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EXPERIMENTAL AND ANALYTICAL DETERMINATION OF INTEGRATED AIRFRAME NOZZLE PERFORMANCE

Operating Manual for Twin-Nozzle/Aftbody Drag and Internal Nozzle Performance Computer Deck

LOCKHEED-CALIFORNIA COMPANY

TECHNICAL REPORT AFFDL-TR-72-101 – VOL II

OCTOBER 1972

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EXPERIMENTAL AND ANALYTICAL DETERMINATION OF INTEGRATED AIRFRAME NOZZLE PERFORMANCE

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FOREWORD

The computer program described herein was developed by the Lockheed-California Company (Calac), Burbank, California, under Contract No. F33657-70-C-0511 of Project No. 668A. The contract was administered by the Air Force Flight Dynamics Laboratory (AFFDL), Wright-Patterson Air Force Base, Ohio, with P.C. Everling (FXM) and J.A. Laughrey (FXM) as Project Engineers. Subcontract support was provided by Pratt and Whitney Aircraft (P&WA), East Hartford, Connecticut.

This is the second of a two-volume final report to be submitted under the contract which was conducted during the period from 1 November 1969 to 31 July 1972. The report describes the operation of the end item computer program developed for predicting twin-nozzle/aftbody drag and internal nozzle performance. In addition to the three principal authors, R.A. Fox and R.D. Grennan of Calac made significant contributions toward preparation of the report manuscript. The authors are indebted to the following Calac personnel for their assistance in developing the computer program: E.L. Bragdon and M.H. Scott, Jr., of Propulsion; R.F. Smith of Aerodynamics; and T.J. Jones, B.A. Schwartz, and D.A. Tappeiner of Computer Services.

This report was submitted by the authors for AFFDL approval on 31 July 1972. A Calac report number, LR 25370, has been assigned to identify the report prior to approval.

This technical report has been reviewed and is approved.

PHILIP P. ANTONATOS
Chief, Flight Mechanics Division
Air Force Flight Dynamics Laboratory
ABSTRACT

A computer program has been developed for predicting twin-nozzle/aftbody drag and internal nozzle performance for fighter type aircraft having twin buried engines and dual nozzles. The program is capable of generating the installed thrust-minus-drag data required for conducting mission analysis studies of aircraft of this type. The configuration variables which can be analyzed include (1) nozzle type (convergent flap and iris, convergent-divergent with and without secondary flow, and shrouded and unshrouded plug), (2) nozzle lateral spacing, (3) interfairing type (horizontal and vertical wedge), (4) interfairing length, and (5) vertical stabilizer type (single and twin).

The performance prediction methods incorporated in the program are based almost entirely on empirical correlations. Specifically, correlations used in conjunction with one-dimensional flow relationships are employed for the prediction of the nozzle thrust and discharge coefficients, and correlations of the test data obtained during the contracted effort are employed for prediction of the aft-end drag. The prediction methods account for the effects of nozzle pressure ratio and flow separation on both internal and external nozzle surfaces.

This manual describes the operation of the computer program in terms of program input requirements, performance prediction methods, and output format and includes a presentation of sample input/output cases and a complete computer listing of the program. The program has been developed for use on the CDC 6600 computer.
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<tr>
<td>$A_e$</td>
<td>Physical nozzle exit area</td>
</tr>
<tr>
<td>$A_{e_{flow}}$</td>
<td>Flow area at nozzle exit</td>
</tr>
<tr>
<td>$A_{e_{sep}}$</td>
<td>Flow area at separation point</td>
</tr>
<tr>
<td>$A_F$</td>
<td>Frontal area</td>
</tr>
<tr>
<td>$A_M$</td>
<td>Maximum cross-sectional area</td>
</tr>
<tr>
<td>$A_{MB}$</td>
<td>Metric break cross-sectional area</td>
</tr>
<tr>
<td>$A_S$</td>
<td>Shroud area (jet plus base areas)</td>
</tr>
<tr>
<td>$A^*_{T}$</td>
<td>Flow area for sonic flow</td>
</tr>
<tr>
<td>$A_W$</td>
<td>Wetted surface area</td>
</tr>
<tr>
<td>$C_{D_{As}}$</td>
<td>Boattail pressure drag coefficient based on boattail cross-sectional area at nozzle exit station.</td>
</tr>
<tr>
<td>$C_{d_{N}}$</td>
<td>Nozzle discharge coefficient</td>
</tr>
<tr>
<td>$C_{d_{N_{max}}}$</td>
<td>Maximum nozzle discharge coefficient</td>
</tr>
<tr>
<td>$C_{D_{PT}}$</td>
<td>Boattail pressure drag coefficient based on shroud cross-sectional area at nozzle exit station.</td>
</tr>
<tr>
<td>$C_{D_{PT}}$</td>
<td>Boattail pressure drag coefficient based on maximum boattail cross-sectional area</td>
</tr>
<tr>
<td>$C_f$</td>
<td>Skin friction coefficient</td>
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LIST OF SYMBOLS (CONTINUED)

\( C_s \)
Stream thrust correction factor

\( C_t \)
Thrust coefficient

\( D \)
Drag

\( F_{id} \)
Ideal gross thrust based on isentropic expansion of actual flow to freestream pressure

\( I_{MS} \)
Integral Mean slope

\( K \)
Drag due to lift factor

\( L_{BT} \)
Boattail length

\( L_{eff} \)
Effective flat plate length

\( m \)
Mass flow rate

\( M_e \)
Exit Mach number

\( M_{sep} \)
Mach number upstream of separation point

\( M_T \)
Throat Mach number

\( P \)
Static pressure

\( P_b \)
Base pressure

\( P_{sep} \)
Static pressure upstream of separation point

\( P_{Te} \)
Total pressure at nozzle exit

\( P_{TT} \)
Total pressure at nozzle throat

\( (P_{TT}/P_\infty)_{CK} \)
Choking pressure ratio

\( (P_{TT}/P_\infty)_{CR} \)
Critical pressure ratio

\( (P_{TT}/P_\infty)_F \)
Pressure ratio at which the nozzle flows full
### LIST OF SYMBOLS (CONTINUED)

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<tr>
<td>(P_T^T/P_\infty^L)</td>
<td>Pressure ratio where linear (C_T) extrapolation ends</td>
</tr>
<tr>
<td>q</td>
<td>Dynamic pressure</td>
</tr>
<tr>
<td>(R_c)</td>
<td>Lip radius of curvature</td>
</tr>
<tr>
<td>(R_{e\theta})</td>
<td>Momentum thickness Reynolds number</td>
</tr>
<tr>
<td>(R'_e)</td>
<td>Reference Reynolds number</td>
</tr>
<tr>
<td>(R_{mf})</td>
<td>Momentum ratio</td>
</tr>
<tr>
<td>R</td>
<td>Radius</td>
</tr>
<tr>
<td>(T_{aw})</td>
<td>Adiabatic wall temperature</td>
</tr>
<tr>
<td>(\mu)</td>
<td>Viscosity</td>
</tr>
<tr>
<td>(\alpha)</td>
<td>Nozzle upstream approach angle</td>
</tr>
<tr>
<td>(\theta)</td>
<td>Internal divergence angle</td>
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<tr>
<td>(\gamma)</td>
<td>Ratio of specific heat values</td>
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<td>Base</td>
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<td>Convergent-Divergent</td>
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<td>CONV</td>
<td>Convergent</td>
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<td>e</td>
<td>Exit</td>
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<td>Equivalent body</td>
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<td>L</td>
<td>Local</td>
</tr>
<tr>
<td>P</td>
<td>Primary flow</td>
</tr>
<tr>
<td>S</td>
<td>Secondary flow</td>
</tr>
<tr>
<td>T</td>
<td>Throat</td>
</tr>
<tr>
<td>Symbol</td>
<td>Description</td>
</tr>
<tr>
<td>--------</td>
<td>---------------------------</td>
</tr>
<tr>
<td>CD</td>
<td>Convergent - divergent</td>
</tr>
<tr>
<td>CDE</td>
<td>Convergent - divergent ejector</td>
</tr>
<tr>
<td>CF</td>
<td>Convergent flap</td>
</tr>
<tr>
<td>CI</td>
<td>Convergent iris</td>
</tr>
<tr>
<td>SP</td>
<td>Shrouded plug</td>
</tr>
<tr>
<td>UP</td>
<td>Unshrouded plug</td>
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SECTION 1

INTRODUCTION

This manual presents a detailed description of the Twin-Nozzle/Aftbody Drag and Internal Nozzle Performance Computer Program. This program was developed under Contract F33657-70-C-0511, Program for Experimental and Analytical Determination of Integrated Airframe-Nozzle Performance.

The purpose of this manual is to describe in detail the capabilities and limitations of the program, the numerical methods used, and the operational procedures required to run the program. The computational procedures are presented both in the form of detailed descriptions and flow charts summarizing the methods. The input instructions consist of a description of each input required and how the input is to be implemented. The output section consists of a description of the output format and an explanation of error messages that are included. Finally, a description of the operational setup needed for program execution is provided including control cards, deck assembly instructions, and necessary external routines.

The capabilities and restrictions of the program including a flow-chart are presented in Section 2. The computational methods used to predict aft-end drag and internal nozzle performance are discussed in Section 3; and the operating instructions, consisting of user and programmer inputs and the output summary, are included in Section 4. Sample cases including examples of input coding sheets and a complete listing of the program are provided in appendixes.
**SECTION 2**

**COMPUTER PROGRAM CAPABILITIES**

2.1 **GENERAL DESCRIPTION OF PROGRAM**

The program consists of a main control routine, three nozzle internal performance subroutines, and an aft-end drag subroutine. The prediction methods incorporated in these subroutines are based almost entirely on empirical correlations. Specifically, correlations developed by P&WA (Reference 41) are employed for prediction of nozzle thrust and discharge coefficients, and correlations of Phase II test data are employed for prediction of twin-nozzle/aftbody drag. The predicted aft-end drags for a subsonic external flow must be used with caution if the user employs the aftbody maximum area station as the reference station for drag accounting since the aftbody metric break station of the Phase II model lies downstream of the maximum area station. Using the maximum area station as a reference station requires in some cases a procedure for obtaining the drag acting on the body between the maximum area and metric break stations. This drag increment is very small for subsonic external flow and may be neglected.

For supersonic external flow, a procedure for obtaining this drag increment was developed and incorporated in the aft-end drag routine to predict the boattail drag aft of the maximum area station. The components of the aft-end drag include boattail pressure and friction drags and annular base drag.

Since the empirical correlations are based on Phase II data and little data was obtained in the 0.9 to 1.2 Mach number range, the predicted aft-end drags for this Mach regime should also be used with caution.

The program will analyze the following five types of nozzles: convergent, convergent-divergent, convergent-divergent ejector, unshrouded plug, and shrouded plug. The nozzle routines yield values of thrust and discharge coefficients, as well as pumping characteristics for ejector nozzles.

There are basically two types of input to the program: fixed and variable. The fixed inputs are constant for a given series of cases and consist of geometrical inputs such as nozzle type and maximum area. The variable inputs may change from case to case and consist of geometrical inputs, such as nozzle area ratio, and operating conditions such as freestream Mach number and nozzle pressure ratio. For most of the variable inputs, the user has the option of using direct input values or having the program read a curve.

2.2 **COMPUTER PROGRAM LOGIC**

The overall logic of the program is illustrated by the flow charts shown in Figure 1. The program consists of a main control routine, three internal
Figure 1. Overall Program Logic Diagram
performance subroutines, and an aft-end drag subroutine. Upon reading and processing of the input the appropriate internal flow routine is selected based on the nozzle type. Convergent and convergent-divergent nozzle cases are analyzed using subroutine NOZZLE, convergent-divergent ejector cases use subroutine EJECTR, and plug nozzle cases use subroutine NOZPLG. When running convergent-divergent, convergent-divergent ejector and shrouded plug nozzles, the user has the option of varying the nozzle internal expansion ratio between two input limiting values in order to obtain the maximum thrust-minus-drag for a given throat area. In all cases, the user has the option of providing either the physical throat area or the flow area at the throat. The area which is not specified as the input is obtained from the other area and the nozzle discharge coefficient.

The nozzle performance subroutines can analyze various internal flow regimes depending on the nozzle type. For convergent nozzles, separate prediction methods are employed when the throat flow is subsonic, the throat flow is critical but not choked (nozzle pressure ratio where the discharge coefficient is invariant with nozzle pressure ratio), and the flow is critical and choked. For convergent-divergent and convergent-divergent ejector nozzles, separate prediction methods are employed when the flow is subsonic throughout the nozzle, the flow is critical with separation occurring in the divergent section, and the flow is critical with no internal flow separation. Thrust and discharge coefficients for these nozzles are computed using one-dimensional flow relationships combined with empirical correction factors. The one-dimensional compound flow analysis of Bernstein (Reference 45) is employed for predicting ejector pumping characteristics.

The method employed for computing plug nozzle thrust coefficients depends on the freestream Mach number. Specifically, for a subsonic external flow, correlations involving plug pressure forces are employed which, when combined with the gross thrust at the nozzle exit, yield plug nozzle thrust coefficients. For a supersonic freestream Mach number, plug surface pressure forces are computed using an approximate construction of the expansion fan generated by the flow expansion around the cowl lip. The plug base pressure correlation is also employed for the supersonic case. Plug nozzle discharge coefficients are computed using correlations of Phase I test data.

The aft-end drag subroutine calculates the three components of the total aft-end drag of the aircraft: boattail pressure drag, boattail friction drag, and annular base drag. The routine tests the flight speed to determine whether to call the subsonic or supersonic boattail and base drag methods. Three separate correlations are employed for predicting the boattail pressure drag for a subsonic external flow: jet-off drag correlations, correlations of the drag increment from jet-off to the nozzle design pressure ratio, and correlations of the drag increment from the design pressure ratio to operation at a higher pressure ratio. The first two correlations are based on nozzle/aftbody geometry while the last correlation is based on nozzle underexpansion losses. For supersonic external flow, jet-off drag correlations and correlations of the drag increment from jet-off to the operating pressure ratio are employed.
This section describes the methods employed for predicting twin-nozzle/aft-body drag and internal nozzle performance. The external drag methods consist primarily of the empirical correlations whose development is described in Volume I of this report (Reference 89). The nozzle internal performance methods are basically those developed by P&W which are described in Reference 41.

3.1 **TWIN-NOZZLE/AFTBODY DRAG**

The computational methods employed for predicting boattail pressure and friction drags and annular base drag are presented in this subsection. All methods are based on empirical correlations of wind tunnel data and, except for the friction drag routine, are different for subsonic and supersonic speeds.

### 3.1.1 Boattail Pressure Drag

#### 3.1.1.1 Subsonic Flow

This subsection presents the methods for predicting the boattail drag aft of the metric break station for Mach numbers less than 1.0. The boattail drag coefficient, referenced to the cross-sectional area at the metric break station \( A_{MB} \), is computed from the following empirical correlation of the Phase II data.

\[
C_{D, PT} = K_1 \left( \frac{M}{M_\infty} \right)^{2/3} \frac{A_P}{A_{MB}} + K_2 \frac{A_S}{A_{MB}} + \frac{K_3}{q_\infty A_{MB}} \tag{1}
\]

where

\[
K_1 = \frac{\Delta C_{D, PT}}{\Delta C_{D, MB}} \left( \frac{M_\infty}{M} \right)^{2/3} \tag{2}
\]

\[
K_2 = \frac{\Delta C_{D, MB}}{\Delta C_{D, MB}} \tag{3}
\]

and

\[
K_3 = \frac{\Delta D}{F_{id}} \tag{4}
\]
\( A_p \) is the projected boattail frontal area, \((A_{MB} - A_S)\), \(A_S\) is the shroud area for both nozzles (sum of jet and base areas) and \( F_{id} \) is the ideal thrust of the twin jet model obtained by isentropic expansion of the exhaust flow to free-stream pressure. The first term in Equation 1 is the jet-off drag, the second term is the drag increment when going from jet-off to operation at the nozzle design pressure ratio and the third term represents the drag increment when going from design pressure ratio operation to operation at a higher pressure ratio. The design pressure ratio for convergent and convergent-divergent nozzles is defined as that pressure ratio associated with a cylindrical plume (static operation) and with critical throat flow. For unshrouded plug nozzles, the design pressure ratio is set equal to the design pressure ratio of a convergent nozzle.

The jet-off drag coefficient parameter, \( K_1 \), is presented in Figures 2 through 4 for the narrow, intermediate, and wide nozzle lateral spacings with horizontal interfairings and a single vertical tail. The drag parameter is obtained from these figures through use of the integral mean slope (IMS) of the equivalent body of revolution and the shroud to metric break area ratio \( (A_S/A_{MB}) \). The correlation results shown in Figures 2 through 4 are applicable for all nozzle configurations except the narrow-spaced normal-power convergent-flap configuration. Correlation results for this configuration are presented in Figure 5. Correlation results for narrow spaced configurations with vertical interfairings are presented in Figure 6. Figure 7 presents correlation results for wide spaced configurations with twin vertical tails. A linear interpolation and extrapolation for area ratios other than those presented in the figures is employed.

