,.287,.400,.487,.556,.595,.605,.605,.605,.605,
                 2.0,.140,.276,.387,.469,.534,.571,.579,.579,.579,.579,
                 3.0,.135,.265,.372,.452,.512,.547,.554,.554,.554,.554,
                 4.0,.130,.252,.357,.434,.490,.522,.526,.526,.526,.526,
                 5.0,.125,.240,.339,.416,.469,.498,.500,.500,.500,.500/
0041              DATA ZMMMC/1.,6.,12.,.0,.02,.04,.06,.08,.10,.01,.02,.04,.08,.12,
                 1.16,.20,.24,.28,.32,.36,.40,
                 21.,1.,1.,1.,1.,1.,1.,1.,1.,1.,1.,1.,
```

FIGURE 3A. FORTRAN IV LISTING (CONTINUED)

```
                 3.979,.981,.984,.987,.990,.993,.996,1.00,1.00,1.00,1.00,1.00,
                 4.944,.945,.950,.958,.966,.975,.984,.990,.996,.999,1.00,1.00,
                 5.901,.905,.912,.927,.942,.954,.964,.974,.984,.990,.900,.900,
                 6.862,.866,.875,.892,.909,.926,.942,.957,.970,.980,.984,.984,
                 7.806,.813,.825,.851,.877,.904,.924,.939,.952,.961,.971,.976/
                  KK=1
                  ASTERK=999999.
C                 AN ADJUSTMENT FOR CP AND CT FOR AF
                  DO 120 K=1,2
                  CALL UNINT (6,AFVAL(1),AFCPC(1,K),AFT,AFCP(K),LIMIT)
                  CALL UNINT (6,AFVAL(1),AFCTC(1,K),AFT,AFCT(K),LIMIT)
              120 CONTINUE
                  DO 100  K=3,7
                  AFCP(K)=AFCP(2)
             100  AFCT(K)=AFCT(2)
                  IF(ZJI.GT..5) GO TO 105
                  AFCPE=2.*ZJI*(AFCP(2)-AFCP(1))+AFCP(1)
                  AFCTE=2.*ZJI*(AFCT(2)-AFCT(1))+AFCT(1)
                  GO TO 110
              105 AFCPE=AFCP(2)
                  AFCTE=AFCT(2)
              110 IF(ZJI.GT.1.0) GO TO 140
                  NBEG=1
                  NEND=4
                  GO TO 148
              140 IF(ZJI.GT.1.5) GO TO 142
                  NBEG=2
                  NEND=5
                  GO TO 148
              142 IF(ZJI.GT.2.0.AND.IW.LT.3) GO TO 147
                  NBEG=3
                  NEND=6
                  GO TO 148
              147 NBEG=4
                  NEND=7
              148 CONTINUE
                  NCL=0
                  DO 130  II=1,6
                  IZ=II
                  IF(ABS(CLI-CCLI(II)).LE..0009) GO TO 135
              130 CONTINUE
                  IF(CLI.GT..6) GO TO 131
                  NCLT=1
                  NCLTT=4
                  GO TO 119
              131 IF(CLI.GT..7)GO TO 132
                  NCLT=2
                  NCLTT=5
                  GO TO 119
              132 NCLT=3
                  NCLTT=6
                  GO TO 119
              135 NCLT=IZ
                  NCL=1
                  NCLTT=IZ
              119 CONTINUE
                  NB= BLADT+.1
                  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)
                CALL UNINT (9,ZJSTAL,CPSTAL(1,L),ZJJ(K),CPP(K),LIMIT)
                CALL UNINT (INN(K),CPANG(1,K,L),BLDANG(1,K),CPP(K),BLL(K),LIMIT)
            210 CPE=CP*AFCP(K)
                CALL UNINT (14,CPEC(1),BLDCR(1,L),CPE,PBL,IMIT)
                CPE1=CPE*PBL*PFCLI(K)
                NNCLT=NCLT
                DO 215 KL=NCLT,NCLTT
                CALL UNINT (NCLX(NNCLT),CPCLI(1,NNCLT),XPCLI(1,NNCLT),CPE1,PXCLI
               1(KL),LIMIT)
                IF (LIMIT.EQ.1) GO TO 591
            215 NNCLT=NNCLT+1
                IF (NCL.EQ.1) GO TO 220
                CALL UNINT (4,CCLI(NCLT),PXCLI(NCLT),CLI,PCLI,LIMIT)
                GO TO 221
            220 PCLI=PXCLI(NCLT)
            221 CONTINUE
                CPE=CPE*PCLI
                CALL UNINT (INN(K),CPANG(1,K,L),BLDANG(1,K),CPE,BLL(K),LIMIT)
                CALL UNINT (INN(K),BLDANG(1,K),CTANG(1,K,L),BLL(K),CTT(K),LIMIT)
                IF(LIMIT.EQ.0) GO TO 211
                GO TO 591
            211 CONTINUE
                GO TO 2501
            250 NNCLT=NCLT
           2200 DO 260 KL=NCLT,NCLTT
                CTA(1)=CT
                CTA(2)=1.5*CT
                DO 2600 KJ=1,5
                NFTX=KJ
                CTE1=CTA(KJ)*AFCT(K)
                CALL UNINT(14,CTEC(1),BTDCR(1,L),CTE,TBL,IMIT)
                CTE1=CTE1*TBL*TFCLI(K)
                CALL UNINT (NCLX(NNCLT),CTCLI(1,NNCLT),XTCLI(1,NNCLT),CTE1,TXCLI
               1(KL),LIMIT)
                IF (LIMIT.EQ.1)GO TO 591
           9998 IF(ZJJ(K).EQ.0.) GO TO 4000
                CALL UNINT (11,ZJCL(1),ZMCRL(1,NNCLT),ZJJ(K),ZMCRT,LIMIT)
           9999 DMN=ZMS(1)-ZMCRT
                GO TO 4050
           4000 ZMCRT=ZMCRO(NNCLT)
                DMN=ZMS(2)-ZMCRT
           4050 XFFT(KL)=1.0
                IF(DMN) 2300,2300,252
            252 CTE2=CTE1*TXCLI(KL)/TFCLI(K)
                CALL BIQUAD (ZMMMC,1,DMN,CTE2,XFFT(KL),LIMIT)
           2300 CTA1(KJ)=CT-CTA(KJ)*XFFT(KL)
                IF(CTA1(KJ).EQ.0..AND.KJ.EQ.1) GO TO 2700
```

FIGURE 3A. FORTRAN IV LISTING (CONTINUED)