The drag parameter, \( K_2 \), for determining the increment in drag when going from jet-off to jet-on at the nozzle design pressure ratio is presented in Figures 8 through 10 for narrow, intermediate and wide nozzle lateral spacings and for Mach numbers ranging from 0.6 to 0.9. This drag increment is presented in terms of an increment in drag coefficient referenced to the twin nozzle shroud exit area (sum of jet and base areas) and is correlated as a function of boattail trailing edge \( \theta_B \), at the nozzle exit. The results shown in the figures are applicable for all configurations.

For convergent and convergent-divergent nozzle installations, the drag parameter, \( K_3 \), which is the increment in drag when going from design pressure ratio operation to operation at a higher pressure ratio, is presented in Figures 11 through 13 as a function of the nozzle underexpansion loss. The drag increment, which is normalized by the ideal thrust, is dependent on both the Mach number and shroud exit to metric break area ratio. Figure 14 and 15 present the drag parameter, \( K_3 \), for the normal and maximum \( A/B \) plug nozzles, respectively. The drag parameter in these figures is presented as a function of a reference convergent nozzle underexpansion loss.

3.1.1.2 Supersonic Flow

This subsection presents the methods for predicting the boattail drag aft of the maximum area (exclusive of wing) station for Mach numbers greater than
Figure 2. Transonic Similarity Correlation of Jet-Off Total Boattail Drag - Narrow Spacing

Figure 3. Transonic Similarity Correlation of Jet-Off Total Boattail Drag - Intermediate Spacing
Figure 4. Transonic Similarity Correlation of Jet-Off Total Boattail Drag - Wide Spacing

Figure 5. Transonic Similarity Correlation of Jet-Off Total Boattail Drag - Narrow Spacing - Convergent Flap Nozzle
Figure 6. Transonic Similarity Correlation of Jet-Off Total Boattail Drag - Vertical Interfairing

Figure 7. Transonic Similarity Correlation of Jet-Off Total Boattail Drag - Twin Vertical Tails
Figure 8. Correlation of Drag Increment From Jet-Off To Design Pressure Ratio - Narrow Spacing

Figure 9. Correlation of Drag Increment From Jet-Off To Design Pressure Ratio - Intermediate Spacing
Figure 10. Correlation of Drag Increment From Jet-Off To Design Pressure Ratio - Wide Spacing

Figure 11. Correlation of Drag Increment From Design To Operating Pressure Ratio - Convergent-Divergent Nozzle
Figure 12. Correlation of Drag Increment From Design to Operating Pressure Ratio - Convergent-Flap Nozzle

Figure 13. Correlation of Drag Increment From Design to Operating Pressure Ratio - Convergent-Iris Nozzle
Figure 14. Correlation of Drag Increment From Design to Operating Pressure Ratio - Normal Power Plug Nozzle

Figure 15. Correlation of Drag Increment From Design to Operating Pressure Ratio - Maximum A/B Power Plug Nozzle
1.0. Boattail drag coefficients, based on maximum area, for a supersonic external flow are computed from the following equation

\[ C_{D_{PT}} = C_{D_{EB}} \left( \frac{\Delta C_{D_{PT}}}{\Delta C_{D_{EB}}} \right) \frac{A_{F}}{A_{M}} + K_{l} \left( \frac{P_{e} - P_{L}}{P_{\infty}} \right) \left( \frac{A_{S}}{A_{M}} \right) \left( \frac{P_{\infty}}{q_{\infty}} \right) \]  

(5)

where the first term is the jet-off drag and the second term is the increment in drag when going from jet-off to jet-on operations.

The equivalent body drag is obtained by entering the method-of-characteristics boattail drag correlation curves presented in Figure 16 with the Mach number and IMS. The ratio of jet-off drag to equivalent body drag \( \frac{C_{D_{PT}}}{C_{D_{EB}}} \) is obtained from the correlation results presented in Figure 17 as a function of Mach number and vertical stabilizer tape.

For jet-on operation, \( K_{l} \), which is the increment in drag from jet-off operation normalized by the product of the difference between the nozzle internal exit pressure and the local boattail surface pressure (assuming no flow separation), is obtained from Figure 18 as a function of nozzle mean boattail angle. The mean boattail angle used is the mean angle over a distance corresponding to one-third of the nozzle exit radius. This length was selected as being representative of the flow separation length. The local boattail flow properties are obtained from a method-of-characteristics solution (a large mesh size was employed to minimize computer time).

The correlation results presented in Figure 18 are restricted to pressure coefficients \( \left( P_{e} - P_{L} \right)/q_{L} \) greater than 1.4. This pressure coefficient value was based on the empirical observation that little or no separation occurs for lower values. The results are also not applicable for Mach numbers greater than 1.6; a linear variation of \( K_{5} \) with Mach number from the Mach 1.6 value to a \( K_{5} \) value of zero at a Mach number of 2.0 is recommended.

3.1.2 Boattail Friction Drag

The required input for computation of the boattail friction drag is the boattail length \( L_{B} \), the wetted surface area \( A_{w} \), and either the momentum thickness \( \theta \) at the start of the boattail or an effective flat plate length \( L_{eff} \) upstream of the start of the boattail. With these inputs, an average boattail skin friction coefficient is computed by use of Sivells-Payne correlation (Reference 12) which, when combined with the wetted area, yields the friction drag as discussed below.

With an input momentum thickness at the start of the boattail the reference length Reynolds number, \( R_{e} \), is obtained by iterative solution of the following equation

\[ \frac{1}{R_{e}} \]
Figure 16. IMS/Supersonic Similarity Correlation Of Method-Of-Characteristics Boattail Pressure Drag
Figure 17. Equivalent Body Correlation Of Phase II Data

Figure 18. Correlation of Drag Increment From Jet-Off To Jet-On Operation - Supersonic Flow
\[ R_{e_0} = \frac{\mu'_1}{\mu_1} \left( \frac{0.044 \, R'_e}{\log_{10} R'_e} - 1.5 \right)^2 \]  (6)

where the primed quantities denote values evaluated at the reference temperature, \( T_1 \), which is obtained from the following equation

\[ T'_1 = T_1 \left[ 1 + 0.035 \, M^2 + 0.45 \left( \frac{T_{aw}}{T_1} \right) - 1 \right] \]  (7)

where

\[ T_{aw} = T_1 \left[ 1 + \sqrt{\frac{\gamma - 1}{2}} \left( 0.89 \, M^2 \right) \right] \]  (8)

If an effective flat plate length upstream of the boattail is input, the reference Reynolds number is obtained from the following equation:

\[ R'_{e_1} = \frac{\rho_1 \, U_\infty \, L_{\text{eff}}}{12 \, \mu_1} \]  (9)

The local skin friction correlation equation taken from Reference 12 is

\[ C_{f_1} \left| T'_{1} \right| = \frac{0.088 \, (\log_{10} R'_{e_1} - 2.3686)}{(\log_{10} R'_{e_1} - 1.5)} \]  (10)

The local skin friction coefficient at the end of the boattail is computed in a manner similar to that described above except that the length employed in the computation of the reference length Reynolds number is

\[ L_2 = L_{\text{eff}} + L_{\text{BT}} \]  (11)

If the momentum thickness Reynolds number is input, the effective flat plate length at the start of the boattail is computed as follows:

\[ L_{\text{eff}} = \frac{12 \, g \, \mu_1 \, R_{e_1}}{\rho_1 \, U_\infty} \]  (12)

The skin friction drag coefficient based on maximum area is

\[ C_{D_f} = \frac{(C_{f_1} + C_{f_2}) \, A_w}{A_M} \]  (13)
3.1.3 **Annular Base Drag**

The annular base pressure for a subsonic external flow is computed from the following modification (developed in Reference 89) of the Brazzel-Henderson base pressure correlation (Reference 33).

\[
\frac{P_b}{P_\infty} = \frac{0.9 + 0.0167 (R_{mf})}{0.94 + 0.06 (A_s/A_M)}
\]  

(14)

where \( R_{mf} \) is the nozzle exit to freestream momentum ratio, defined as

\[
R_{mf} = \frac{(MV)_{e}}{(MV)_{\infty}} = \frac{\gamma_{e} \rho_{e} A_{e} M_{e}^{2}}{\gamma_{\infty} \rho_{\infty} A_{M} M_{\infty}^{2}}
\]  

(15)

For a supersonic external flow, the following base pressure correlation developed by Brazzel-Henderson is also employed.

\[
\frac{P_b}{P_\infty} = \left[ \frac{T_{e}}{T_{e,\infty}} \right] \left[ \frac{3.5}{0.5 + 3.0 A_s/A_M} \right] \left[ 0.19 + 1.28 \left( \frac{R_{mf}}{1 + R_{mf}} \right) \right] + 0.047 (5-M_{\infty}) \left[ 2 \left( \frac{\Delta X_{e}}{D_{M}} \right) + \left( \frac{\Delta X_{e}}{D_{M}} \right)^2 \right]
\]  

(16)

The first term on the right side of Equation (16) normalizes the jet temperature to the jet temperature of a sonic nozzle. The second term corrects for boattail effects, and the third term is a correlation based on the ratio of nozzle exit momentum flux to freestream momentum flux. A nozzle position (relative to the end of the boattail) correction is obtained by the fourth term.
3.2 NOZZLE THRUST COEFFICIENT

This section describes the numerical methods employed for computation of nozzle thrust and discharge coefficients. Prediction methods for convergent, convergent-divergent, convergent-divergent ejector, and plug nozzles are described. The thrust coefficient is defined as the ratio of actual gross thrust to ideal gross thrust based on isentropic expansion of the actual mass flow to freestream pressure. The discharge coefficient is defined as the ratio of actual mass flow to ideal mass flow computed assuming one-dimensional sonic flow at the nozzle throat.

3.2.1 Convergent Nozzles

Convergent nozzle thrust coefficients are computed by use of the following equation,

\[ C_T = \frac{\left( \frac{P_e}{P_{T T}} \right)^{\frac{A_e^{\text{flow}}}{A_T^*}} \left( 1 + \gamma \frac{M_e^2}{2} \right) + \frac{P_e'}{P_{T T}'} \left( \frac{A_e}{A_T} - \frac{A_e^{\text{flow}}}{A_T^*} \right) - \frac{P_\infty}{P_{T T}} \frac{A_e}{A_T^*} }{P_{T T}^*/(P_{T T}' A_T^*)} \]  \hspace{1cm} (17)

where

\[ \frac{P_{T T}^*/(P_{T T}' A_T^*)}{P_{T T}^*/A_T^*} = \left\{ \frac{\sqrt{\gamma^2 - 1}}{\gamma - 1} \left( \frac{2}{\gamma + 1} \right)^{1/2} \left[ 1 - \left( \frac{P_e'}{P_{T T}'} \right)^{\frac{1}{\gamma}} \right] \right\} \]  \hspace{1cm} (18)

The term enclosed within the brackets in Equation 17 is the total momentum of the flow at the nozzle exit, normalized by \( P_{T T} A_T^* \).

The stream thrust correction factor, \( C_S \), in the above equation is assumed to be 0.997. Equation 17 differs slightly from the equation presented in Reference 41 with the addition of the second term within the brackets. This term represents the pressure force (normalized by \( P_{T T} A_T^* \)) exerted on the area increment between the physical and effective exit flow areas. The pressure, \( P_e' \), is assumed to be equal to freestream pressure for nozzle pressure ratios less than critical (unity throat Mach number for one-dimensional flow). For nozzle pressure ratios greater than the choking pressure ratio (pressure ratio where the flow field is fixed and the discharge coefficient is independent of pressure ratio) \( P_e' \) is assumed equal to the exit pressure, \( P_e \). A linear variation of \( P_e \) with nozzle pressure ratio is assumed between the critical and choking pressure ratios. The critical pressure ratio, \( (P_{T T} / P_\infty)_{\text{CR}} \), and choking pressure ratio, \( (P_{T T} / P_\infty)_{\text{CK}} \), are computed from the following equations.
\[
(P_{T_T}/P_\infty)_{CR} = \left(\frac{\gamma + 1}{2}\right) \frac{\gamma}{(\gamma - 1)} \]  
(19)

\[
(P_{T_T}/P_\infty)_{CK} = 3.5 - \tan \left\{ 23.8063 \left( C_{dN_{\text{max}}} - 0.95 \right) \right\} \]  
(20)

Equation 20 was empirically derived (Reference 41) and represents the nozzle pressure ratio at which the discharge coefficient, \( C_{dN_{\text{max}}} \), remains fixed.

As discussed in Reference 41, the discharge coefficient, \( C_{dN_{\text{max}}} \), is sensitive to both the upstream approach angle, \( \alpha \), and the nozzle lip radius of curvature, \( R_c \). Correlations of the discharge coefficient \( (C_{dN_{\text{max}}}) \) as a function of approach angle and radius of curvature ratio, \( R_c/R_{T} \), are presented in Figures 19 and 20 respectively. The appropriate discharge coefficient, \( C_{dN_{\text{max}}} \), to be used in Equation 20 is the larger of the two values obtained from Figures 19 and 20.

The nozzle discharge coefficient obtained as described above is, of course, the appropriate discharge coefficient for nozzle pressure ratios greater than the choking pressure ratio (i.e., \( C_{dN} = C_{dN_{\text{max}}} \)). For nozzle pressure ratios less than the choking pressure ratio, the nozzle discharge coefficient, \( C_{dN} \), is determined from the following equation:

\[
C_{dN} = C_{dN_{\text{max}}} - C_2 \left\{ \left( \frac{P_{T_T}}{P_\infty} - \left( \frac{P_{T_T}}{P_\infty} \right)_{CK} \right) \right\}^2 + C_3 \left\{ \left( \frac{P_{T_T}}{P_\infty} - \left( \frac{P_{T_T}}{P_\infty} \right)_{CK} \right)^3 \right\} \]  
(21)

where

\[
C_2 = 8 B^3 / \left[ (C_{dN_{\text{max}}} - 0.965)^2 + 4 B^2 \right] \]  
(22)

and

\[
C_3 = 0.0011 - 0.00205 \left[ \sin (74.8 \left( C_{dN_{\text{max}}} - 0.952 \right)) \right] \\
+ \left[ (0.92 - C_{dN_{\text{max}}}) 0.0574 + \left| (0.92 - C_{dN_{\text{max}}}) 0.0574 \right| \right] / 2 \]  
(23)

The constant, \( B \), is set equal to 0.01. The above equations are empirically derived in Reference 41.
Figure 19. Correlation of Maximum Discharge Coefficient with Internal Approach Angle

Figure 20. Correlation of Maximum Discharge Coefficient with Shroud Lip Curvature
The area ratios employed in the thrust coefficient equation (Equation 17) are obtained as follows. For nozzle pressure ratios less than critical, the ratio of actual to sonic flow areas \( \frac{A_{e\text{flow}}}{A_T} \) is obtained in the usual manner from the exit Mach number, \( M_e \). For nozzle pressure ratios greater than critical, the actual sonic flow area ratio is unity. The physical exit to sonic flow area ratio is obtained from the following equation for nozzle pressure ratios less than critical.

\[
\frac{A_e}{A_T} = \frac{A_{e\text{flow}}}{A_T} = \frac{1}{C_{dN}} \frac{A_{e\text{flow}}}{A_T}
\]  

(24)

For nozzle pressure ratios greater than critical, the exit to sonic flow area ratio is equal to the inverse of the discharge coefficient.

3.2.2 Convergent-Divergent Nozzle

The method employed for computing convergent-divergent nozzle thrust coefficients depends upon whether the flow is unchoked, choked with internal flow separation, or choked and flowing full (i.e., no internal separation). For nozzle pressure ratios less than critical (unity throat Mach number for one-dimensional flow), the flow is subsonic and the nozzle is treated as a subsonic diffuser. The computational procedure is as follows. A throat Mach number is first assumed and a recovery loss coefficient \( \Delta P_T/q_T \), is obtained from Figure 21 as a function of nozzle internal divergence angle, \( \theta \). The nozzle exit to throat total pressure ratio is obtained from the following equation.

\[
\frac{P_{T_e}}{P_{T_T}} = \frac{q_T}{P_{T_T}} \left( \frac{P_{T_e}}{q_T} - \frac{\Delta P_{T_T}}{q_T} \right)
\]

(25)

The nozzle exit to sonic area ratio is then computed as

\[
\frac{A_e}{A_T} = \frac{\left( \frac{A_{T}}{A_{T}} \right)}{A_{e\text{flow}}} = \frac{P_{T_e}}{P_{T_T}} \left( \frac{A_{e\text{flow}}}{A_T} \right) \left( \frac{P_{T_e}}{P_{T_T}} \right)
\]

(26)

\[
\frac{A_e}{A_T} = \frac{A_{T\text{flow}}}{A_T} \left( \frac{A_{T}}{A_{T\text{flow}}} \right) \left( \frac{A_{e\text{flow}}}{A_T} \right)
\]

(27)
Figure 21. Correlation of Nozzle Internal Divergence Loss

Figure 22. Correlation of Stream Thrust Correction Factor
The throat flow to sonic flow area ratio in Equation 27 is obtained as a function of the assumed throat Mach number and the throat flow to geometric throat area ratio is obtained from the nozzle discharge coefficient ($A_{T_{\text{flow}}}/A_T = C_{dN}$). The discharge coefficient is taken as the larger of the two values obtained from Figures 19 and 20. The exit to sonic area ratio obtained from Equation 26 yields an exit Mach number which in turn yields an exit static pressure. If the exit static pressure does not equal the freestream static pressure the calculations are repeated using a different value for the throat Mach number. The thrust coefficient is then computed from Equation 17 with $A_e$ assumed equal to $A_{e_{\text{flow}}}$. The stream thrust correction factor is obtained from Figure 22 as a function of exit to sonic flow area ratio and internal divergence angle.

For nozzle pressure ratios greater than critical but less than that required for the nozzle to flow full (no separation), two computational procedures are employed. For nozzle pressure ratios slightly greater than critical, a linear variation of thrust coefficient from the critical value of thrust coefficient is assumed. This linear variation is terminated (based on empirical observation) at a nozzle pressure ratio computed from the following equation.

$$\left( \frac{P_{T_{\text{sep}}}}{P_{T_{\text{sep}}}^*} \right) = \left( \frac{P_{T_{T_{\text{sep}}}}}{P_{T_{T_{\text{sep}}}}^*} \right) \left( \frac{P_{e}}{P_{e_{\infty}}} \right)$$  \hspace{1cm} (28)

where $P_{T_{\text{sep}}}/P_{e}$ is obtained (assuming the nozzle flows full) from one dimensional flow relationships and

$$\left( \frac{P_{e}}{P_{\infty}} \right) = 0.1 \left\{ 10^{0.0328\Theta} + 0.72 \right\} \left[ 10 \left( \frac{A_e}{A_{T_{\text{sep}}}} - 1 \right) \right]^{-0.77}$$  \hspace{1cm} (29)

The thrust coefficient for nozzle pressure ratios greater than the computed pressure ratio from Equation 28, but less than that for the flowing full case, is computed from the following equation.

$$C_T = C_S \left[ \frac{P_{\text{sep}}}{P_{T_{T_{\text{sep}}}}} \frac{A_{e_{\text{sep}}}}{A_T^*} \left( 1 + \gamma \frac{M_{\text{sep}}^2}{M_{\text{sep}}^*} \right) \right] + \int \frac{P_{\text{sep}}}{P_{T_{T_{\text{sep}}}}} \frac{A_{e_{\text{sep}}}}{A_T^*} \left( \frac{P_{\infty}}{P_{T_{T_{\text{sep}}}}} \frac{A_{e_{\text{sep}}}}{A_T^*} \right) \frac{\partial q}{\partial t} \left( \frac{P_{e}}{P_{\infty}} \right)$$  \hspace{1cm} (30)
where $P_{sep}$ is the static pressure just upstream of the separation point, $A_{sep}$ is the flow area at the separation point, $M_{sep}$ is the Mach number at the separation point, and the integral term is the pressure force acting on the nozzle inner surface in the separated flow region. The stream thrust parameter, $C_s$, is obtained from Figure 22 as a function of $A_{sep}/A^*$ and $\theta$.

The surface static (upstream of separation point) to total pressure ratio is computed from the following equation.

$$\frac{P_{sep}}{P_{T,T}} = 0.63 + 0.04 \ln (0.01) \frac{P_{\infty}}{P_{T,T}}$$

Equation 31 results determine the Mach number, $M_{sep}$, which in turn locates (through the area ratio function) the separation point. The integral term in Equation 30 is computed from the following empirical equation.

$$\int \frac{P_{sep}}{P_{T,T}} A_{sep} \sim \frac{P_{\infty}}{P_{T,T}} \left(6 + \frac{P_{sep}}{P_{T,T}} \right) \left(\frac{A_{sep}}{A^*} - \frac{A_{sep}}{A^*_T} \right)$$

When the nozzle is flowing full, Equation 17 is used for computing thrust coefficients. The exit flow area ($A_{e flow}$) is, however, set equal to the physical area ($A_e$). The pressure ratio ($P_{T,T}/P_{\infty}$) where the nozzle is just flowing full is computed from the following equation.

$$\left(\frac{P_{T,T}}{P_{\infty}}\right)_F = \frac{P_{sep}}{P_{\infty}} \left(\frac{P_{T,T}}{P_{e}}\right)$$

where $P_{T,T}/P_e$ is obtained from a one-dimensional flowing full analysis and $P_{sep}/P_{\infty}$ is a constant obtained from Equation 31 (after rearranging).

The nozzle discharge coefficient for convergent-divergent nozzles is defined as the ratio of actual mass flow to ideal convergent nozzle mass flow, or

$$C_{d,N} = \frac{\dot{m}_{C-D,\text{act}}}{\dot{m}_{C-\text{CONV},\text{id}}}$$

In terms of ideal conditions, the above equation becomes
where $A_T \text{flow} / A_T$ is the larger of the two values obtained from Figures 19 and 20. For pressure ratios greater than critical for the reference convergent nozzle, the ideal mass flow for the C-D nozzle is identical to the ideal mass flow of the convergent nozzle. Thus, the discharge coefficients can be obtained, as previously described, from Figures 19 and 20. For pressure ratios less than critical for the reference convergent nozzle, the ideal C-D nozzle mass flow is greater than the ideal convergent nozzle mass flow. This is because the critical pressure ratio for a C-D nozzle is lower than the critical pressure ratio for a convergent nozzle due to the diffusion in the divergent section. The discharge coefficient equation is rewritten, therefore, as

$$C_{d_n} = \frac{A_T \text{flow}}{A_T}$$

(35)

where $A_T \text{flow} / A_T$ is the larger of the two values obtained from Figures 19 and 20. For pressure ratios greater than critical for the reference convergent nozzle, the ideal mass flow for the C-D nozzle is identical to the ideal mass flow of the convergent nozzle. Thus, the discharge coefficients can be obtained, as previously described, from Figures 19 and 20. For pressure ratios less than critical for the reference convergent nozzle, the ideal C-D nozzle mass flow is greater than the ideal convergent nozzle mass flow. This is because the critical pressure ratio for a C-D nozzle is lower than the critical pressure ratio for a convergent nozzle due to the diffusion in the divergent section. The discharge coefficient equation is rewritten, therefore, as

$$C_{d_n} = \frac{M_T (1 + \frac{\gamma - 1}{2} M_T^2)}{M_e (1 + \frac{\gamma - 1}{2} M_e^2)} \left( \frac{\gamma + 1}{2(\gamma - 1)} \right) \frac{A_T \text{flow}}{A_T}$$

(36)

where $M_T$ is the C-D nozzle throat Mach number and $M_e$ is the exit Mach number of the reference convergent nozzle.

3.2.3 Convergent-Divergent Ejector Nozzle

The computational method employed for predicting C-D ejector nozzle performance follows closely the method employed for C-D nozzles. The primary difference is the addition of a routine for computing the ejector pumping characteristics. The method employed is the one-dimensional compound-compressible flow analysis of Bernstein (Reference 45). Bernstein's method is programmed so as to obtain secondary to primary mass flow ratio as a function of secondary to primary total pressure ratio and vice versa.

With the addition of the nozzle secondary flow, the nozzle thrust coefficient equation with no internal flow separation becomes

$$C_T = \left[ \frac{P_e}{P_T} \frac{A_{eP}}{A_{TP}^*} (1 + \frac{\gamma M_e^2}{2}) + \frac{P_e}{P_T} \frac{A_{eS}}{A_{TP}^*} (1 + \frac{\gamma M_e^2}{2}) \right] \left( 1 + \frac{P_e}{P_T} \frac{A_{eP}}{A_{TP}^*} \right)$$

$$- \frac{P_e}{P_T} \frac{A_{eS}}{A_{TP}^*} \left( 1 + \frac{P_e}{P_T} \frac{A_{eS}}{A_{TS}^*} \right)$$

(37)
where the secondary and primary flow areas, Mach numbers, and exit pressure at the nozzle exit are obtained from standard one-dimensional calculations employing the secondary to primary mass flow ratios and total pressure ratios. The stream thrust correction factor, \( C_q \), is obtained from Figure 22 as a function of internal divergence angle and shroud exit to primary nozzle area ratio. For cases with internal flow separation, the thrust coefficients are computed by a method similar to that employed for C-D nozzles. Primary nozzle discharge coefficients are also computed in the same manner as for C-D nozzles.

3.2.4 Plug Nozzles

The plug nozzle performance routine is based on both analytical and empirical correlation methods. Specifically, for supersonic flight Mach numbers a combined analytical/empirical method is employed, while an empirical method is employed for subsonic flight Mach numbers. The reason for this is that, for supersonic flight Mach numbers, the nozzle pressure ratio is sufficiently high such that there is little or no influence of the external flow on the plug surface pressure distributions. For subsonic flight Mach numbers, the influence of the external flow is felt over a large portion of the plug surface, especially at low nozzle pressure ratios.

The method employed for computing the plug surface pressure force and nozzle thrust coefficient for a supersonic external flow is as follows. First, the total flow expansion around the shroud lip is computed assuming the flow expands to freestream static pressure. This flow turning is divided into a number of equal turning increments. For the initial flow angle increment, the Mach number at the shroud lip is computed using the Prandtl-Meyer relationship. The right running characteristic ray is then constructed and its intersection with the plug surface computed. For this computation, the characteristic ray is assumed to be straight. The plug surface Mach number at the intersection point is obtained from the Prandtl-Meyer relationship assuming a flow deflection equal to twice the flow turning increment at the shroud lip. This procedure accounts, approximately, for the expansion fan reflection from the plug surface. The method is approximate, since the actual characteristic ray is curved rather than straight, as assumed. Nonetheless the surface pressure distributions computed as described are in excellent agreement with exact method-of-characteristic calculations.

The above procedure is repeated until the flow is expanded to freestream pressure or the end of the plug is reached. In the former case, where the last ray intersects the surface upstream of the plug base, the external flow will definitely influence the plug surface pressure distributions. It is assumed, however, that the region influenced by the external flow is small. It is further assumed that the pressures in this region are near freestream pressure. Based on empirical observations, the above assumptions will introduce little error provided the nozzle pressure ratio is greater than approximately 4.0 and the plug configuration is similar to those tested.
The nozzle gross thrust is the sum of the gross thrust at the nozzle exit, the plug surface pressure force, and the plug base force (or drag). The gross thrust at the nozzle exit for unshrouded nozzles is computed in the same manner as for convergent nozzles and for shrouded plug nozzles in the same manner as for C-D nozzles. Plug base pressure correlations are employed for computing plug base forces. The plug base pressure is computed from the following correlation equation:

\[
\frac{P_b}{P_T} = \frac{4.312}{1.975} \left( \frac{P_T}{P_\infty} \right)
\]

This equation is applicable for nozzle pressure ratios ranging from approximately 4.5 to the pressure ratio where the ratio of base pressure to nozzle total pressure remains invariant with nozzle pressure ratio. The plug base to nozzle total pressure ratio becomes invariant with pressure ratio when the last characteristic ray from the shroud lip lies downstream of the base wake region.

The invariant base pressure is computed from the following equation:

\[
\frac{P_b}{P_T} = 0.517 \left( \frac{P_P}{P_T} \right)_e + 0.0046
\]

where \( \frac{P_P}{P_T} \) is the ratio of plug surface static pressure just upstream of the plug base to nozzle total pressure. For nozzle pressure ratios less than 4.5, the base pressure is assumed equal to freestream static pressure.

For a subsonic external flow, the plug nozzle thrust coefficient is computed from the following equation:

\[
C_T = C_{Te} + \frac{\Delta D}{Fid} - K_4
\]

where

\[
K_4 = \frac{\Delta D}{Fid} - (C_T - C_{Te})
\]

\( C_{Te} \) in the above equation is the ratio of computed gross thrust at the nozzle exit to ideal gross thrust (Fid) obtained by expanding the flow isentropically to freestream static pressure, and \( \Delta D \) is the drag increment between operation at the design pressure ratio and operation at a higher pressure ratio and is obtained from Figures 14 and 15 as a function of the underexpansion loss, \( 1-C_{Te} \). The plug thrust/drag parameter, \( K_4 \), is obtained through interpolation and extrapolation of the correlation results presented in Figures 23 and 24.
Figure 23. Correlation of Plug Thrust and Boattail Drag Increment - Normal Power Plug Nozzle

Figure 24. Correlation of Plug Thrust and Boattail Drag Increment - Maximum A/3 Power Plug Nozzle
SECTION 4

OPERATING INSTRUCTIONS

4.1 INPUT REQUIREMENTS

The input for the external drag and internal nozzle performance computer
program consists of fixed and variable parameters in a main 25 card set plus
optional curve data and input routine control cards. The fixed inputs, which
are constants for each computer run, are discussed in Subsection 4.1.1. The
variable inputs, which allow a series of values or curve data to be input for
each run, are discussed in Subsection 4.1.2, followed by a description of the
required input control cards in Subsection 4.1.3. The 25 card main input
data set is summarized in Table 1, including card numbers, data descriptions
and locations, available input options, and where appropriate, identifiers for
the optional curve data inputs. Tables 2 and 3 describe the input curve
formats. Sample input sheets are given in Appendix A.

4.1.1 Fixed Input

The fixed input data required are the title, the basic aircraft external
geometric data, and the nozzle internal geometry data. The title, on card 1,
may consist of any combination of alpha-numeric characters and may be placed
anywhere in columns 1 through 72. This title will be printed at the top of
each page of computer printout. The first three inputs on card 2 are input
keys for selection of nozzle spacing, nozzle type, and interfairing type,
and have the options shown in Table 1. The inputs are integers (no decimal)
in input in fields of 3 columns starting with column 1. The integer inputs
must be right-adjusted; i.e., the final digit must fall in the last column
of the input field. The last six inputs on card 2 are real numbers (input
with decimals) in fields of six columns starting with column 10. These in-
puts include wing area, maximum cross-sectional area, ratio of metric break
area to maximum area, the initial boattail length, initial boattail integral
mean slope (IMSP), and boattail wetted area for the portion of the aftbody
between the maximum are a location and the metric break.

Nozzle internal fixed inputs are shown in Table 1 under each nozzle type
heading. The nozzle fixed inputs are on the last non-blank card in the data
set; however, enough blank cards must be added at the end of the set to make
a total of 25 cards. The inputs required for convergent nozzles are the
minimum and maximum throat areas corresponding to normal and max A/B power
settings, input as real numbers on the first two fields of 6 on card 22. For
convergent-divergent nozzles, the axial length of the nozzle divergent sec-
tion, the minimum nozzle expansion ratio, and the maximum nozzle expansion
ratio are input as real numbers on card 22 in fields of 6 columns, starting
with column 1. The fixed inputs for the convergent-divergent ejector nozzle
### Table 1. Main Data Set Input Key