```
0149              IF(KJ.LE.1) GO TO 2600
0150              IF(ABS(CTA1(KJ-1)-CTA1(KJ))/CT.LE..001) GO TO 2700
0151              CTA(KJ+1)=-CTA1(KJ-1)*(CTA(KJ)-CTA(KJ-1))/(CTA1(KJ)-CTA1(KJ-1))+
                 1CTA(KJ-1)
0152        2600 CONTINUE
0153              WRITE (6,391)
0154        2700 CTN(KL)=CTA(NFTX)/XFFT(KL)
0155         260 NNCLT=NNCLT+1
0156              IF (NCL.EQ.1) GO TO 270
0157              CALL UNINT (4,CCLI(NCLT),TXCLI(NCLT),CLI,TCLI,LIMIT)
0158              CALL UNINT (4,CCLI(NCLT),XFFT(NCLT),CLI,XFT1(K),LIMIT)
0159              CALL UNINT (4,CCLI(NCLT),CTN(NCLT),CLI,CTT(K),LIMIT)
0160              GO TO 271
0161         270 TCLI=TXCLI(NCLT)
0162              XFT1(K)=XFFT(NCLT)
0163              CTT(K)=CTN(NCLT)
0164         271 CTE=CTT(K)*AFCT(K)*TCLI
0165              CALL UNINT(INN(K),CTANG(1,K,L),BLDANG(1,K),CTE,BLL(K),LIMIT)
0166              CALL UNINT (INN(K),BLDANG(1,K),CPANG(1,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,BLLL(IBB),LIMIT)
0172              BLLLL=BLLL(IBB)
0173              GO TO (310,350,310),IW
0174        310   CALL UNINT (4,ZJJ(NBEG),CTT(NBEG),ZJI,CTTT(IBB),LIMIT)
0175              CTG(1)=.100
0176              CTG(2)=.200
0177              CALL UNINT (7,ZJJ(1),TFCLI(1),ZJI,TFCLII,LIMIT)
0178              DO 390 IL=1,5
0179              CT=CTG(IL)
0180              CTE=CTG(IL)*AFCTE
0181              CALL UNINT (14,CTEC(1),BTDCR(1,L),CTE,TBL,IMIT)
0182              CTE1=CTE*TBL*TFCLII
0183              NNCLT=NCLT
0184              DO 396 KL=NCLT,NCLTT
0185              CALL UNINT (NCLX(NNCLT),CTCLI(1,NNCLT),XTCLI(1,NNCLT),CTE1,TXCLI(
                 1KL),LIMIT)
0186              IF (LIMIT.EQ.1) GO TO 591
0187              IF(ZJI.EQ.0.) GO TO 3000
0188              CALL UNINT(11,ZJCL(1),ZMCRL(1,NNCLT),ZJI,ZMCRT,LIMIT)
0189              DMN=ZMS(1)-ZMCRT
0190              GO TO 3050
0191        3000 ZMCRT=ZMCRO(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 (ZMMMC,1,DMN,CTE2,XFFT(KL),LIMIT)
0197         396 NNCLT=NNCLT+1
0198              IF (NCL.EQ.1) GO TO 395
0199              CALL UNINT (4,CCLI(NCLT),TXCLI(NCLT),CLI,TCLII,LIMIT)
0200              CALL UNINT (4,CCLI(NCLT),XFFT(NCLT),CLI,XFT,LIMIT)
0201              IF(XFT.GT.1.)XFT=1.0
0202              GO TO 394
0203         395 TCLII=TXCLI(NCLT)
0204              XFT=XFFT(NCLT)
```

FIGURE 3A. FORTRAN IV LISTING (CONTINUED)