<table>
<thead>
<tr>
<th>CARD</th>
<th>QUANTITY</th>
<th>TYPE</th>
<th>MODE</th>
<th>COLUMNS</th>
<th>CODE</th>
<th>DESCRIPTION</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td>Title</td>
<td>Fixed</td>
<td>Alpha-numeric</td>
<td>1-72</td>
<td></td>
<td>Title or identification of case to be printed at top of print-out</td>
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<td>2</td>
<td>Nozzle Spacing Ratio, S/D</td>
<td>Fixed</td>
<td>Integer</td>
<td>1-3</td>
<td>1</td>
<td>Narrow (S/D = 1.25) single vertical</td>
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<td>2</td>
<td>Intermediate (S/D = 1.625) single vertical</td>
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<td>3</td>
<td>Wide (S/D = 2.0) single vertical</td>
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<td>4</td>
<td>Wide with twin vertical</td>
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<td></td>
<td>Nozzle Type, NT</td>
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<td>Convergent-Divergent</td>
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<td>Shrouded Plug</td>
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<td>2</td>
<td>Vertical</td>
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<td>Wing Area, A_{wing}</td>
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<td>Maximum Area, A_{M}</td>
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<td>Aircraft maximum area excluding lifting portion of wing -- ft²</td>
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<td>Metric Break Area</td>
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<td>22-27</td>
<td></td>
<td>Fuselage area at wing trailing edge station, A_{MB}/A_{M} = 0.85</td>
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<td>Ratio, A_{MB}/A_{M}</td>
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<td>Axial distance between A_{M} and A_{MB} stations</td>
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<td>IMSF</td>
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<td>IMS for initial boattail surface.</td>
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<td>(X = X/D, Y = A/A, Z = 0) IDC020</td>
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<td>Wetted area for initial boattail surface</td>
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<td>Indicated air speed - knots</td>
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<td>Ambient temperature, °R</td>
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<td>Actual aircraft model</td>
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<td>Nozzle Specific Heat Ratio, ( \gamma_p )</td>
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<td>Input ( \gamma_p )</td>
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<td>Curve ((X=PS, Y=\gamma_p, Z=0)) IDC082</td>
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<td>Nozzle Throat Area</td>
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<td>Input physical area, ( A_T ) -- ( \text{ft}^2 )</td>
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<td>Curve ((X=Ma, Y=A_T, Z=0)) IDC092</td>
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<td>Input flow area, ( A_{Tflow} ) -- ( \text{ft}^2 )</td>
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<td>Curve ((X=Ma, Y=A_{Tflow}, Z=0)) IDC094</td>
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<td>Nozzle Throat Approach Angle, ( \alpha )</td>
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<td>Input ( \alpha ), degrees</td>
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<td>Curve ((X=A_T, Y=\alpha, Z=0)) IDC102</td>
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<td>Nozzle Throat Geometry</td>
<td>Variable</td>
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<td>Input ( R_c/R_T ) if ( NT&lt;4 )</td>
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<td>Input ( R_c/R_T )/( S^2 ) if ( NT\geq4 )</td>
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<td>Curve ((X=A_T, Y=R_c/R_T \text{ or } R_cR_T/S^2, Z=0)) IDC112</td>
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<td>Nozzle Expansion Ratio, ( A_E/A_T )</td>
<td>Variable</td>
<td>Mixed</td>
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<td>1</td>
<td>( A_E/A_T = 1.0 ) (convergent &amp; Unshrouded plug nozzles)</td>
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<td>2</td>
<td>Input ( A_E/A_T ), exit to throat area ratio</td>
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<td>Curve ((X=A_T, Y=A_E/A_T, Z=0)) IDC123</td>
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<td>4</td>
<td>Maximum thrust minus drag</td>
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<td>TYPE</td>
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<td>COLUMNS</td>
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<tr>
<td>13</td>
<td>Nozzle Annular Base Area Ratio, $A_B/A_E$</td>
<td>Variable</td>
<td>Mixed</td>
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<td>1</td>
<td>Input $A_B/A_E$, base to exit area ratio</td>
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<td>2</td>
<td>Curve $(X=A_E, Y=A_B/A_E, Z=0)$ IDC132</td>
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<td>14</td>
<td>Nozzle Base Length to Diameter Ratio, $\Delta X/D_M$</td>
<td>Variable</td>
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<td>Input $\Delta X/D_M$</td>
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<td>2</td>
<td>Curve $(X=A_E, Y=\Delta X/D_M, Z=0)$ IDC142</td>
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<td>15</td>
<td>Nozzle Boattail Trailing Edge Angle, $\theta_E$</td>
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<td>Input $\theta_E$, degrees</td>
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<td>Curve $(X=A_E, Y=\theta_E, Z=0)$ IDC152</td>
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<td>Mean Nozzle Boattail Trailing Edge Angle, $\theta_M$</td>
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<td>Mixed</td>
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<td>Input $\theta_M$, degrees</td>
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<td>2</td>
<td>Curve $(X=A_E, Y=\theta_M, Z=0)$ IDC162</td>
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<td>17</td>
<td>Total Boattail Length to Diameter Ratio, $L/D_M$</td>
<td>Variable</td>
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<td>Input $L/D_M$</td>
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<td>2</td>
<td>Curve $(X=A_M-A_P, Y=L/D_M, Z=0)$ IDC172</td>
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<td>18</td>
<td>IMS for Surface Aft of Metric Break Station, IMSA</td>
<td>Variable</td>
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<td>Input IMSA</td>
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<td>Curve $(X=A_M-A_F, Y=IMSA, Z=0)$ IDC182</td>
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<td>3</td>
<td>Curve $(X=X/D_M, Y=A/A_M, Z=0)$ IDC183</td>
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<td>19</td>
<td>Adjusted Projected Frontal Area Ratio, $\Delta A/A_M$</td>
<td>Variable</td>
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<td>Input $\Delta A/A_M$</td>
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<td>Curve $(X=A_M-A_F, Y=\Delta A/A_M, Z=0)$ IDC192</td>
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<td>20</td>
<td>Boundary Layer Momentum Thickness Ratio, $\theta /D_M$</td>
<td>Variable</td>
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<td>Input $\theta /D_M$</td>
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<td>Curve $(X=M_\infty, Y=\theta /D_M, Z=0)$ IDC202</td>
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<td>Curve $(X=M_\infty, Y=\theta /D_M, Z=Re/ft)$ IDC203</td>
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<td>Input effective flat plate length to maximum diameter ratio instead of $\theta /D_M$</td>
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<td>Total Boattail Wetted Area Ratio, $A_W/A_M$</td>
<td>Variable</td>
<td>Mixed</td>
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<td>Input $A_W/A_M$</td>
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<td>Minimum Nozzle Throat Area, $A_{T_{MIN}}$</td>
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<td>Normal power throat area</td>
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<td>Maximum Nozzle Throat Area, $A_{T_{MAX}}$</td>
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<td>7 - 12</td>
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<td>Max $A/B$ throat area</td>
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<td>QUANTITY</td>
<td>TYPE</td>
<td>MODE</td>
<td>COLUMNS</td>
<td>CODE</td>
<td>DESCRIPTION</td>
</tr>
<tr>
<td>--------</td>
<td>-------------------------------</td>
<td>------------</td>
<td>------</td>
<td>---------</td>
<td>------</td>
<td>-----------------------------------------------------------------------------</td>
</tr>
<tr>
<td></td>
<td>CONVERGENT-DIVERGENT NOZZLE</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>22</td>
<td>Length of Internal Expansion</td>
<td>Fixed</td>
<td>Real</td>
<td>1 - 6</td>
<td></td>
<td>Surface length between ( A_T ) and ( A_E ) stations, ft.</td>
</tr>
<tr>
<td></td>
<td>Surface, FL</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Minimum Nozzle</td>
<td>Fixed</td>
<td>Real</td>
<td>7 - 12</td>
<td></td>
<td>Minimum physical exit to throat area ratio</td>
</tr>
<tr>
<td></td>
<td>Expansion Ratio, ( (A_E/A_T)_{MIN} )</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Maximum Nozzle</td>
<td>Fixed</td>
<td>Real</td>
<td>13 - 18</td>
<td></td>
<td>Maximum physical exit to throat area ratio</td>
</tr>
<tr>
<td></td>
<td>Expansion Ratio, ( (A_E/A_T)_{MAX} )</td>
<td></td>
<td></td>
<td></td>
<td>19 - 72</td>
<td>Blank</td>
</tr>
<tr>
<td>23-25</td>
<td></td>
<td></td>
<td></td>
<td>1 - 72</td>
<td></td>
<td>Blank</td>
</tr>
<tr>
<td></td>
<td>CONVERGENT-DIVERGENT EJECTOR NOZZLE</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>22</td>
<td>Shroud Throat Area Ratio, ( A_{ST}/A_T )</td>
<td>Variable</td>
<td>Mixed</td>
<td></td>
<td>1</td>
<td>Input ( A_{ST}/A_T )</td>
</tr>
<tr>
<td>23</td>
<td>Pumping Characteristics</td>
<td>Variable</td>
<td>Mixed</td>
<td></td>
<td>1</td>
<td>Input ( P_{TS}/P_{TP} )</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2</td>
<td>Curve ( X=M_{\infty}, Y=P_{TS}/P_{TP}, Z=0 ) IDC222</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3</td>
<td>Input Corrected ( W_S/W_P )</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>4</td>
<td>Curve ( X=M_{\infty}, Y=\text{Corrected } W_S/W_P, Z=0 ) IDC234</td>
</tr>
</tbody>
</table>
TABLE 1. MAIN DATA SET INPUT KEY (Continued)

<table>
<thead>
<tr>
<th>CARD</th>
<th>QUANTITY</th>
<th>TYPE</th>
<th>MODE</th>
<th>COLUMNS</th>
<th>CODES</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>24</td>
<td>Secondary to Primary Gas Constant Ratio, $R_S/R_P$</td>
<td>Variable</td>
<td>Mixed</td>
<td></td>
<td>1</td>
<td>Input $R_S/R_P$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2</td>
<td>Curve $(X=PS, Y=R_S/R_P, Z=0)$ IDC242</td>
</tr>
<tr>
<td>25</td>
<td>Length of Internal Expansion Surface, FL</td>
<td>Fixed</td>
<td>Real</td>
<td>1-6</td>
<td></td>
<td>Surface length between $A_{ST}$ and $A_E$ stations, ft.</td>
</tr>
<tr>
<td></td>
<td>Minimum Nozzle Expansion Ratio, $(A_E/A_T)_{\text{Min}}$</td>
<td>Fixed</td>
<td>Real</td>
<td>7-12</td>
<td></td>
<td>Minimum physical exit to throat area ratio</td>
</tr>
<tr>
<td></td>
<td>Maximum Nozzle Expansion Ratio, $(A_E/A_T)_{\text{Max}}$</td>
<td>Fixed</td>
<td>Real</td>
<td>13-18</td>
<td></td>
<td>Maximum physical exit to throat area ratio</td>
</tr>
<tr>
<td></td>
<td>Secondary Flow Specific Heat Ratio, $\gamma S$</td>
<td>Fixed</td>
<td>Real</td>
<td>19-24</td>
<td></td>
<td>Secondary air usually obtained from inlet, $\gamma S = 1.4$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>25-72</td>
<td>Blank</td>
</tr>
</tbody>
</table>

**PLUG NOZZLES**

<table>
<thead>
<tr>
<th>CARD</th>
<th>QUANTITY</th>
<th>TYPE</th>
<th>MODE</th>
<th>COLUMNS</th>
<th>CODES</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>22</td>
<td>Plug Length to Diameter Ratio, $L_P/D_M$</td>
<td>Variable</td>
<td>Mixed</td>
<td></td>
<td>1</td>
<td>Input $L_P/D_M$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2</td>
<td>Curve $(X=A_T, Y=L_P/D_M, Z=0)$ IDC222</td>
</tr>
<tr>
<td>23</td>
<td>Plug Angle, $\alpha P$</td>
<td>Fixed</td>
<td>Real</td>
<td>1-6</td>
<td></td>
<td>Conical plug angle, degrees</td>
</tr>
<tr>
<td></td>
<td>Plug Base Area, $A_{Pb}$</td>
<td>Fixed</td>
<td>Real</td>
<td>7-12</td>
<td></td>
<td>Truncated plug base area, ft$^2$</td>
</tr>
<tr>
<td>CARD</td>
<td>QUANTITY</td>
<td>TYPE</td>
<td>MODE</td>
<td>COLUMNS</td>
<td>CODE</td>
<td>DESCRIPTION</td>
</tr>
<tr>
<td>------</td>
<td>----------</td>
<td>------</td>
<td>------</td>
<td>---------</td>
<td>------</td>
<td>-------------</td>
</tr>
<tr>
<td></td>
<td>Minimum Nozzle Throat Area, $A_{T_m}$</td>
<td>Fixed</td>
<td>Real</td>
<td>13 - 18</td>
<td></td>
<td>Normal power throat area</td>
</tr>
<tr>
<td></td>
<td>Maximum Nozzle Throat Area, $A_{T_{max}}$</td>
<td>Fixed</td>
<td>Real</td>
<td>19 - 24</td>
<td></td>
<td>Max A/B throat area</td>
</tr>
<tr>
<td></td>
<td>Minimum Nozzle Expansion Ratio, $(A_E/A_T)_{min}$</td>
<td>Fixed</td>
<td>Real</td>
<td>25 - 30</td>
<td></td>
<td>Minimum physical exit to throat area ratio</td>
</tr>
<tr>
<td></td>
<td>Maximum Nozzle Expansion Ratio, $(A_E/A_T)_{max}$</td>
<td>Fixed</td>
<td>Real</td>
<td>31 - 36</td>
<td></td>
<td>Maximum physical exit to throat area ratio</td>
</tr>
<tr>
<td>24-25</td>
<td></td>
<td></td>
<td></td>
<td>37 - 72</td>
<td></td>
<td>Blank</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1 - 72</td>
<td></td>
<td>Blank</td>
</tr>
</tbody>
</table>

* Format for the mixed mode variable input cards is:

Columns          Quantity                     Mode  
1 - 3            Card number                    Integer 
4 - 6            Number of input values           Integer 
7 - 9            Input code                      Integer 
10 - 69          10 fields of 6 columns for input data Real
### TABLE 2. UNIVARIANT CURVE DATA INPUT KEY

<table>
<thead>
<tr>
<th>CARD</th>
<th>COLUMNS</th>
<th>MODE</th>
<th>CODE</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1-6</td>
<td>Alpha-Numeric</td>
<td>--</td>
<td>Curve identifier</td>
</tr>
<tr>
<td></td>
<td>7-9</td>
<td>Integer</td>
<td>1</td>
<td>Linear interpolation</td>
</tr>
<tr>
<td></td>
<td>10-12</td>
<td>Integer</td>
<td>2</td>
<td>Parabolic interpolation</td>
</tr>
<tr>
<td></td>
<td>13-15</td>
<td>Integer</td>
<td>0</td>
<td>No extrapolation on X</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td>Extrapolation on X</td>
</tr>
<tr>
<td>2</td>
<td>1-72</td>
<td>Real</td>
<td>--</td>
<td>Data in order X, Y, X, Y, ... in</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>fields of six columns each. May</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>require several cards</td>
</tr>
</tbody>
</table>

### TABLE 3. BIVARIANT CURVE DATA INPUT KEY

<table>
<thead>
<tr>
<th>CARD</th>
<th>COLUMNS</th>
<th>MODE</th>
<th>CODE</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1-6</td>
<td>Alpha-Numeric</td>
<td>--</td>
<td>Curve identifier</td>
</tr>
<tr>
<td></td>
<td>7-9</td>
<td>Integer</td>
<td>3</td>
<td>Linear interpolation on both X and Z</td>
</tr>
<tr>
<td></td>
<td>10-12</td>
<td>Integer</td>
<td>4</td>
<td>Parabolic interpolation on both X and Z</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>5</td>
<td>Parabolic interpolation on X and linear on Z</td>
</tr>
<tr>
<td></td>
<td>13-15</td>
<td>Integer</td>
<td>-1</td>
<td>Extrapolation on X only</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0</td>
<td>No extrapolation</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td>Extrapolation on both X and Z</td>
</tr>
<tr>
<td></td>
<td>16-72</td>
<td>Integer</td>
<td>--</td>
<td>Number of Z values to be read (may be up to 19)</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>Real</td>
<td>--</td>
<td>Number of X and Y numbers for each Z, in order of input, in fields of 3 columns each</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Data in order Z, X, Y, X, Y, ... , Z, X, Y, ... in fields of six columns each. May require several cards.</td>
</tr>
</tbody>
</table>
are on card 25 and are the same as for the convergent-divergent nozzle except for the addition of the secondary flow specific heat ratio (real number) in columns 19 through 24. The plug nozzle fixed inputs, real numbers in the first six fields of 6 columns on card 23, are the conical plug angle, the plug base area, the minimum throat area, the maximum throat area, the minimum nozzle expansion ratio, and the maximum nozzle expansion ratio.

The following nomenclature is employed for the fixed input terms in Table 1. Self explanatory items are not included.

**S/D** - Nozzle Spacing Ratio - The ratio of the distance between the centerlines of the nozzles to the maximum nozzle diameter. The approximate values of 1.25 for narrow, 1.625 for intermediate, and 2.0 for wide spaced nozzles are suggested since the data correlations are based on data for these ratios.

**NT** - Nozzle Type - Convergent type nozzles include convergent-flap and convergent-iris types.

**IT** - Interfairing Type - The distinguishing characteristics of the interfairings is the orientation of the trailing edge (vertical or horizontal).

**A_M/B_A** - Metric Break Area Ratio - The approximate value of 0.85 is suggested since the data correlations were obtained with this value.

**IMSF** - Forward Integral Mean Slope - IMS value for the surface between the maximum fuselage area and the metric break stations. A negative input means that an area distribution curve (X/D vs A/A_M) is being included and IMSF will be computed internally.

**A_WP/A_M** - Initial Boattail Wetted Area Ratio - The wetted area (not including the lifting portion of the wing) from the maximum fuselage area station to the metric break station, divided by the maximum area.

**(A_E/A_T)_MIN** - Minimum Nozzle Expansion Ratio - The minimum expansion ratio used to test for maximum thrust-minus-drag.

**(A_E/A_T)_MAX** - Maximum Nozzle Expansion Ratio - The maximum expansion ratio used to test for maximum thrust-minus-drag. Twenty expansion ratio values are tested between the minimum and maximum values.

### 4.1.2 Variable Inputs

The variable inputs are those data which are changed as parameters of the performance analysis plus the portions of the aircraft internal and external geometry which change with variations of these parameters. Each type of variable input occurs on a different card, allowing the user to input several
values of each run parameter on each card. The program runs all possible combinations of the run parameters, cycling from larger to smaller sequence card numbers and from left to right for a given sequence number.

The input cards for the variable input data, cards 3 through 21 plus nozzle type dependent cards, all have the same data format. The first three fields on each card are of 3 columns each, starting with column 1. These three inputs are integers and include, in order, a sequence or identification number which is the same as the card number, the number of values of the variable input which appear on the card, and an input code selecting from the possible input types allowed for each variable input, as noted in Table 1. All the integer inputs must be right-adjusted in their respective fields. Up to ten values of each parameter may be input on each card in the following ten real number fields of six columns each, columns 10 through 69.

The following input code (ICODE) combinations for input of the freestream conditions in cards 3, 4 and 5 are unacceptable.

<table>
<thead>
<tr>
<th>ICODE (3)</th>
<th>ICODE (4)</th>
<th>ICODE (5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>1</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>≥2</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>≥2</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>≥2</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>≥2</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>≥2</td>
<td>4</td>
<td>3</td>
</tr>
</tbody>
</table>

If any of these ICODE combinations are used, an error message will result with a brief description of the inconsistency.

The following nomenclature is employed for the variable input items in Table 1.

PS - Power Setting - The value of power setting is used only as an independent variable on optional user-supplied curves (see cards 7, 8, and CD ejector card 24). The scheme of the power setting values is left up to the user.

$P_{T_p}/P_{\infty}$ - Nozzle Pressure Ratio - Primary total to freestream pressure ratio in the case of an ejector nozzle.

$\gamma_p$ - Nozzle Specific Heat Ratio - Primary stream specific heat ratio in the case of an ejector nozzle.

Nozzle Throat Area - Either the physical throat area ($A_T$) or the aerodynamic throat area ($A_{T\text{flow}}$) may be input. Whichever is input, the program will compute the other internally.
- Nozzle Throat Approach Angle - The angle between the internal wall and the nozzle centerline in the conical part (if any) upstream of the nozzle (primary) throat. For plug nozzles, enter zero.

Nozzle Throat Geometry - For convergent, convergent-divergent, and convergent-divergent ejector nozzles, the ratio of the internal contour radius of curvature (if any) at the nozzle (primary) throat to the throat radius \( R_C/R_T \). For plug nozzles, the input value is \( R_C R_T/S^2 \), where \( R_C \) is the average radius of curvature between the internal shroud and plug at the throat, \( R_T \) is the average radius between the shroud and the plug at the throat, measured from the nozzle centerline, and \( S \) is the height of the throat region measured normal to the plug.

- Nozzle Expansion Ratio - A value not equal to 1.0 for the case of a convergent or unshrouded plug nozzle will result in an error message. A request for the maximum thrust-minus-drag will perturb the expansion ratio from the minimum to the maximum value.

- Nozzle Base Length to Diameter Ratio - The axial distance covered by the base of a nozzle, such as in the case of a flap nozzle, divided by the equivalent maximum diameter.

- Mean Nozzle Boattail Trailing Edge Angle - The mean boattail angle at the end of the boattail over a distance of one-third the exit radius.

- Total Boattail Length to Diameter Ratio - The total length from the maximum area station to the end of the nozzle or interfacing, whichever extends further, divided by the equivalent maximum diameter. The independent variable in the curve IDC172 is the difference between the maximum and total frontal areas, equivalent to the base plus exit areas.

- Aft Integral Mean Slope - A code equal to 3 means an area distribution curve is being furnished consisting of \( X/D_M \) versus \( A/A_M \) aft of the metric break in order to calculate IMAS internally. The initial area (metric break area) must be the maximum area of the array and the areas must be continually decreasing with increasing \( X \).

- Adjusted Projected Frontal Area Ratio - An non-zero input is used when the configuration is characterized by an increase in area distribution, such as in the case of the fantail portion of a maximum afterburning nozzle. The value of \( \Delta A \) is that frontal area, forward and rearward facing, which is not included in the frontal area determined by taking the maximum minus the exit plus base areas.

- Nozzle Boattail Trailing Edge Angle - The nozzle boattail angle at the trailing edge of the boattail surface.
$A_W/A_M$ - Total Boattail Wetted Area Ratio - The wetted area (not including the control surfaces) from the maximum area station to the end of the body.

$A_{AT}/A_T$ - Shroud Throat Area Ratio - The ratio of the minimum area of the mixed region of an ejector nozzle to the primary throat area.

Pumping Characteristics - User has the option of furnishing either the secondary to primary total pressure ratio, $P_{Ts}/P_{Tp}$, or the corrected mass flow ratio, $W_s\sqrt{T_s}/W_p\sqrt{T_p}$.

$L_P/D_M$ - Plug Length to Diameter Ratio - The length of the exposed portion of the plug divided by the equivalent maximum diameter of the configuration.

Most of the variable inputs may be input as curves as an allowable option. To exercise this option, the user places a 1 in column 6 (number of input values) and the appropriate input code in column 9. The data curves are then input as either univariant (one independent and one dependent variable) or bi-variant (one dependent and two independent variables) according to the input code selected. The identifier (name) of each curve (as given in Table 1) is formed by adding the (two-digit) card number and (one-digit) input code number to the characters IDC. For instance, a bi-variant curve for nozzle pressure ratio is called IDCO73. The curve data are input on cards following the 25 cards in the main input set.

Univariant curve data must begin with a card containing the curve identifier (alpha-numeric) in columns 1 through 6, an interpolation code integer in columns 7 through 9, an extrapolation code integer in columns 10 through 12, and the total number (integer) of input fields for X and Y data for the curve in columns 13 through 15. The succeeding cards contain the data in the order $X_1, Y_1, X_2, Y_2, \ldots$ in real number (decimal) fields of six columns each starting in column 1. The univariant curve data input key is found in Table 2.

Bivariant curve data begin with a card containing the identifier (columns 1 through 6), the interpolation code in columns 7 through 9, the extrapolation code in columns 10 through 12, the number of Z values (integer, columns 13 through 15), and the number of X and Y fields for each Z in integer fields of three columns each starting with column 16 and input in the same order as the Z values. The following cards contain the data in the order $Z_1, X_{11}, Y_{11}, X_{12}, Y_{12}, \ldots Z_2, X_{21}, Y_{21}, X_{22}, Y_{22}, \ldots$ in real number fields of six columns each starting in column 1. The bivariant curve data input key is found in Table 3. An example of each curve type is given in Appendix A.

**4.1.3 Input Routine Control Cards**

The input routine control card follows a complete main input set of 25 cards and optional input curves and allows the user one of four options. If further variations in the nozzle independent variable-type inputs (cards 3 - 21) are
desired with the inclusion of a new title card, a 99 card (columns 2 and 3) containing the number of variation cards to follow (columns 5 and 6) is used. If no new title card is to follow but variation cards are included, an 88 card is used (8 in columns 2 and 3, the number of variation cards in columns 5 and 6). The variation input cards need contain only those data changed from the previous case but may not be used to change either fixed input or nozzle-dependent variable input. Additional optional data curves follow the variation cards but a new curve may not be used to replace a curve used in the basic case. If another basic case of 25 cards is to follow, an 888 card is used (columns 1, 2, and 3, all other columns blank) followed by the 25 cards and optional data curves. The input routine is terminated by the use of a 999 card. The arrangement of the input, curve, and control cards is shown in Figure 25.

4.2 PROGRAM OUTPUT

The aircraft geometric characteristics and internal and external performance parameters are printed at the end of each case. Input inconsistency or non-convergence of a program iterative routine causes the program to print an error message and advance to the next case. A discussion of the output format, including a listing of all the error messages, is presented below.

4.2.1 Format Description

The input title for the computer run is printed out at the beginning of each set of output data. This is followed by the configuration description (nozzle spacing, interfairing type, nozzle type, vertical stabilizer type, and clean or actual aircraft model) at the left side of the page. The aft-end geometric characteristics and the internal and external performance parameters are listed in four columns, each of which contains descriptive variable names and the associated input or computed value. The first (left hand) column lists the input flight conditions and computed performance parameters. The next column lists the fixed and nozzle-power setting dependent aircraft geometric parameters. Nozzle internal areas and exhaust flow characteristics are listed in the third column. The fourth and final column contains the boattail pressure and friction drags, the base drag, and the total aft-end drag in both force and coefficient forms. The drag coefficient reference area and the portion of the aircraft to which the analysis applies are defined by the comment lines printed out after the numerical data. Sample output pages are shown in Appendix A.

4.2.2 Error Messages

An inconsistent set of input data or a convergence failure in a program subroutine will result in an error message being printed out. When a situation causing an error message is encountered, the program ceases computation on the case being processed and proceeds to the next case. Each error message contains a brief description of the type of error and is generally self-explanatory. In the throat area iteration in the main routine, a location number is printed out in case of non-convergence identifying which of several similar iterations the case passed through.
Figure 25. Data Deck Arrangement
Input inconsistencies found by the main program are as follows:

- **DIMENSIONAL FLIGHT SPEED INPUT** requires ambient pressure and temperature inputs.
- **NON-STANDARD TEMPERATURE INCREMENT** may be used only with altitude input for pressure.
- **NON-UNITY DIVERGENCE AREA INPUT** for non-diverging nozzle.

Additional input data checks are made by nozzle performance subroutines. Error messages from these checks are:

- **Subroutine EJECTR**: Secondary flow total pressure less than freestream static.
- **Subroutine NOZPLG**: Plug nozzle must be choked.

Error messages which may result from non-convergence of iterative computations are as follows:

- **MAIN Routine**: A will not converge.
- **Subroutine AFTEND**: Reynolds number iteration failed.
- **Subroutine EJECTR**: Pumping characteristics iteration failed.
- **Subroutine NOZPLG**: MACH number iteration failed.
- **Subroutine NOZZLE**: Nozzle throat area iteration failed.
- **Subroutine NOZPLG**: Mach number iteration failed at local expansion angle.

### 4.3 PROGRAM SETUP

The computer program has been written in FORTRAN IV compatible with the SCOPE 3.3 system for the CDC 6600 digital computer. The program requires 300,000 octal bytes of core, 20 seconds of run time per 100 cases, and standard input/output files, except an alternate file used by LSTDAT, described below.

The computer program source deck contains one main routine and 13 subroutines. These are listed below in hierarchical order, i.e., each indentation indicates that the subroutines in that list are first used by the subroutines in the preceding list.
MAIN
AFTEND
ATM02
EJECTR
FLTSPD
ITRATI
LSTDAT
NOZPLG
NOZZLE
XTRP

AREAS
ITERAT.
ITRATA
ITRATE

A brief description of each routine is provided below:

MAIN - Processes input, calls subroutines, and prints results.
AFTEND - Computes twin-nozzle/aftbody drag.
ATM02 - Obtains ambient pressure and temperature for the 1962 U.S. standard atmosphere.
EJECTR - Computes thrust coefficient for a convergent-divergent ejector nozzle.
FLTSPD - Provides freestream Mach number, true air speed, and indicated air speed provided one of these parameters is known.
ITRATI - One-dimensional solution of a non-linear equation.
LSTDAT - Reads in from regular input file, stores an alternate input file to be read by the program for the purpose of listing the input data.
NOZPLG - Computes thrust coefficient for shrouded and unshrouded plug nozzles.
NOZZLE - Computes thrust coefficient for convergent and convergent-divergent nozzles.
XTRP - Interpolates and extrapolates input data curves.
AREAS - Determines area and Mach number for both primary and secondary ejector nozzle flow streams provided the pumping characteristics and static to total pressure ratios for one of the streams is known.
ITERAT - Computes Mach number from the Prandtl-Meyer expansion angle.
ITRATA - N-dimensional non-linear simultaneous equation solution.

ITRATE - One-dimensional solution of a non-linear equation.

The order for deck assembly is standard. Job control cards are placed at the front, followed by the source deck containing the main routine and subroutines listed above. Cards with case input data including the input curves, follow the source deck. As noted earlier, only standard input and output files are required, except for the alternate file used by LSTDAT.
APPENDIX I
SAMPLE CASES
<table>
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<th>TEST CASE 1</th>
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**FORM 8104-1**
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FORM 8104-1
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FORM 8101-1
TEST CASE 1 - CONVERGENT-DIVERGENT NOZZLE - MAXIMUM THRUST-MINUS-DRAG

CONFIGURATION
NARROW SPACING
HORIZONTAL INTERFAIRING
CONVERGENT-DIVERGENT NOZZLE
SINGLE VERTICAL STABILIZER
CLEAN AIRCRAFT MODEL

FLIGHT CONDITIONS
MACH NO 0.9000
P AMB,PSF 630.0
T AMB,R 512.0

PERFORMANCE
PS 3.0000
PTJ/PANB 2.0000
CT 0.9930
CT-J-DJ 0.9326

FIXED AIRFRAME
WING AREA 18.52
MAX AREA 1.609
M.B. AREA 1.308
INIT.-BT.-LENGTH 2.326
INIT.BT ANET 10.218

NOZZLE PARAMETERS
FLOWING FULL
THROAT GEOM AREA 0.1850
THROAT FLW AREA 0.1839
EXIT AREA 0.2220
D B T 0.2812
D T O TAL 38.3

AFT-END DRAG
DB T PRESS 29.2
DB T FRICT 9.4
D B 3.7
D T O TAL 38.3

GAMMA 1.4000
CS 0.9965
CDN 0.9940
CD T FRIC T 0.00127
CD BASE 0.00011
CD T O TAL 0.00579

ALL DRAGS FOR TWO NOZZLES
DRAG COEFFICIENTS REFERENCED TO WING AREA
DRAGS ARE FOR AFT-END AFT OF METRIC BREAK
ALL AREAS ARE IN SQUARE FEET

Figure 30. Sample Computer Program Output - Case 1
TEST CASE 2 - C-O EJECTOR NOZZLE - FLIGHT SPEED, ALTITUDE INPUT

CONFIGURATION
WIDE SPACING
HORIZONTAL INTERFAIRING
CONVERGENT-DIVERGENT EJECTOR NOZZLE
SINGLE VERTICAL STABILIZER
CLEAN AIRCRAFT MODEL

FLIGHT CONDITIONS
MACH NO 0.8841
P AMB,PSF 629.7
T AMB,R 415.1

PERFORMANCE
PS 11.00000
PTJ/PAMB 3.00000
CT 0.9965
C(T-DTJ) 0.8926

FIXED AIRFRAME
WING AREA 18.52
MAX AREA 2.050
W.B.AREA 1.790
INIT,BT-LENGTH 1.578
INIT,BT &ET 14.000

NOZZLE PARAMETERS
FLOWING FULL
THROAT GEOM AREA 0.928
THROAT FLOW AREA 0.0850
EXIT AREA 0.1419
D TOTAL 17.2

AFT-END DRAG
DBT PRESS 7.3
DBT Frict 9.5
CS 0.9970
CON 0.9141
MSP 0.2000
PTJ/PTP 0.4231

ALL DRAGS FOR TWO NOZZLES
DRAG COEFFICIENTS REFERENCED TO WING AREA
DRAGS ARE FOR AFT-END AFT OF METRIC BREAK
ALL AREAS ARE IN SQUARE FEET

TEST CASE 2 - C-O EJECTOR NOZZLE - FLIGHT SPEED, ALTITUDE INPUT

CONFIGURATION
WIDE SPACING
HORIZONTAL INTERFAIRING
CONVERGENT-DIVERGENT EJECTOR NOZZLE
SINGLE VERTICAL STABILIZER
CLEAN AIRCRAFT MODEL

FLIGHT CONDITIONS
MACH NO 0.8841
P AMB,PSF 629.7
T AMB,R 415.1

PERFORMANCE
PS 11.00000
PTJ/PAMB 3.00000
CT 0.9965
C(T-DTJ) 0.8926

FIXED AIRFRAME
WING AREA 18.52
MAX AREA 2.050
W.B.AREA 1.790
INIT,BT-LENGTH 1.578
INIT,BT &ET 14.000

NOZZLE PARAMETERS
FLOWING FULL
THROAT GEOM AREA 0.928
THROAT FLOW AREA 0.0850
EXIT AREA 0.1419
D TOTAL 17.2

AFT-END DRAG
DBT PRESS 7.3
DBT Frict 9.5
CS 0.9970
CON 0.9141
MSP 0.2000
PTJ/PTP 0.4231

ALL DRAGS FOR TWO NOZZLES
DRAG COEFFICIENTS REFERENCED TO WING AREA
DRAGS ARE FOR AFT-END AFT OF METRIC BREAK
ALL AREAS ARE IN SQUARE FEET

Figure 31. Sample Computer Program Output - Case 2
TEST CASE 2 - C-D EJECTOR NOZZLE - FLIGHT SPEED, ALTITUDE INPUT

**CONFIGURATION**
- WIDE SPACING
- HORIZONTAL INTERFAIRING
- CONVERGENT-DIVERGENT EJECTOR NOZZLE
- SINGLE VERTICAL STABILIZER
- CLEAN AIRCRAFT MODEL

### FLIGHT CONDITIONS

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<th>T AMB/R</th>
<th>FIXED AIRFRAME</th>
<th>NOZZLE PARAMETERS</th>
<th>AFT-END DRAG</th>
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### PERFORMANCE

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**ALL DRAGS FOR TWO NOZZLES**

**DRAG COEFFICIENTS REFERENCED TO WING AREA**

**ALL AREAS ARE IN SQUARE FEET**

---

Figure 31. Sample Computer Program Output - Case 2 (Continued)
TEST CASE 3 - CONVERGENT NOZZLE - CALCULATE IMSF, IMSA FROM AREA DIST.