```
  394 CT=CTG(IL)
      CTE=CTG(IL)*AFCTE*TCLII
      CTG1(IL)=CTE-CTTT(IBB)
      IF(ABS(CTG1(IL)/CTTT(IBB)).LT..001) GO TO 392
      IF(IL.LE.1) GO TO 390
      CTG(IL+1)=-CTG1(IL-1)*(CTG(IL)-CTG(IL-1))/(CTG1(IL)-CTG1(IL-1))+
     1CTG(IL-1)
  390 CONTINUE
      WRITE (6,391)
  391 FORMAT ( ' INTEGRATED DESIGN CL ADJUSTMENT NOT WORKING PROPERLY FO
     XR CT DEFINITION')
  392 CTTT(IBB)=CT
      GO TO (360,350,340),IW
  350 CALL UNINT (4,ZJJ(NBEG),XFT1(NBEG),ZJI,XFT,LIMIT)
      IF(XFT.GT.1.)XFT=1.0
 340  CALL UNINT (4,ZJJ(NBEG),CPP(NBEG),ZJI,CPPP(IBB),LIMIT)
      CPG(1)=.150
      CPG(2)=.200
      CALL UNINT (4,ZJJ(NBEG),PFCLI(NBEG),ZJI,PFCLII,LIMIT)
      DO 290 IL=1,5
      CP=CPG(IL)
      CPE=CPG(IL)*AFCPE
      CALL UNINT (14,CPEC(1),BLDCR(1,L),CPE,PBL,IMIT)
      CPE1=CPE*PBL*PFCLII
      NNCLT=NCLT
      DO 280 KL=NCLT,NCLTT
      CALL UNINT (NCLX(NNCLT),CPCLI(1,NNCLT),XPCLI(1,NNCLT),CPE1,PXCLI(
     1KL),LIMIT)
      IF (LIMIT.EQ.1) GO TO 591
  280 NNCLT=NNCLT+1
      IF(NCL.EQ.1) GO TO 282
      CALL UNINT (4,CCLI(NCLT),PXCLI(NCLT),CLI,PCLII,LIMIT)
      GO TO 284
  282 PCLII=PXCLI(NCLT)
  284 CP=CPG(IL)
      CPE=CPE*PCLII
      CPG1(IL)=CPE-CPPP(IBB)
      IF(ABS(CPG1(IL)/CPPP(IBB)).LE..001) GO TO 287
      IF(IL.EQ.1) GO TO 290
      CPG(IL+1)=-CPG1(IL-1)*(CPG(IL)-CPG(IL-1))/(CPG1(IL)-CPG1(IL-1))+
     1CPG(IL-1)
  290 CONTINUE
      WRITE (6,285)
  285 FORMAT (' INTEGRATED DESIGN CL ADJUSTMENT NOT WORKING PROPERLY FOR
     1CP DEFINITION')
  287 CPPP(IBB)=CP
  360 L=L+1
  500 CONTINUE
      IF(NBB-1) 510,590,510
  510 CALL UNINT (4,XLB(1),BLLL(1),BLADT,BLLLL,LIMIT)
      GO TO(520,530,520),IW
  520 CALL UNINT (4,XLB(1),CTTT(1),BLADT,CT,LIMIT)
      GO TO 590
  530 CALL UNINT (4,XLB(1),CPPP(1),BLADT,CP,LIMIT)
  590 CONTINUE
      GO TO 600
  591 CT=ASTERK
      CP=ASTERK
```

FIGURE 3A. FORTRAN IV LISTING (CONTINUED)

```
0258          600 CONTINUE
0259              RETURN
0260              END
```

FIGURE 3A. FORTRAN IV LISTING (CONTINUED)

```
0001            SUBROUTINE ZNOISE (BLADT,DIA,TIPSPD,VKTAS     ,BHP     ,DIST     ,SPL,
               1FC     ,XNOE)
0002            DIMENSION                     PNLA(20),PNLB(10),PNLC(13,7,4),DIAM(20),
               1RBL(4),TMTH(20)
0003            DIMENSION  DUM1(200), DUM2(200)
0004            EQUIVALENCE  (PNLC(1,4,2),DUM1(1)), (PNLC(1,7,3),DUM2(1))
0005            DATA  TMTH             /.3,.35,.4,.45,.5,.55,.6,.65,.7,.75,.8,.85,.9
               X/
0006            DATA  PNLC       /            -2.5,-1.8,-1.0,.0,.8,1.4,1.8,2.0,2.25,
               X2.75,3.5,4.3,5.3,
               X                              -5.5,-4.5,-3.3,-2.0,-.9,-.2,.0,.3,.75,
               X1.3,2.1,3.0,4.0,
               X                              -6.5,-6.1,-5.6,-4.99,-3.8,-2.6,-1.6,-1.,
               X-.75,-.4,.4,1.6,3.1,
               X                              -7.5,-7.25,-7.,-6.9,-6.8,-6.3,-5.0,-2.9,
               X-1.9,-1.4,-.6,.4,2.1,
               X                              -9.4,-9.75,-9.9,-9.9,-9.75,-9.3,-8.5,
               X-7.4,-6.3,-5.0,-3.5,-1.5,.9,
               X                              -10.6,-10.8,-10.9,-10.9,-10.6,-10.3,-9.6
               X,-8.6,-7.5,-6.2,-4.6,-2.8,-.8,
               X                              -11.4,-11.6,-11.7,-11.7,-11.5,-11.2,
               X-10.4,-9.4,-8.3,-7.0,-5.4,-3.6,-1.6,
               X                              -.25,.70,1.7,2.45,3.0,3.3,3.3,3.5,3.7,
               X4.1,4.6,5.3,6.7,
               X                              -1.3,-.6,.2,.8,1.4,1.7,2.4,3.0,3.4,3.4,
               X3.5,4.3,6.0,
               X                              -3.6,-3.0,-2.1,-1.2,-.3,.4,.95,1.3,1.5,
               X1.9,2.4,3.3,5.0/
0007            DATA  DUM1  /                 -5.7,-4.8,-3.8,-2.7,-1.7,-.8,-.2,.0,.1,
               X.3,.8,1.7,3.6,
               X                              -6.5,-6.0,-5.4,-4.8,-4.3,-3.6,-3.1,-2.5,
               X-1.8,-1.0,-.1,1.1,2.6,
               X                              -7.6,-7.4,-7.3,-7.2,-6.9,-6.6,-6.1,-5.4,
               X-4.5,-3.3,-2.0,-.4,1.3,
               X                              -9.7,-9.7,-9.7,-9.5,-9.4,-9.0,-8.5,-7.8,
               X-6.9,-5.9,-4.6,-2.9,-.8,
               X                              2.1,2.8,3.4,3.7,4.1,4.4,4.6,4.75,5.0,
               X5.3,5.8,6.5,7.3,
               X                              .2,1.0,2.0,2.7,3.4,3.5,3.5,3.6,3.8,4.2,
               X4.7,5.5,6.9,
               X                              -1.2,-.7,.1, .75,1.4,1.8,2.3,2.5,2.6,
               X3.0,3.5,4.5,6.4,
               X                              -2.8,-2.2,-1.6,-1.0,-.5,.0,.4,.7,1.1,
               X1.7,2.4,3.3,4.8,
               X                              -4.7,-3.9,-3.2,-2.5,-1.8,-1.3,-.7,-.5,
               X-.2,.3,1.0,2.0,3.6,
               X                              -6.5,-6.1,-5.5,-4.9,-4.2,-3.7,-3.1,-2.5,
               X-1.9,-1.3,-.5,.7,2.5/
0008            DATA  DUM2  /                 -8.3,-7.7,-7.3,-6.8,-6.3,-5.7,-5.1,-4.5,
               X-3.8,-3.0,-2.0,-.7,1.3,
               X                              4.0,4.3,4.7,5.4,5.9,6.3,6.3,6.3,6.4,6.6,
               X7.0,7.6,9.0,
               X                              3.2,3.3,3.5,3.6,4.0,4.5,5.1,5.7,6.0,6.0,
               X6.1,6.6,7.6,
               X                             2.1,2.4,2.7,3.0,3.3,3.7,3.9,4.0,4.2,4.5,
               X4.8,5.4,6.3,
               X                              1.3,1.6,1.8,2.1,2.3,2.5,2.7,3.0,3.3,3.6,
               X4.1,4.7,5.6,
```

FIGURE 3A. FORTRAN IV LISTING (CONTINUED)