**Configuration**
- Narrow Spacing
- Horizontal Interfaring
- Convergent Nozzle
- Single Vertical Stabilizer
- Clean Aircraft Model

**Flight Conditions**
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<th>T Amb./R</th>
<th>Pts/Pamb</th>
<th>C(T-ODT)</th>
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**Fixed Airframe**
- Wing Area: 18.52
- Max Area: 1.699
- M.B. Area: 1.388
- Init.B Length: 2.236
- Init.AAT: 10.218

**Nozzle Parameters**
- Flowing Full: 0.1847
- Throat Geom Area: 0.1847
- Throat Flow Area: 0.1847
- Exit Area: 0.1847
- Gamma: 1.4000
- Cs: 0.9970
- Cb: 0.9798
- Wsp: 0.0
- Pts/Ptp: 0.0

**Aft-End Drag**
- Drag Press: 9.5
- Drag Frict: 9.0
- Base Frict: 0.5
- Total Frict: 19.0

**Test Case 3 - Convergent Nozzle - Calculate IMSF, IMSA from Area Dist.**

**Configuration**
- Narrow Spacing
- Horizontal Interfaring
- Convergent Nozzle
- Single Vertical Stabilizer
- Clean Aircraft Model

**Flight Conditions**
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<tr>
<th>Mach</th>
<th>P Amb./PSF</th>
<th>T Amb./R</th>
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<th>C(T-ODT)</th>
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<td>667.2</td>
<td>438.9</td>
<td>1.0000</td>
<td>0.9567</td>
</tr>
</tbody>
</table>

**Fixed Airframe**
- Wing Area: 18.52
- Max Area: 1.699
- M.B. Area: 1.388
- Init.B Length: 2.236
- Init.AAT: 10.218

**Nozzle Parameters**
- Flowing Full: 0.1847
- Throat Geom Area: 0.1847
- Throat Flow Area: 0.1847
- Exit Area: 0.1847
- Gamma: 1.4000
- Cs: 0.9970
- Cb: 0.9798
- Wsp: 0.0
- Pts/Ptp: 0.0

**Aft-End Drag**
- Drag Press: 4.7
- Drag Frict: 9.0
- Base Frict: 0.5
- Total Frict: 14.2

**All Drags for Two Nozzles**
**Drag Coefficients Referenced to Wing Area**
**Drags are for Aft-End Aft of Metric Break**
**All Areas are in Square Feet**

Figure 32. Sample Computer Program Output - Case 3
**TEST CASE 4 - UNSHROUDED PLUG NOZZLE - VARY ALTITUDE, CALC. IMSF, IMSA**

**CONFIGURATION**
- WIDE SPACING
- HORIZONTAL INTERFAIRING
- UNSHROUDED PLUG NOZZLE
- TWIN VERTICAL STABILIZERS
- ACTUAL AIRCRAFT

**FLIGHT CONDITIONS**

| MACH NO | 0.9000 |
| P AMB/PSF | 972.5 |
| T AMB/R | 472.3 |

**PERFORMANCE**

| PS | 1.0000 |
| PTJ/PAMB | 4.0000 |
| CT | 0.9705 |
| CIT-DTJ | 0.9259 |

**FIXED AIRFRAME**

| WING AREA | 18.52 |
| PAX AREA | 2.050 |
| P/B AREA | 1.790 |
| INIT.BT.LENGTH | 1.578 |
| INIT.BT ARCT | 16.400 |

**NOZZLE PARAMETERS**

| FLOWING FULL | WING AREA | THROAT GEOM AREA | 0.1795 |
| THROAT FLOW AREA | 0.1759 |
| EXIT AREA | 0.1795 |
| D TOTAL | 31.6 |

**AFT-END DRAG**

| DBT PRESS | 13.4 |
| DBT FRICT | 15.5 |
| D BASE | 2.8 |
| D TOTAL | 31.6 |

**ADVANCED MATERIALS**

| CS | 0.9504 |
| WSP | 0.0 |
| PTS/PTP | 0.0 |

**ALL DRAGS FOR TWO NOZZLES**

DRAG COEFFICIENTS REFERENCED TO WING AREA
DRAGS ARE FOR AFT-END AFT OF METRIC BREAK
ALL AREAS ARE IN SQUARE FEET

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**Figure 33. Sample Computer Program Output - Case 4**
APPENDIX II
PROGRAM LISTINGS
READ(0,1020)(Q,I=1,8)

25 IF(ICODE(I),EQ,4 .AND. NT.GT.1)DAET=(AEATMN-AEATM)/20.
   IF(INSF.GE.0.)GO TO 250
READ(0,1040)(INCURV(J),J=1,22)
NIMSF=INCURV(3)/2
READ(0,1030)(XX(I),AA(I),I=1,NIMSF)
NIM=1
SA=NIMSF-1
FO 370 I=1,NIM

370 DIFF(I)=(AA(I+1)-AA(I))/XX(I+1)-XX(I)
   D2 380 I = I,NIM
   ADIFF=-AA(I+1)+AA(I)
SA=ADIFF*DIFF(I)+DIFF(I+1)-DIFF(I)/2.*SA
   I4SF=SA/I-1,-AA(NIMSF)
   I4SF=ABS(NMSF)
250 IF(IND.NE.888)G0 TO 265
   D2 26 I=1,1700

26 IDC(I)=0.

265 D2 30 I=7,24
   IF(IND.NE.888 .AND. NVARY(I),EQ,3)GO TO 30
   ILOC=BLK(I-6)
   IF(I.EQ.7 .AND. ICODE(I),EQ,3)ILOC=ILOC+50
   IF(I.EQ.9 .AND. ICODE(I),EQ,1)ILOC=ILOC+50
   IF(I.EQ.20 .AND. ICODE(I),EQ,3)ILOC=ILOC+300
   IF(I.EQ.18 .AND. ICODE(I),EQ,3)ILOC=ILOC+50
   IF(I.EQ.23 .AND. ICODE(I),EQ,4)ILOC=ILOC+50
   IF(VT.NE.3 .AND. I.GE.22)GO TO 29
   IF(ICODE(I),EQ,1)GO TO 30
   IF(ICODE(I),EQ,3 .AND. I.EQ.9 .OR. I.EQ.23)GO TO 30
   LG3 TO 30
   IF(ICODE(I),EQ,4 .AND. I.GT.22 .AND. I.EQ.12)GO TO 30
   IF(ICODE(I),EQ,2 .AND. I.EQ.12)GO TO 30
   IF(INC(I),EQ,3)GO TO 30
   READ(0,1040)(INCURV(J),J=1,22)
   INC=INCURV(3)
   IF(ICODE(I),NE.3)G0 TO 29
   IF(I.EQ.12 .OR. I.EQ.18)GO TO 29
   CONTINUE
   C***BIVARIATE
   NUMZ=INCURV(3)
   NUMZ4=NUMZ+3
   Z4MAX=0.
   IK=0
   IZSUM=0.
127 D2 27 J=4,NUMZ4
   IZSUM=IZSUM+INCURV(J)

27 Z4MAX=AMAX1(FLOAT(INCURV(J)),Z4MAX)
   IZMAX=Z4MAX
   IZ4X=IZMAX+1
   NJM4XY=2+IZSUM
   READ(0,1030)(CURV(K),K=1,NJM4XY)
   D2 28 IR=1,NUMZ
   IZ=INCURV(IR+3)+1
   D2 280 IR=1,IZ

280 IDC(ILOC+K+6)=CURV(IS+1-ZMXI*(IR-1))
   IDC(ILOC+K+6)=IZ+1
   K=IK+IZ+1
   CONTINUE
IDC(ILOC+5) = INCURV(3) MAIN 173
IDC(ILOC+4) = ZMAX + 2. MAIN 174
IDC(ILOC+1) = INCURV(1) MAIN 175
IDC(ILOC+2) = INCURV(2) MAIN 176
G3 T) 30 MAIN 177
29 IDC(ILOC+4) = INCURV(3) MAIN 178
IDC(ILOC+1) = INCURV(1) MAIN 179
IDC(ILOC+2) = INCURV(2) MAIN 180
READ(1,1030) (IDC(J+ILOC+4),J=1,IN) MAIN 181
30 CONTINUE MAIN 182
DM = 2.*SORT(AM/PNI) MAIN 183
LPRINT = 2 MAIN 184
390 IF ICODE(18) .NE. 3) GO TO 40 MAIN 185
SA = 0. MAIN 186
AMAMB = 1./AMBAM MAIN 187
DMDB = 1./SORT(AMBAM) MAIN 188
NIMSA = IDC 183(4)/2. MAIN 189
NIMA1 = NIMSA-1 MAIN 190
DI 395 I = 1,NIMSA MAIN 191
XX(I) = (IDC 183(2*I+3)-LMBDM)*DMDB MAIN 192
AA(I) = IDC 183(2*I+4)*AMAMB MAIN 193
IF(I.GE. 2) DIFF(I-1) = (AA(I)-AA(I-1))/XX(I)-XX(I-1) MAIN 194
395 CONTINUE MAIN 195
DII 397 I = 1,NIMA1 MAIN 196
397 SA = (AA(I)-AA(I+1))*DIFF(I) + (AA(I)-AA(I+1))*DIFF(I+1)-DIFF(I))/2. MAIN 197
DI 40 MAIN 198
QIN(18,1)=SA/(1.-AA(NIMSA)) MAIN 199
QIV(18,1)=ABS(QIN(18,1)) MAIN 200
DI 3003 I = 1,INUM3 MAIN 201
DI 3004 I = 1,INUM4 MAIN 202
DI 3005 I = 1,INUM5 MAIN 203
DI 3006 I = 1,INUM6 MAIN 204
DI 3007 I = 1,INUM7 MAIN 205
DI 3008 I = 1,INUM8 MAIN 206
DI 3009 I = 1,INUM9 MAIN 207
DI 3010 I = 1,INUM10 MAIN 208
DI 3011 I = 1,INUM11 MAIN 209
DI 3012 I = 1,INUM12 MAIN 210
DI 3013 I = 1,INUM13 MAIN 211
DI 3014 I = 1,INUM14 MAIN 212
DI 3015 I = 1,INUM15 MAIN 213
DI 3016 I = 1,INUM16 MAIN 214
DI 3017 I = 1,INUM17 MAIN 215
DI 3018 I = 1,INUM18 MAIN 216
DI 3019 I = 1,INUM19 MAIN 217
DI 3020 I = 1,INUM20 MAIN 218
DI 3021 I = 1,INUM21 MAIN 219
DI 3022 I = 1,INUM22 MAIN 220
DI 3023 I = 1,INUM23 MAIN 221
DI 3024 I = 1,INUM24 MAIN 222
V3 = QIN(C3,13) MAIN 223
V4 = QIN(C4,14) MAIN 224
V5 = QIN(C5,15) MAIN 225
V6 = QIN(C6,16) MAIN 226
V7 = QIN(C7,17) MAIN 227
V8 = QIN(C8,18) MAIN 228
V9 = QIN(C9,19) MAIN 229
V10  = QIN(10,110)
V11  = QIN(11,111)
V12  = QIN(12,112)
V13  = QIN(13,113)
V14  = QIN(14,114)
V15  = QIN(15,115)
V16  = QIN(16,116)
V17  = QIN(17,117)
V18  = QIN(18,118)
V19  = QIN(19,119)
V20  = QIN(20,120)
V21  = QIN(21,121)
V22  = QIN(22,122)
V23  = QIN(23,123)
V24  = QIN(24,124)
V209 = 0.
FLAGQ = 0.
ITMD = 0.

IF (ICODE(3) .GE. 2 ) GO TO 35
C ICDE(3) = 1 SECTION ****
IF (ICODE(4) .NE. 1) GO TO 31
IF (ICODE(5) .EQ. 1) GO TO 47
IF (ICODE(5) .EQ. 2) GO TO 2001
V5 = QIN(5,15)/(1.*2*QIN(3,13)**2)
GJ TO 47
31 IF (ICODE(4) .NE. 2) GO TO 33
GE3PA = QIN(4,14)/QIN(4,14)/2.084482E7 + 1.
32 CALL ATM02(GEOPA, 0., V5, V4, ERR)
IF (ICODE(5) .EQ. 1) V5 = QIN(5,15)
IF (ICODE(5) .EQ. 2) V5 = V5 + QIN(5,15)
IF (ICODE(5) .EQ. 3) V5 = QIN(5,15)/(1.*2*QIN(3,13)**2)
GJ TO 47
33 IF (ICODE(4) .NE. 3) GO TO 34
GE3PA = QIN(4,14)
GJ TO 32
34 IF (ICODE(5) .EQ. 2) GO TO 2001
IF (ICODE(5) .EQ. 3) V5 = QIN(5,15)/(1.*2*QIN(3,13)**2)
V4 = QIN(4,14)/RTRR*V5*2.27E-8*(V5)**(1.5)/(V3*SQRT(GAMFS*RTRR*V5)))
1 (V5+198.6))
GJ TO 47
35 IF (ICODE(4) .NE. 1) GO TO 37
IF (ICODE(5) .EQ. 2) GO TO 2001
IF (ICODE(5) .EQ. 3) GO TO 2000
36 CALL FLSPD1(ICODE(3), QIN(3,13), V3, VK, VM, VI, VMI, V4, V5)
IF (ICODE(5) = 3) 47,38,38
37 IF (ICODE(4) .NE. 2) GO TO 39
GE3PA = QIN(4,14)/QIN(4,14)/2.084482E7 + 1.
361 CALL ATM02 (GEOPA, 0., V5, V4, ERR)
IF (ICODE(5) .EQ. 1) V5 = QIN(5,15)
IF (ICODE(5) .EQ. 2) V5 = QIN(5,15)*V5
IF (ICODE(5) .NE. 3) GO TO 36
K2 = 0
GJ TO 36
38 TTF = V5*(1.*2*V3**2)-QIN(5,15)
SAVV5 = V5
CALL ITRATE (V5, TTF, 0., KT)

***CONTINUING
IF (ABS(ITF) .LT. 0.01) GO TO 47
IF (T ,GT. 25) GO TO 2007
IF (SAVV5 - V5 , GT. 0.1) V5 = AMAX1(V5, 0.8*SAVV5)
IF (SAVV5 - V5 , LT. 0.1) V5 = AMIN1(V5, 1.2*SAVV5)
IF (T , EQ. 1) V5 = 0.01*V5
G0 T0 38

39 IF (ICODE(4) , NE. 3) GO TO 2000
G0 T0 361

47 IF (ICODE(7) , LE. 11) GO TO 49
IF (ICODE(7) , GE. 3) GO TO 48
CALL XTRP (V3,V7,V6,1DC072)
GO T0 49

48 CALL XTRP (V3,V7,V6,1DC073)

49 IF (ICODE(8) , LE. 1) GO TO 50
CALL XTRP (V6,V8,0.,1DC082)

50 IF (V7 , GE. 6) GO TO 127
IF (ICODE(9) , GE. 3) GO TO 66
IF (ICODE(9) , LE. 1) GO TO 54
CALL XTRP (V3,V9,0.,1DC092)

54 IF (ICODE(10) , LE. 1) GO TO 56
CALL XTRP (V9,V10,0.,1DC102)

55 IF (ICODE(11) , LE. 1) GO TO 58
CALL XTRP (V9,V11,0.,1DC112)

58 CALL XTRP (V10,V58,0.,1DC12)
CALL XTRP (V11,V59,0.,1RCRT)
V60 = AMAX1(V59,V58)
A = F3(V60)
IF (V7 , NE. 1) GO TO 64
IF (V7 , GE. F3(V60)) GO TO 64
V60 = F4(V60,V7)
V64 = V9*V60
G0 T0 153

66 IF (ICODE(9) , EQ. 3) GO TO 67
CALL XTRP (V3,V9,0.,1DC094)

67 IF (ICODE(10) , LE. 2) GO TO 94
IF (ICODE(11) , LE. 2) GO TO 79
CALL XTRP (V10,V68,0.,1DC5)
CALL XTRP (V11,V69,0.,1RCRT)
V70 = AMAX1(V68,V69)
V60 = V70
A = F3(V70)
IF (V7 , NE. 1) GO TO 76
IF (V7 , GE. F3(V70)) GO TO 76
V70 = F3(V70,V7)
V60 = V70

V75 = V9/V70
V64 = V9
V9 = V76
G0 T0 153

79 V75 = V9
K3NV = 0

80 CALL XTRP (V79,V11,0.,1DC12)
CALL XTRP (V11,V81,0.,1RCRT)
V82 = V79*V81
CALL TRATI (V79,V82,V9,0.0.,AM,30,-753,K0NV)
IF (K0NV = 2) 8C,84,2003

***CONTINUING***
CALL XTRP(V10, V84, 0.0, FIG5)
V85 = AMAX1(V81, V84)
V60 = V85
A = F3(V85)
IF(VT .NE. 1) GO TO 91
IF(V7 .GE.F3(V85))GO TO 91
V85 = F4(V85, V7)
V60 = V85
91 V91 = V9/V85
V64 = V9
V9 = V91
GJ TJ 153
94 IF(ICODE(11) .GE. 2) GO TO 112
KJNV = 0
V96 = V9
97 CALL XTRP(V96, V10, 0.0, IDC102)
CALL XTRP(V10, V98, 0.0, FIG5)
V99 = V96*V98
CAL. ITRATI(V56, V9-V99)/V9, 0., AM, 30, -73, 3, KONV)
IF((CONV-2) .EQ. 97, 101, 2004
101 CALL XTRP(V11, V101, 0.0, RCRTCD)
V102 = AMAX1(V98, V101)
V60 = V102
A = F3(V102)
IF(VT .NE. 1) GO TO 108
IF(V7 .GE.F3(V102))GO TO 108
V102 = F4(V102, V7)
V60 = V102
108 V108 = V9/V102
V64 = V9
V9 = V108
GJ TJ 153
112 V112 = V9
KJNV = 0
113 CALL XTRP(V112, V10, 0.0, IDC102)
CALL XTRP(V10, V114, 0.0, FIG5)
CALL XTRP(V112, V11, 0.0, IDC112)
CALL XTRP(V11, V116, 0.0, RCRTCD)
V117 = AMAX1(V114, V116)
A = F3(V117)
IF(VT .NE. 1) GO TO 121
IF(V7 .GE.F3(V117))GO TO 121
V117 = F4(V117, V7)
121 V121 = V112*V117
CALL ITRATI(V112, (V9-V121)/V9, 0., AM, 30, -70, 3, KONV)
IF((CONV-2) .EQ. 113, 123, 2005
123 V60 = V117
V64 = V9
V9 = V112
GJ TJ 153
127 IF(ICODE(9) .GE. 3) GO TO 136
IF((ICODE(9) .LE. 1) GO TO 130
CALL XTRP(V9, V9, 0.0, IDC092)
130 IF(ICODE(11) .LE. 1) GO TO 132
CALL XTRP(V9, V11, 0.0, IDC112)
132 CALL XTRP(V11, V32, 0.0, FIG2181)
V60 = V132

***Continuing
V64= V9*V132
GJ T3 153

136 IF (ICODE(9).EQ.3) GO TO 138
CALL XTRP (V3,V9,0.,IDC094)

138 IF (ICODE(11).LE.1) GO TO 148
V139=V9
KONV=0

139 CALL XTRP ( V139,V11,0.,IDC112)
CALL XTRP ( V11,V141,0.,F32181)
V142=V139*V141
CALL ITRAT1 (V139,(V9-V142)/V9,0.,AM,30,-70,3,KONV)
IF (KONV-2) 135,144,2005

144 V60=V141
V64=V9
V9=V139
GJ T3 153

148 CALL XTRP ( V11,V148,0.,F2181)
V149=V9/V148
V60=V148
V64=V9
V9=V149

153 IF (ICODE(12).GE.4) GO TO 157
IF (ICODE(12).LE.2) GO TO 158
CALL XTRP (V9,V12,0.,IDC123)
GJ T3 158

157 V12= AEAATM
158 IF(V12.NE.1 .AND. (NT.LE.1 .OR. NT.EQ.4))GO TO 2008
V158= V12*V9
IF(ICODE(13).LE.1) GO TO 161
CALL XTRP (V158,V13,0.,IDC132)

161 IF (ICODE(14).LE.1) GO TO 163
CALL XTRP (V156,V14,0.,IDC142)

163 IF (ICODE(15).LE.1) GO TO 165
CALL XTRP (V156,V15,0.,IDC152)

165 IF(ICODE(16).LE.1) GO TO 167
CALL XTRP (V156,V16,0.,IDC162)

167 IF (NT.LT.4) GO TO 168
IF (ICODE(22).LE.1) GO TO 1671
CALL XTRP(V9,V22,0.,IDC222)

1671 AEP = V158/COS(ALPHAP*RAD)**2
R>BP = SQRT(AAP/PI)
LP = V22*DP
R>PP = LP*TAN(ALPHAP*RAD)
RPT = RP + RPB
APT = PI*RPT**2
V168 = AEP + APT + V13*V158
GJ T3 169

168 V168=2.*(V158+V13*V158)
169 IF (ICODE(17).LE.1) GO TO 171
CALL XTRP (V168,V17,0.,IDC172)

171 IF (ICODE(18).LE.2) GO TO 173
CALL XTRP (V168,V18,0.,IDC182)

173 IF (ICODE(19).LE.1) GO TO 175
CALL XTRP (V168,V19,0.,IDC192)

175 IF (ICODE(20).LE.1) GO TO 185
IF (ICODE(20).GE.4) GO TO 183
IF (ICODE(20).EQ.3) GO TO 180
CAL_XTRP(V3,V20,0.,IDC202)
GJ T) 185

180  V180 = V4*V3*SQR(T(1.40*RRR*V5)*(V5+198.6)/(2.27E-8*(V5)**(1.5))/
1(RRR*V5)
CALL XTRP(V3,V20,V180,IDC203)
GJ T) 185

183  TAW = V5*(1.+2.*.89*V3**2)
TPRI = V5*(1.+0.35*V3**2+.45*(TAW/V5-1.))
LEFF = QN(20.,120.)*DM
AMU = 2.27E-8*TPRI **1.5/(TPRI+198.6)
RHO = GRAY*V4/(RRR*V5)
UFS = V3*SQR(T(AMFS*RRR*V5))
RHO = GRAY*V4/(RRR*TPRI)
REP = LEFF*RHO*UFS/(AMUP*GRAY)
AMU = 2.27E-8*V5 **1.5/(V5+198.6)
RETHE = AMUP/RHO*UFS/(AMUP*GRAY)
V20* = GRAY*RETHE*AMUP/RHO*UFS*DM

185  IF(ICODE(21).LE.1) GO TO 187
CALL XTRP(V15,V21,0.,IDC212)

187  IF(VT.LE.2) GO TO 204
IF(VT.GE.4) GO TO 204
IF(ICODE(22).LE.1) GO TO 191
CALL XTRP(V9,V22,0.,IDC222)

191  IF(ICODE(23).GE.3) GO TO 196
Q00 = 1.
IF(ICODE(23).LE.1) GO TO 195
CALL XTRP(V3,V23,0.,IDC232)

195  GJ T) 199

196  Q00 = 2.
IF(ICODE(23).EQ.3) GO TO 199
CALL XTRP(V3,V23,0.,IDC234)

199  IF(ICODE(24).LE.1) GO TO 204
CALL XTRP(V6,V24,0.,IDC242)

204  AB = V13*V15
AMF = AMFAM*AM
LM4B = LMBDM*DM
WS3WP1 = 0.
PTS+TP = 0.
IF(VT.NE.3)GAMS = V8
QMODEL = ICODE61
CON = V60
N3ZERR = 0
IF(VT .LE. 2) CALL NOIZLE(V9,V64,V12,V8,V7,QMODEL,NT,FL,CT,N)
1 FLANZ,JERR,TD,S,XMOM,CTID,A,XMEXIT)
IF(WJZJER,NE. 0.) GO TO 217
V30 = V12/V22

207  IF(VT .EQ. 3) CALL EJFCTR(V9,V22,V64,V65,VOO,1.,V22,V7,V23,QQQ,V8,GAMS)

1 V24 ,CON,CT,WS3WP1,PTS+TP,FLAG,NOZERR,LEXP,CTID,XMOM,QMODEL,
2 CS,TID,XMEXIT)
IF(WJZJERR .NE. 0.) GO TO 217

209  IF(VT .GE. 4) CALL NOZPLG(V9,V12,LP,ALPHAP,APB,V3,V7,CT,FLAG,
1 WJZJERR,TD,S,QMODEL ,V3,TID,XMOM,ATMIN,ATMAX,XMEXIT)
IF(WJZJERR .NE. 0.) GO TO 217
QFS = GAMS/2.*V4*V3**2
AM = AMBAM*AM
CALL AFTEND(V3,QFS,V4,V5,

2 V64,V158,AB,NT,V3,V7,AM,A,AM,LMBDM,ISO,IT, MAIN 514

***CONTINUING
V12
214
2000
2500
2001
2501
2003
2503
2004
2504
2005
2505
2007
2507
2008
2508
C PUT OUT CASE ANSWERS
216 IF (LPRINT .NE. 2) GO TO 2160
WRITE (6, 3999)
LPRINT = 0
WRITE (6, 3998) TITLE
GO TO 2161
2160 WRITE (6, 4000) TITLE
2161 AFI = AM-V168
AFMET = AMB-V168
IFLAGFLAG
ISDX=100
IF(ISD.EQ.4)ISDX=109
WRITE (6, 4001) (DOB(I*(ISO*9-9),L=1,9), DOB(I*9+27+L),L=1,9)
1 DOB(INT*9+45+L),L=1,9), DOB(I*9-1+L),L=1,9), DOB(I*9+108)
2 L),L=1,9)
WRITE (6, 4002)
WRITE (6, 4003) V3,AWING,(DOB2(IFLAG*9+L-9),L=1,7), DBTP,V4,AM,

### CONTINUING
**CONTINUING**
7, 4X, F7.3, 5X, *GAMMA*, 14X, F7.4, 1X
4004 F3R4AT (1H, T1C, #PS#, 13X, F7.4, T65, #CS#, 17X, F7.4, 5X, #CDBT PRESS*, MAIN 629
1, 4X, F8.5, /, 1H , T10, #PTJ/PAMB#, 7X, F7.4, 5X, #VARIABLE AIRFRAME*, MAIN 630
2, 11X, #CON#, 16X, F7.4, 5X, #CDBT FRICT*, 4X, F8.5, /, 1H , T10, #CT#, MAIN 631
3 13X, F7.4, 5X, #BASE AREA#, 7X, F7.3, 5X, #WSWP#, 15X, F7.4, 5X, MAIN 632
4 #CD BASE#, 7X, F8.5, /, 1H , T10, #CT-DTJ#, 8X, F7.4, 5X, #TOTAL AFRONT#, MAIN 633
5AL#, 1X, F7.3, 5X, #PTS/PTP#, L2X, F7.4, 5X, #CD TOTAL#, 6X, F8.5, /, 1H , MAIN 634
6 T37, #METRIC AFRONTAL#, F7.3, /, 1H , T37, #MSA#, L2X, F7.4, /, 1H , MAIN 635
7 T37, #IMST#, 12X, F7.4, 1X
4005 F3R4AT (1H0, T1C, #ALL DRAGS FOR TWO NOZZLES#, /, 1H , T10, #DRAG COE#, MAIN 636
1FFICIENTS REFERENCED TO WING AREA#, /, 1H , T10, #DRAGS ARE FOR AFT#, MAIN 637
2-END AFT OF *, 4A4, /, 1H , T10, #ALL AREAS ARE IN SQUARE FEET#, MAIN 640
END
***END
***BEGIN

SUBROUTINE AREAS(PTPUP,PTSTOP,GAMM,WSOP1)
COMMON /AREA/GAMMS,GAMS,AP3AT,AS3AT,QMP,QMS
PTSTOP = PTPUP*PTSTOP
Q4P = SQRT(2./GAMMS*(PTPUP**2*(GAMMS/GAMS)-1.1))
Q4S = SQRT(2./GAMMS**2*(PTSTOP**2*(GAMMS/GAMS)-1.1))
BP = 1. + GAMMS/2.*QMP**2
BS = 1. + GAMMS/2.*QMS
AP3AT = 1./(WSOP1*SQRT(BP/BS)*QMP/QMS+1.)
AS3AT = 1. - AP3AT
RETURN
END

***END
***BEGIN***

SUBROUTINE ATMC2(ALT,DELT,TAM,PAM,ERR)

ERR = 0

ALTKM = ALT*3C4.8E-6

IF(ALTKM .GT. 11.)GO TO 10

TAM = 288.15 - 6.5*ALTKM

PAM = 2116.22*[(288.15-6.5*ALTKM)/288.15]**5.255876

GO TO 40

10 IF (ALTKM .GT. 20.) GO TO 20

TAM = 216.65

PAM = 472.685*EXP(-.157688*(ALTKM-11.))

GO TO 40

20 IF (ALTKM .GT. 32.) GO TO 30

TAM = 216.65 + (ALTKM-20.)

PAM = 114.345*(216.65/TAM)**34.1632

GO TO 40

30 IF (ALTKM .GT. 47.) GO TO 60

TAM = 228.65 + 2.8*(ALTKM-32.)

PAM = 18.129 * (228.65/TAM)**12.2011

GO TO 40

40 TAM = (TAM*1.8) + FLT

50 RFTJRN

60 WRITE(6,1000)

GO TO 50

1000 FORMAT(1HO,*ATMO ROUTINE LIMITS EXCEEDED* I)

END

***END***
### Data **KIVC** / 5. 1. 0. 15. 4.

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**DATA KICVS2 / 5, 1, 0, 0, 22, 4, 0, 1, 0, 0.004, -0.007, -0.005, AFTEN054**

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**DATA KICVS3 / 5, 1, 0, 0, 22, 4, 0, 1, 0, 0.004, -0.002, AFTEN054**

---

*CONTINUING*
<p>| A | 0.0 | 0.0 | 2.0 | 0.06 | 4.0 | 0.313 | 6.0 | 0.019 | AFTEN111 |
| B | 0.0 | 0.06 | 10.0 | 0.0325 | 12.0 | 0.039 | 14.0 | 0.046 | AFTEN112 |
| C | 0.054 | 18.0 | 0.065 | 20.0 | 0.08 | / | AFTEN113 |
| DATA K4IMS1 | 5.0 | 1.0 | 0.0 | 32.0 | 3.0 | AFTEN114 |
| A | 16.0 | -1.0 | -2.0 | 0.052 | -1.0 | 0.355 | -1.25 | 0.056 | AFTEN115 |
| B | -1.0 | 0.059 | -7.5 | 0.063 | -5.0 | 0.068 | -2.5 | 0.074 | AFTEN116 |
| C | 0.0 | 0.080 | 14.0 | 0.0 | / | AFTEN117 |
| D | 16.0 | 3.4 | -2.0 | 0.085 | -1.5 | 0.091 | -1.25 | 0.096 | AFTEN118 |
| E | -1.0 | 0.102 | -7.5 | 0.110 | -5.0 | 0.121 | -2.5 | 0.1375 | AFTEN119 |
| F | 0.0 | 0.157 | 14.0 | 0.0 | / | AFTEN120 |
| G | 30.0 | 4.7 | -2.0 | 1.0 | -1.5 | 0.112 | -1.25 | 0.12 | AFTEN121 |
| H | -1.0 | 0.129 | -7.5 | 1.0 | -5.0 | 0.152 | -2.5 | 0.17 | AFTEN122 |
| I | 0.0 | 0.198 | -2.5 | 0.244 | -5.5 | 0.346 | -5.5 | 0.344 | AFTEN123 |
| J | 0.75 | 0.291 | 1.0 | 0.246 | 1.25 | 0.216 | 1.5 | 0.198 | / | AFTEN124 |
| DATA K4IMS2 | 5.0 | 1.0 | 0.0 | 30.0 | 3.0 | AFTEN125 |
| A | 12.0 | .13 | -1.8 | 0.041 | -1.5 | 0.340 | -1.0 | 0.043 | AFTEN126 |
| B | -1.0 | 0.044 | -5.0 | 0.048 | -3.0 | 0.051 | 16.0 | 0.0 | AFTEN127 |
| C | 12.0 | 3.0 | -1.75 | 0.072 | -1.5 | 0.075 | -1.0 | 0.085 | AFTEN128 |
| D | -1.0 | 0.094 | -5.0 | 0.105 | -3.0 | 0.118 | 16.0 | 0.0 | AFTEN129 |
| E | 28.0 | 4.1 | -1.7 | 0.08 | -1.5 | 0.083 | -1.0 | 0.095 | AFTEN130 |
| F | -1.0 | 0.103 | -5.0 | 0.115 | -2.5 | 0.144 | 0.0 | 0.212 | AFTEN131 |
| G | 0.25 | 0.34 | 0.38 | 0.424 | 0.38 | 0.424 | 0.3 | 0.40 | AFTEN132 |
| H | 1.0 | 0.295 | 1.25 | 0.26 | 1.4 | 0.24 | / | AFTEN133 |
| DATA K4IMS3 | 5.0 | 1.0 | 0.0 | 32.0 | 3.0 | AFTEN134 |
| A | 16.0 | .12 | -1.75 | 0.038 | -1.5 | 0.037 | -1.25 | 0.037 | AFTEN135 |
| B | -1.0 | 0.038 | -7.5 | 0.04 | -5.0 | 0.043 | -2.5 | 0.047 | AFTEN136 |
| C | -1.0 | 0.05 | 14.0 | 0.0 | / | AFTEN137 |
| D | 16.0 | 2.6 | -1.75 | 0.061 | -1.5 | 0.061 | -1.25 | 0.063 | AFTEN138 |
| E | -1.0 | 0.065 | -7.5 | 0.069 | -5.0 | 0.073 | -2.5 | 0.079 | AFTEN139 |
| F | -1.0 | 0.083 | 14.0 | 0.0 | / | AFTEN140 |
| G | 30.0 | 3.9 | -1.75 | 0.069 | -1.5 | 0.073 | -1.25 | 0.077 | AFTEN141 |
| H | -1.0 | 0.083 | -7.5 | 0.09 | -5.0 | 0.098 | -2.5 | 0.116 | AFTEN142 |
| I | 0.0 | 0.18 | .25 | 0.275 | .47 | 0.393 | .47 | 0.393 | AFTEN143 |
| J | .75 | .34 | 1.0 | .303 | 1.25 | .27 | 1.6 | .229 | / | AFTEN144 |
| DATA K4IMS4 | 5.0 | 1.0 | 0.0 | 34.0 | 3.0 | AFTEN145 |
| A | 12.0 | .15 | -1.75 | 0.075 | -1.5 | 0.076 | -1.0 | 0.08 | AFTEN146 |
| B | -1.0 | 0.084 | -5.0 | 0.088 | -3.0 | 0.092 | 20.0 | 0.0 | AFTEN147 |
| C | 12.0 | .34 | -1.7 | 0.062 | -1.5 | 0.063 | -1.0 | 0.066 | AFTEN148 |
| D | -1.0 | 0.07 | -.5 | 0.074 | -3.0 | 0.077 | 20.0 | 0.0 | AFTEN149 |
| E | 32.0 | .47 | -1.7 | .04 | -1.5 | .04 | -1.0 | 0.045 | AFTEN150 |
| F | -.5 | .052 | -3.5 | .059 | -3.5 | .055 | -2.5 | .07 | AFTEN151 |
| G | 0.0 | .115 | .25 | .177 | .5 | .256 | .6 | .289 | AFTEN152 |
| H | .6 | .289 | .75 | .258 | 1.0 | .214 | 1.25 | .179 | AFTEN153 |
| I | 1.0 | 161 | / | AFTEN154 |
| DATA K4IMS5 | 5.0 | 1.0 | 0.0 | 30.0 | 3.0 | AFTEN155 |
| A | 14.0 | .116 | -1.65 | 0.045 | -1.5 | .045 | -1.25 | .047 | AFTEN156 |
| B | -1.0 | 0.049 | -7.5 | .052 | -.5 | 0.055 | -22.0 | .061 | 14.0 | AFTEN157 |
| C | 14.0 | .20 | -1.65 | .064 | -1.5 | .064 | -1.25 | .065 | AFTEN158 |
| D | -1.0 | .068 | -7.5 | .071 | -1.5 | .075 | -25.0 | .08 | 14.0 | AFTEN159 |
| E | 28.0 | .38 | -1.78 | .1 | -1.5 | .103 | -1.25 | .106 | AFTEN160 |
| F | -1.0 | 0.112 | -7.5 | 0.119 | -5.0 | .113 | -2.5 | 0.149 | AFTEN161 |
| G | 0.0 | .23 | .25 | .428 | .5 | .47 | .5 | 0.47 | AFTEN162 |
| H | .75 | .349 | 1.0 | .345 | 1.32 | .338 | / | AFTEN163 |
| DATA K4IMS6 | 2.0 | 1.0 | 0.0 | 26.0 | / | AFTEN164 |
| A | -1.75 | .065 | -1.5 | .066 | -1.25 | 0.067 | -1.0 | 0.07 | AFTEN165 |
| B | -1.75 | .075 | -.5 | .088 | -2.5 | .112 | 0.0 | .15 | AFTEN166 |
| C | .25 | .215 | .48 | .3 | .48 | .3 | .75 | .25 | AFTEN167 |</p>
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<td></td>
<td>.129, 32.0</td>
<td></td>
<td>.134, 36.0</td>
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<td>I</td>
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<td>0.003, 4.0</td>
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<td>0.002, 8.0</td>
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<td>J</td>
<td>6.004, 8.</td>
<td>10.</td>
<td>.006, 10.0</td>
<td></td>
<td>.002, 12.0</td>
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<td>.012, 16.0</td>
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<tr>
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<td>14.0-049, 16.</td>
<td>18.</td>
<td>.085, 22.0</td>
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<td>.114, 20.0</td>
<td></td>
<td>.125, 24.0</td>
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<tr>
<td>L</td>
<td>22.0-125, 24.</td>
<td>26.</td>
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<td></td>
<td>.129, 32.0</td>
<td></td>
<td>.134, 36.0</td>
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</tbody>
</table>