```
                 X                                  .25,.5,.75,1.0,1.3,1.5,1.8,2.1,2.4,2.8,
                 X3.4,4.2,5.4,
                 X                                  -2.3,-1.8,-1.3,-.8,-.5,-.1,.3,.5,.8,1.2,
                 X1.8,2.5,3.6,
                 X                                  -5.0,-4.5,-3.7,-2.8,-2.3,-1.8,-1.4,-1.0,
                 X-.7,-.2,.5,1.3,2.5/
 0009              DATA  DIAM          /5.0,6.5,8.5,11.,14.5,18.,25./
 0010              DATA  BBL /2.,3.,4.,6./
 0011              TMT= SQRT(TIPSPD**2+(VKTAS    /.5925)**2)/1120.*FC
 0012              NBB=1
 0013              IB=BLADT-1.0+.001
 0014              GO TO (2,2,2,5,6,6,6),IB
 0015            2 KK=IB
 0016              GO TO 7
 0017            5 NBB=4
 0018              KK=1
 0019              GO TO 7
 0020            6 KK=4
 0021              NBB=4
 0022            7 CONTINUE
 0023              DO 8 K=KK,NBB
 0024              DO 9  I=1,7
 0025            9 CALL UNINT (13,TMTH(1),PNLC(1,I,K),TMT, PNLA(I)  ,LIMIT)
 0026            8 CALL UNINT ( 7,DIAM(1),PNLA(1),DIA, PNLB(K),LIMIT )
 0027              PNLD = PNLB(KK)
 0028              IF (IB.EQ.5) CALL UNINT(4,BBL(1),PNLB(1),BLADT,PNLD,LIMIT)
 0029              RMT  = TIPSPD/1120.
 0030              SPL  = 107.7+ 6.69*ALOG(BHP    )-4.34*ALOG(BLADT**2*DIA**2*DIST**2/
                 XXNOE) + 38.1* RMT + PNLD
 0031              IF(LIMIT.NE.0) SPL=999999.
 0032              RETURN
 0033              END
```

FIGURE 3A. FORTRAN IV LISTING (CONTINUED)

```
FORTRAN IV G LEVEL  20.1                    WAIT              DATE = 72031              08/48/14

      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=ZND/20000.
      ZK6=(BHP/10./DIA**2)**.12
      ZK7=(ZMWT+1.0)**.5
      WTFAC=ZK2*ZK3*ZK6*ZK7
C     WTCON DEFINES AIRPLANE CATEGORY
      IWTCON=WTCON
      ZC=3.5*ZK2*BLADT*ZK4**2*(1./ZK5)**.3
      GO TO (10,20,30,40,50),IWTCON
   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 WTFAC=WTFAC*ZK4**.7*ZK5**.4
      WT70=220.*WTFAC+ZC*(5.0/3.5)
      WT80=190.*WTFAC+ZC
      GO TO 60
   50 WT70=220.*WTFAC*ZK4**.7*ZK5**.4+ZC*(5.0/3.5)
      WT80=190.*WTFAC*ZK4**.7*ZK5**.3
   60 RETURN
      END
```

FIGURE 3A. FORTRAN IV LISTING (CONTINUED)

```
0001                SUBROUTINE COST (WTCON,BLADT,CLF1,CLF,CK70,CK80,CAMT,DAMT,NAMT,
                   1CQUAN       ,WT70,WT80,COST70,COST80,CCLF1,CCLF,CCK70,CCK80,IENT)
0002                DIMENSION CQUAN(2,11),COST70(10),COST80(10),ZFFAC(2,5),ZQUAN(2,5),
                   1ZEFAC(5)
0003                DATA  ZFFAC / 3.5,3.5,3.7,3.7,3.2,3.2,2.6,3.5,2.0,3.4  /
0004                DATA  ZEFAC            /1.0,1.5,3.5,3.5,3.5/
0005                DATA ZQUAN  / 1910.,2230.,2810.,5470.,1030.,1990.,295.,680.,
                   X 65.,368. /
0006                ICON=WTCON +.01
0007                GO TO (5,100),IENT
0008              5 IF(CLF1)10,10,20
0009             10 CCLF1=3.2178
0010                CCLF=1.02
0011                GO TO 1000
0012             20 CCLF1=CLF1
0013                CCLF=CLF
0014                GO TO 1000
0015            100 IF(CK70)40,40,50
0016             40 CCK70=ZFFAC(1,ICON)*(3.0*BLADT**.75+ZFFAC(ICON))
0017                GO TO 60
0018             50 CCK70=CK70
0019             60 IF(CK80)70,70,90
0020             70 CCK80=ZFFAC(2,ICON)*(3.0*BLADT**.75+ZEFAC(ICON))
0021                GO TO 110
0022             90 CCK80=CK80
0023            110 IF(CAMT)120,120,130
0024            120 CQUAN(1,1)=ZQUAN(1,ICON)
0025                CQUAN(2,1)=ZQUAN(2,ICON)
0026                GO TO 140
0027            130 CQUAN(1,1)=CAMT
0028                CQUAN(2,1)=CAMT
0029            140 XLN=(ALOG(CCLF)-ALOG(CCLF1))/6.90775527
0030                DO 200 I=1,NAMT
0031                COST70(I)=CCK70*EXP(ALOG(CQUAN(1,I))*XLN+ALOG(CCLF1))*WT70/CCLF1
0032                COST80(I)=CCK80*EXP(ALOG(CQUAN(2,I))*XLN+ALOG(CCLF1))*WT80/CCLF1
0033                CQUAN (1,I+1)=CQUAN (1,I)+DAMT
0034                CQUAN (2,I+1)=CQUAN (2,I)+DAMT
0035            200 CONTINUE
0036           1000 RETURN
0037                END
```

FIGURE 3A. FORTRAN IV LISTING (CONTINUED)

```
0001      SUBROUTINE REVTHT (RTC,ROT,AFT,CLI,BLADN,DIA,CP,THETA,RORO,BHPI,
         1RPMI,PCPWC,ANDVK)
0002      DIMENSION TAFC(42),QAFC(42),          DCQPPC(37),CTPC(72),
         1TCPC(102),CQPC(62),QCPC(62),CQPCZ(19),RPMC(9),BHPC(9),ASSJ(9),
         STHRSTC(9),PCCHC(182),VKC(9)
0003      DATA TAFC/ 1.,7.,4.,80.,100.,120.,140.,160.,180.,200.,.3,.5,.7,.8,
         11.188,1.188,1.188,1.188,1.0,1.0,1.0,1.0,.874,.879,.885,.886,.785,
         2.791,.797,.801,.715,.724,.734,.739,.661,.675,.689,.696,.631,.645,
         3.660,.667/
0004      DATA QAFC/ 2.,7.,4.,80.,100.,120.,140.,160.,180.,200.,.3,.5,.7,.8,
         11.190,1.190,1.190,1.190,1.0,1.0,1.0,1.0,.875,.872,.869,.866,.787,
         2.780,.774,.770,.724,.711,.704,.700,.665,.656,.646,.642,.624,.612,
         3.601,.596/
0005      DATA DCQPPC/3.,6.,4.,.0,.2,.4,.6,.8,1.0,.3,.4,.6,.8,-.0002,.0,
         1.00048,.00090,-.0004,.0,.00081,.00160,-.0006,.0,.0012,.0024,
         2 -.00078,.0,.00158,.00312,-.00097,.0,.00194,.00391,-.00114,0.,
         3.00231,.00458/
0006      DATA PCCHC/5.,11.,14.,.0,.1,.2,.3,.4,.5,.6,.7,.8,.9,1.0,-30.,-25.,
         1-20.,-17.,-12.5,-8.8,-5.5,-2.3,1.5,5.0,8.5,11.9,15.,15.1,
         21.,1.,1.,1.,1.,1.,1.,1.,1.,1.,1.,1.,1.,1.,
         3.875,.875,.925,1.,1.,1.,1.,1.,1.,1.,1.,1.,1.,1.,
         4.750,.750,.791,.849,1.,1.,1.,1.,1.,1.,1.,1.,1.,1.,
         5.623,.623,.660,.708,.828,1.,1.,1.,1.,1.,1.,1.,1.,1.,
         6.500,.500,.527,.564,.665,.802,1.,1.,1.,1.,1.,1.,1.,1.,
         7.375,.375,.396,.421,.499,.619,.778,.995,1.,1.,1.,1.,1.,1.,
         8.250,.250,.263,.282,.339,.419,.547,.730,1.,1.,1.,1.,1.,1.,
         9.124,.124,.130,.140,.173,.230,.320,.452,.716,.995,1.,1.,1.,1.,
         A.0,.0,.0,.0,.014,.043,.091,.188,.400,.694,1.,1.,1.,1.,
         B.0,.0,.0,.0,.0,.0,.0,.0,.095,.375,.695,1.,1.,1.,
         C.0,.0,.0,.0,.0,.0,.0,.0,.0,.0,.350,.685,.998,1./
0007      DATA CTPC /6.,6.,9.,.0,.2,.4,.6,.8,1.0,-30.,-25.,-20.,-15.,-10.,
         1-5.,0.,5.,10.,
         2-.0955,-.0855,-.0700,-.0498,-.0262,-.0005,.0270,.0590,.1035,
         3-.1225,-.1110,-.0950,-.0735,-.0490,-.0218,.0060,.0415,.0840,
         4-.1590,-.1440,-.1265,-.1040,-.0785,-.0505,-.0215,.0110,.0500,
         5-.2080,-.1895,-.1715,-.1490,-.1230,-.0965,-.0700,-.0340,.0070,
         6-.2685,-.2550,-.2395,-.2210,-.2025,-.1825,-.1595,-.1145,-.0550,
         7-.3550,-.3430,-.3290,-.3130,-.2920,-.2690,-.2400,-.1980,-.1370/
0008      DATA TCPC /7.,9.,9.,.2,.3,.4,.5,.6,.7,.8,.9,1.0,-30.,-25.,-20.,
         1-15.,-10.,-5.,0.,5.,10.,
         2-.077,-.079,-.080,-.083,-.081,-.078,-.0745,-.071,-.0675,
         3-.105,-.109,-.111,-.1085,-.104,-.100,-.095,-.090,-.0835,
         4-.142,-.146,-.148,-.143,-.1365,-.1305,-.1225,-.112,-.1035,
         5-.188,-.188,-.1865,-.1825,-.175,-.165,-.1535,-.1385,-.122,
         6-.228,-.225,-.222,-.2185,-.211,-.198,-.1815,-.161,-.1385,
         7-.261,-.2585,-.2545,-.2485,-.2395,-.225,-.205,-.179,-.148,
         8-.294,-.288,-.2815,-.273,-.261,-.2445,-.2225,-.1895,-.1495,
         9-.325,-.316,-.306,-.294,-.2775,-.2585,-.2345,-.196,-.147,
         A-.355,-.343,-.328,-.3125,-.292,-.269,-.240,-.198,-.137/
0009      DATA CQPC /8.,5.,9.,.0,.4,.6,.8,1.0,-30.,-25.,-20.,-15.,-10.,-5.,
         10.,5.,10.,
         2.031,.0241,.0171,.0108,.0056,.0022,.0017,.0028,.0060,
         4.0363,.0283,.0201,.0127,.0064,.0025,.0014,.0014,.0035,
         6.0430,.0330,.0236,.0150,.0075,.0027,.0008,.0005,.0016,
         8.0523,.0406,.0289,.0182,.0091,.0030,-.0002,-.0013,-.0015,
         1.0629,.0493,.0346,.0220,.0110,.0037,-.0012,-.0046,-.0062/
0010      DATA QCPC /9.,5.,9.,.2,.4,.6,.8,1.0,-30.,-25.,-20.,-15.,-10.,-5.,
         10.,5.,10.,
```

FIGURE 3A. FORTRAN IV LISTING (CONTINUED)

```
                    2.0107,.0088,.0068,.0049,.0030,.0011,-.0004,-.0019,-.0033,
                    4.0202,.0162,.0122,.0085,.0049,.0012,-.0020,-.0048,-.0072,
                    6.0353,.0272,.0195,.0128,.0070,.0016,-.0030,-.0065,-.0093,
                    8.0491,.0379,.0278,.0180,.0091,.0025,-.0026,-.0062,-.0080,
                    1.0629,.0493,.0346,.0220,.0110,.0037,-.0012,-.0046,-.0062/
0011                 DATA CQPCZ/ 10.,8.,0.,.0018,.0028,.0039,.0056,.0108,.0171,.0241,
                    1.031,-3.5,-6.3,-7.9,-10.,-15.,-20.,-30./
0012                 DATA ASSJ /.0,.25,.50,.75,1.00,1.25,1.50,1.75,2.00/
0013                 CBRT(X)=ABS(X)**(1./3.)*X/ABS(X)
0014                 CALL BIQUAD (TAFC,1,AFT,CLI,TAF,LIMIT)
0015                 CALL BIQUAD (QAFC,1,AFT,CLI,QAF,LIMIT)
0016                 IF (RTC-1.) 20,10,20
0017              10 CDPQ=CP/6.2832*(3./BLADN)**.83*QAF
0018                 CALL BIQUAD (DCQPPC,1,ASSJ(1),CLI,DCQPP,LIMIT)
0019                 CPQ=CDPQ-DCQPP
0020                 CALL BIQUAD (CQPCZ,1,CPQ,0.,THETA,LIMIT)
0021            20   DO 50 I=1,5
0022                 CALL BIQUAD (CQPC,1,ASSJ(I),THETA,CQP,LIMIT)
0023                 CALL BIQUAD (CTPC,1,ASSJ(I),THETA,CTP,LIMIT)
0024                 CALL BIQUAD (PCCHC,1,ASSJ(I),THETA,PCCH,LIMIT)
0025                 IF(PCCH.GT.1.) PCCH=1.
0026                 CALL BIQUAD (DCQPPC,1,ASSJ(I),CLI,DCQPP,LIMIT)
0027                 DCTPP=.0975*CLI-.039
0028                 CP=(CQP+PCCH*DCQPP)*6.2832/(QAF*(3.0/BLADN)**.83)
0029                 CT=(CTP+PCCH*DCTPP)/(TAF*(3.0/BLADN)**.83)
0030                 IF(ROT.EQ.1.) GO TO 30
0031                 CONST=BHPI/RPMI*PCPWC/100.
0032                 RPMC(I)=SQRT (10.E10*RORO*CONST/(2.0*DIA**5*CP))
0033                 IF(RPMC(I ).GT.RPMI.AND.RTC.NE.2.) RPMC(I)=RPMI
0034                 BHPC(I)=CONST*RPMC(I)
0035                 GO TO 40
0036              30 BHPC(I)=BHPI*PCPWC/100.
0037                 CONST1=10.E10*BHPC(I)*RORO/(2.0*DIA**5*CP)
0038                 RPMC(I)=CBRT(CONST1)
0039              40 VKC(I)=ASSJ(I)*RPMC(I)*DIA/101.4
0040                 THRSTC(I)=CT*RPMC(I)**2*DIA**4/(1.514*10.E5*RORO)
0041                 THRSTC(I )=ABS(THRSTC(I ))
0042              50 CONTINUE
0043                 NNJ=5
0044                 IF (VKC(5).GT.ANDVK) GO TO 90
0045                 DO 80 I=6,9
0046                 TJ=1./ASSJ(I)
0047                 CALL BIQUAD (QCPC,1,TJ,THETA,QCP,LIMIT)
0048                 CALL BIQUAD (TCPC,1,TJ,THETA,TCP,LIMIT)
0049                 CP=(QCP               )*6.2832/(QAF*(3.0/BLADN)**.83)/TJ**2
0050                 CT=(TCP               )/(TAF*(3.0/BLADN)**.83)/TJ**2
0051                 IF (ROT.EQ.1.) GO TO 60
0052                 CONST=BHPI/RPMI*PCPWC/100.
0053                 RPMC(I)=SQRT (10.E10*RORO*CONST/(2.0*DIA**5*CP))
0054                 BHPC(I)=CONST*RPMC(I)
0055                 GO TO 70
0056              60 BHPC(I)=BHPI*PCPWC/100.
0057                 CONST1=10.E10*BHPC(I)*RORO/(2.0*DIA**5*CP)
0058                 RPMC(I)=CBRT(CONST1)
0059              70 VKC(I)=DIA*RPMC(I)/(TJ*101.4)
0060                 THRSTC(I)=CT*RPMC(I)**2*DIA**4/(1.514*10.E5*RORO)
0061                 THRSTC(I)=ABS(THRSTC(I))
0062                 NNJ=NNJ+1
```

FIGURE 3A. FORTRAN IV LISTING (CONTINUED)

```
       1000 FORMAT (13E10.4)
            IF(VKC(I).GT.ANDVK) GO TO 90
         80 CONTINUE
         90 NOUNT=ANDVK/10.+2.
            TRIG=0.
            VK=0.
            DO 100 I=1,NOUNT
            CALL UNINT (NNJ,VKC(1),BHPC(1),VK,SHPV,LIMIT)
            CALL UNINT(NNJ,VKC(1),RPMC(1),VK,RPMV,LIMIT)
            CALL UNINT(NNJ,VKC(1),THRSTC(1),VK,THRSTV,LIMIT)
            IF(SHPV.GT.BHPI) SHPV=BHPI
            IF(RPMV.GT.RPMI) RPMV=RPMI
            IF(I.GT.1) GO TO 94
            WRITE (6,92) DIA,PCPWC,THETA,VK,THRSTV,SHPV,RPMV
         92 FORMAT (F10.1,F9.0,F9.1,F8.1,F9.0,F8.0,F7.0)
            GO TO 98
         94 WRITE(6,96) VK,THRSTV,SHPV,RPMV
         96 FORMAT(28X,F8.1,F9.0,F8.0,F7.0)
         98 IF(TRIG.EQ.1.) GO TO 110
            VK=VK+10.
            IF(VK.LT.ANDVK) GO TO 100
            VK=ANDVK
            TRIG=1.
        100 CONTINUE
        110 RETURN
            END
```

FIGURE 3A. FORTRAN IV LISTING (CONTINUED)

```
FORTRAN IV G LEVEL  20.1                UNINT              DATE = 72031          08/48/14

0001                 SUBROUTINE UNINT ( N, XA, YA, X , Y, L)
               C       REWRITTEN    SEPTEMBER  18,  1967
               C      UNIVARIATE TABLE ROUTINE WITH SEPERATE ARRAYS FOR X AND Y - S 66
               C
               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
0002                  DIMENSION  XA(1), YA(1), D(4), P(5)
0003                   L=0
0004                   I=1
               C      TEST FOR OFF LOW END   NO   #  YES
0005                     IF ( XA(1)-X )    100, 150,  10
0006              10   L=1
0007                     GO TO 150
0008             100     DO 120 I=2,N
0009                     IF ( XA(I)-X)  120, 150, 200
0010             120  CONTINUE
               C      OFF HIGH END
0011                   I = N
0012                   L= 2
0013             150   Y= YA(I)
0014                     GO TO 999
               C      TEST FOR FIRST INTERVAL
0015             200     IF(I-2) 240,220,240
               C      FIRST INTERVAL
0016             220   JX1  = 1
0017                   RA  = 1.
0018                     GO TO 400
               C      TEST FOR LAST INTERVAL
0019             240     IF(I-N) 300, 250, 300
               C      LAST INTERVAL
0020             250   JX1  = N-3
0021                   RA  = 0.
0022                     GO TO 400
0023             300   JX1  = I-2
0024                   RA  = (XA(I)-X) /(XA(I)-XA(I-1) )
0025             400   RB  = 1. - RA
               C
               C      GET COEFFICIENTS AND RESULTS
0026                   J = JX1
0027                     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                  D(4) = X - XA(J)
0032                  P(4) = P(1) + P(2)
0033                  P(5) = P(2) + P(3)
               C      RESULT
0034                  Y = YA(JX1) * RA/P(1) * D(2)/P(4) * D(3) +
                     1  YA(JX1+1) * (-RA/P(1) * D(1)/P(2) * D(3) + RB/P(2) * D(3)/P(5)
                     2  *D(4)) + YA(JX1+2) *(RA/P(2) * D(1)/P(4) * D(2) - RB/P(2)
                     3  * D(2)/P(3) * D(4)) + YA(JX1+3) * RB/P(5) * D(2)/P(3) * D(3)
0035             999   RETURN
0036                     END
```

FIGURE 3A. FORTRAN IV LISTING (CONTINUED)

```
FORTRAN IV G LEVEL  20.1                 BIQUAD              DATE = 72031              08/48/14

                 SUBROUTINE  BIQUAD (T, I, XI, YI, Z, K)
              ENTRY          BIQUD  (T, I, XI, YI, 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(1),XC(4), D(4), P(5), Y(4),C(4)
      C
              EQUIVALENCE (XC(1), D(1))
      C
      C       TABLE SET UP
      C          T%I<     # TABLE NUMBER
      C          T%I&1<   # NUMBER OF %X< VALUES
      C          T%I&2<   # NUMBER OF %Y< VALUES   %0. FOR UNIVARIATE TABLE<
      C          T%I&3<   # VALUES OF %X< IN ASCENDING ORDER
               NX = T(I+1)
               NY = T(I+2)
               J1  = I+3
               J2 = J1 + NX - 1
               X = XI
      C       SEARCH IN X SENSE
               L = 0
                 GO TO 1000
      C       RETURN HERE FROM SEARCH OF X
        100    K = KX
               JX= JX1
      C       THE FOLLOWING CODE PUTS X AND/OR Y VALUES IN XC BLOCK
        105      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 UNIVARE OR BIVARIATE
        200      IF (NY)  300,210,300
        210    Z=0.
               JY = JX+NX
                 DO 220 J=1,4
               Z= Z + C(J)*T(JY)
        220    JY = JY+1
                 GO TO 9999
      C
      C       BIVARIATE TABLE
        300      L=1
               X = YI
               J1 = J2+1
               J2 = J1+NY-1
      C       SEARCH IN  Y SENSE  JX1 # SUBSCRIPT OF 1ST Y
                 GO TO 1000
        500    K = K+3*KX
      C       INTERPOLATE IN X SENSE
      C       SUBSCRIPT - BASE   NO. OF COL.     NO. OF YS
               JY  =     J2+1    + (JX-I-3)*NY  + JX1-J1
                 DO 550 M=1,4
               JX  = JY
               Y(M) = 0.
                 DO  520 J=1,4
               Y(M) = Y(M) + C(J)*T(JX)
        520    JX = JX+NY
```

FIGURE 3A. FORTRAN IV LISTING (CONTINUED)

```
FORTRAN IV G LEVEL  20.1                BIQUAD               DATE = 72031           08/48/14

 0038           550    JY = JY+1
               C
               C       GET COEFF. IN Y SENSE
 0039                     GO TO 105
 0040           600    Z = 0.
 0041                     DO 700 J=1,4
 0042           700    Z = Z + C(J)*Y(J)
 0043           9999   RETURN
               C
               C       SEARCH ROUTINE - INPUT J1,J2,X
               C                         -OUTPUT RA,RB,KX,JX1
 0044           1000   KX = 0
 0045                     DO 1010 J=J1,J2
 0046                     IF (T(J)- X) 1010,1050,1050
 0047           1010   CONTINUE
               C       OFF HIGH END
 0048                  X = T(J2)
 0049                  KX = 2
               C       USE LAST 4 POINTS AND CURVE B
 0050           1020   JX1 = J2-3
 0051                  RA = 0.
 0052                     GO TO 1600
               C       TEST FOR  - -  OFF LOW END,  FIRST INTERVAL, OTHER
 0053           1050      IF(J-J1-1)     1080     ,      1090        , 1100
 0054           1080    IF(T(J)-X) 1082,1090,1082
 0055           1082   KX = 1
 0056                  X = T(J1)
 0057           1090   JX1 = J1
 0058                  RA = 1.
 0059                     GO TO 1600
               C       TEST  FOR LAST INTERVAL  NO, YES, NO
 0060           1100      IF (J - J2)           1500,1020,1500
 0061           1500   JX1 = J-2
 0062                  RA = (T(J) - X )/(T(J) - T(J-1) )
 0063           1600   RB = 1. - RA
               C
               C       RETURN BACK TO MAIN BODY
 0064                     IF (L)  500, 100, 500
               C
               C       COEFFICINT ROUTINE - INPUT  X, X1, X2, X3, X4, RA, RB
 0065           2000      DO 2010 J=1,3
 0066           2010   P(J) = XC(J+1)-XC(J)
 0067                  P(4)=P(1)+P(2)
 0068                  P(5)=P(2)+P(3)
 0069                     DO 2020 J=1,4
 0070           2020   D(J) = X-XC(J)
 0071                  C(1)=(RA/P(1))*(D(2)/P(4))*D(3)
 0072                  C(2)=(-RA/P(1))*(D(1)/P(2))*D(3)+(RB/P(2))*(D(3)/P(5))*D(4)
 0073                  C(3)=(RA/P(2))*(D(1)/P(4))*D(2)-(RB/P(2))*(D(2)/P(3))*D(4)
 0074                  C(4)=(RB/P(5))*(D(2)/P(3))*D(3)
               C       RETURN TO MAIN BODY
 0075                     IF(L)  600,200,600
 0076                    END
```

FIGURE 3A. FORTRAN IV LISTING (CONCLUDED)

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