### CONTINUING
PI = 3.1415927
GAMFS = 1.4
RRR = 1716.5
GRAV = 32.174
AJ = AE + AB
DELA = DELAAM*AM
AMF = AMFAM*AM
AMT = AMTAM*AM
AP = AF - DELA/2.
GAMAV = (GAM+GAMS)/2.
PEPE = XMOM/(GAMAV*AE**2)
DM = 2.*SORT(AM/PI)
DELX = DELXAM*DM
AFFRR = 0.0
6
THETRA = THETAM*0.07453
RMZAM = IMSA*(AMB/AM)*1.5
IMST = (RMZA/AMB)*(AM-2.*((AP+AB)) + IMSF/AM*(AM-AMB))*AM/(AM-2.*
1
(AP+AB))
40 RMF = XMOM *2.0 / (1.4*AM*MO**2)
IF(MO .GE. 1.0) GO TO 60
PBPE= (0.9+0.0167*RMF)/(0.94+0.06*(2.0*(AB+AE)/AM))
DB = (1.0-PBPE)*PQ*2.0*AB
GJ = 62
60 TETE = (1.0*(GAM-1.0)/2.0)/(1.0+(GAM-1.0)/2.0*ME**2)
DEQ = SQRT(2.0*AM/3.141592)
PBBEP = TETE*3.5/(3.5*AM/AM**2)
1
1/(AM)*0.19+1.28*RMF/(1.0+RMF)) +
1
0.047*(5.0-MO)*(2.0*DELX/DEQ+(DELX/DEQ)**2)
DB = (1.0-PBPE)*PQ*2.0*AB
62 IF(MO .LE. 1.0) GO TO 100
X = SQRT(MO**2-1.0)*IMST
Z = 2.0*(AP+AB)/AM
CAL. XTRP(X,RK6,Z,RK6IMST)
IF(ISD .LE. 3) CALL XTRP(MO,RK2,0.,K2MO1)
IF(ISD .GE. 4) CALL XTRP(MO,RK2,0.,K2MO2)
R<3.0=0.0
IF(MO .GE. 2.0) GO TO 75
X1 = 0.0
X3 = LDM*SQRT(4.0*AM/3.141592)
Y1 = DEQ/2.0
Y3 = SQRT((AE+AB)/3.141592)
Y2 = Y3*(X3-X1)*TAN(THETR)
XM1 = MO
XM2 = MO
XM3 = MO
NM = 1
ALPHAO = ATAN(1.0/SQRT(XM2**2-1.0))

***CONTINUING
THFTR = THFTR / 2.0

ALPHA = ATAN(1.0 * SQRT(XM3**2 - 1.0))
ALPHA = (ALPHA + ALPHAD) * 0.5
ALPH = TAN(ALPHA) - TAN(THFTR - ALPHAR)
BET = (Y3 - Y1) / ALP

DET = XI* TAN(ALPHAD) / ALP
DET = X3*TAN(THFTR - ALPHAR) / ALP
XX2 = BET + DET
YY2 = (XX2 - XI) * TAN(ALPHAD) + Y1
YR = (YY2 + Y3) / 2.0

TTT = 1.0 / (1.0 + 0.2 * XM3**2)
T2TT = 1.0 / (1.0 + 0.2 * XM2**2)
T3TT = (T3TT + T2TT) / 2.0

FRO = SQRT(1.0 / TTT / TTT / COS(ALPHAR)
FQ = TAN(THF) / TAN(ALPHAR)

GRO = YR * (FRO / 1.0) + 1.0

XM4 = ERG / (FRO / GRO * (X3 - XX2 + THFTR) + XM2 * SQRT(T2TT / T3TT))

IF(ABS(XM4 - XM3) * 0.0001 * XM3) GO TO 70

XM3 = XM4
IF(XM4 * NE. 1.01 .AND. NN.EQ. 1) XM3 = 1.2 * XM
IF(XM4 * LE. 1.01 .AND. NN.EQ. 1) XM3 = 1.2 * XM
NN = NN + 1
IF(NN.LF. 100) GO TO 65

AFTER = 1.0

WRITE (6,9960)
RETURN

70 XM = A MAX((1.05, XM4)

PLPE = ((1.0 + 0.2 * XM2) / (1.0 + 0.2 * XM4)) * 0.5

QL = 0.7 * PO / XM ** 2 * PLPE

IF(P/EPE - PLPE) / PO / QL .GE. 1.41 CALL XTPR(THETAM, RK3, MO, THF)

75 DBT = RK6 / (MO * 0.0) * (AM - RK3, A8) / RK4

G3 T3 211

100 X = (40 * 2 - 1.0) / (MO * 2 * IMSA) ** 6.666667
X = A MAX((X, -2.0))
Z = 2.0 * (AP + AB) / AM

IF(N.EQ. 1 .AND. DELXDM .GT. 0.1) GO TO 145
IF(T.EQ. 1 .AND. ISD .EQ. 1) CALL XTPR(X, RK4, Z, K4IMS1)
IF(T.EQ. 1 .AND. ISD .EQ. 2) CALL XTPR(X, RK4, Z, K4IMS2)
IF(T.EQ. 1 .AND. ISD .EQ. 3) CALL XTPR(X, RK4, Z, K4IMS3)
IF(T.EQ. 2 .AND. ISD .EQ. 1) CALL XTPR(X, RK4, Z, K4IMS4)
IF(T.EQ. 2 .AND. ISD .EQ. 2) CALL XTPR(X, RK4, Z, K4IMS5)
G3 T3 149

145 CAL. XTPR(X, RK4, Z, K4IMS6)

148 IF(ISD .EQ. 1) CALL XTPR(THETAE, RK5, MO, K5THM1)
IF(ISD .EQ. 2) CALL XTPR(THETAE, RK5, MO, K5THM2)
IF(ISD .EQ. 3) CALL XTPR(THETAE, RK5, MO, K5THM3)

FIND = PTPFS * P4 / AQCD * SQRT(2.0 * GAM ** 2 / (GAM - 1.0) * (2.0 / (GAM + 1.0)))

IF((GAM + 1.0) / (GAM - 1.0) * (1.0 - 1.0 / PTPFS) ** 2 / (GAM - 1.0)) **

R1 = 0.0
IF(T.EQ. 1) GO TO 210
IF(N.EQ. 1) GO TO 185
IF(N.EQ. 3) CALL XTPR(1 - CT, RK1, MO, K1CV)
IF(N.EQ. 3) GO TO 210
IF(N.EQ. 4) CALL XTPR(1 - CT, RK1, MO, K1CV)
IF(N.EQ. 4) CALL XTPR(1 - CT, RK5, MO, K1CV)
G3 T3 186

***CONTINUING
185  IF(IDELXDM.EQ. C.) CALL XTRP(1.-CT,RKL,M0,KLCVLI)
 IF(IDELXDM.EQ. C.) CALL XTRP(1.-CT,RKS,M0,KLCVLS)
 IF(IDELXDM.EQ. C.) CALL XTRP(1.-CT,RKL,M0,KLCVL1)
 IF(IDELXDM.EQ. C.) CALL XTRP(1.-CT,RKS,M0,KLCVSL1)

186  RKL = RKS + (AT-ATMIN)/(RKL-RKS)/(ATMAX-ATMIN)

210  DBT = RK4*[(MSA/M0)*.6666667*Q*(AMB-2.*AP*AB))+RKS*Q*2.*
 L (AF*AB)+RKL*2.0*FID

211  LMB = LMBDM*DM
 LL = LDM*DM
 FHTETA = THETDM*DM
 RHO = PO*GRAV/(RRR*TO)
 MU = 2.27E-8*TO**1.5/(TO+198.6)
 UO = MO*SQR(T(GAMFS*RRR*TO))
 RETHFT = RHO*UO*FHTETA/(GRAV*MU)
 TAW = TO*(1.4*178*MO**2)
 TP = TO*(1. + .035*MO**2 + .45*(TAW/TO - 1.1)
 MUP = 2.27E-8*TP**1.5/(TP+198.6)

215  ANR = 0.44*RETHP/(ALOG10(RETHP)-1.5)**2/MJ
 SAVRP = RETHP
 CALL ITRAT1(RETHP,FUNC,0.,KT)
 IF(ABS(FUNC) .LT. 1.E-2) GO TO 225
 IF(SAVRP-RETHP .LT. 0.) RET = RET + SAVRP
 IF(KT.EQ.1) RET = 1.0*RETHP
 GO TO 215

220  IF(N .LT. 1.) WRITE(6,9970)
 RETURN

225  RHDP = PO*GRAV/(RRR*TP)
 LEFF = GRAV*UO*RETHP/(RHDP*UO) + LMB
 LVAR = LL - LMB
 AMET = AWT - AWF
 LFLG = 1

230  LT = LEFF + LVAR
 RELP = RHDP*UO*LT/(GRAV*UO)
 CF = (1.08*(ALOG10(RELP) - 2.36861)/TO/(ALOG10(RELP)-1.5)**3 /TP
 DTF = CF*Q*AMET
 IF(MO +LT, 1.) GO TO 250
 IF(LFLG .EQ. 2) GO TO 235
 LFLG = 2
 LEFF = LEFF - LMB
 LVAR = LMB
 AMET = AWF
 DTF1 = DTFF
 GO TO 230

235  DTF = (DTF + DTF1 + DTF)

250  DT = DBTP + DB + D4TF
 QAWING = QAWING
 CDTP = DBTP/QAWING
 CDTF = DTF/QAWING
 COB = DB/QAWING

***CONTINUING
RETURN
9960 FORMAT (*) EXTERNAL EXIT MAC-1 NUMBER ITERATION FAILED*)
9970 FORMAT (*O REYNOLDS NUMBER ITERATION FAILED*)
END

***FND
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<th>DATA</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
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<th>G</th>
<th>H</th>
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<th>J</th>
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<td>FIG11A /</td>
<td>1.4</td>
<td>0.8</td>
<td>1.025</td>
<td>0.997</td>
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<td>0.997</td>
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<td>0.995</td>
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<tr>
<td>FIG11B /</td>
<td>1.1</td>
<td>1.2</td>
<td>0.997</td>
<td>0.987</td>
<td>1.3</td>
<td>0.986</td>
<td>1.4</td>
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<td>1.5</td>
<td>0.986</td>
<td>1.6</td>
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<td>0.986</td>
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<td>0.975</td>
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<td>1.8</td>
<td>0.975</td>
<td>1.9</td>
<td>0.975</td>
<td>2.0</td>
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</table>
RT = SQRT(AT/PI)
THET = ATAN((RE-RT)/SQRT(RE-(RE-RT)**2))
THETA = THET / RAD
IF(DUMVAR.GT. C.O) GO TO 3
Pشب = 1.0
WSQP = 0.0
FFID = 0.0
AEDAPS = AE/ATFLOW
GL2G1 = (GAM+1.0)/(2.0*(GAM-1.0))
QMQ = 1.
KTH = 0.
4 FJNC5 = AEDAPS-((2.0*(GAM -1.0)*QMQ**2)/(GAM +1.0)**G12G1/QMQ
SVQM = QMQ
CALL ITRATE(QMQ, FUNC5, 0., KTH)
IF (ABS(FUNC5) .LE. 1.E-4) GO TO 5
IF (KTH.EQ. 25) GO TO 475
IF (UPE.EQ. II) OMO .GT. 1.01
IF (SVQM.QE. QMQ .GT. 0.1) QMQ = AMAX1(QMQ , .5*(1.0+SVQM0))
IF (SVQM0 .LT. 0.1) QMO = AMIN1(QMO , 1.2*SVQM0)
GO TO 4
5 P3PTT = (1.5* QMO**2 *(GAM -1.0)***(-GAM / (GAM -1.0))
FSAPS = P3PTT*AEDAPS*1.0*(GAM*QMQ**2)
CALL XTKPIAFOAPS.FIG11)
Org = GAMS*(GAM-1.0)/(2.0/GAM+1.0)**(GAM+1.0)/(GAM-1.0)
1.**(GAM-1.0)/ANPR)**((GAM-1.0)/GAM))
FLAG = 4.
TID = FFID
XVEXIT = QMO
CT = CS*FSAPS- AEDAPS/ANPR/FFID
IF(P3PTT.GT. 1./ANPR) CT = CS-.007
XMQ = P3PTT*AEDAPS*GAM*QMQ**2)*ANPR/ATFLOW
GO TO 500
3 IF(QMO.EQ.2.) GO TO 2
Pشب = DUMVAR
IF(AVPRP.PT.PTS) (GE. 1.) GO TO 2
WRITE(6,1020)
GO TO 490
2 GAM3 = GAM + 1.
GAM4 = GAM - 1.
GAMPS = GAMS + 1.
GAMQS = GAMS - 1.
ZZ = 0.
AEDAPS = AEDAT/APTJAT/CDN
ATDAPS = 1./APTOAT/CDN
C*** WASAP SECTION
IF(QMO.EQ.1.) GO TO 19
WSQP = DUMVAR
WSQP = DUMVAR
S3NYE = 0
X(1) = .25
X(2) = .75
XIV(1) = 0.
XIV(2) = 0.
X4AX(1) = 1.
X4AX(2) = 1.
EPSL(1) = 1.0-4
***CONTINUING
-91
EPS(2) = 1.E-4
10 PDPFP=X(I)
PDPTS=X(I)
PTSDTP=X(I/X(2)
WSWPA = ATJAP*SQR(2./GAMM*(GAMP/2.1***(GAMP/GAMM)) - (1./POPTP)**(1.EJECT 112
1./GAM) /SQR(1.-POPTP**GAMM/GAMM))
F(1)=
1WSWPI = WSDWP*sqrt(KP/RS*GAMS/GAM*GAMM/GAMMS*(1.-POPTS**GAMMS/GAMM))
GAMS)**PTSDTP*POPTS**GAMM/GAM)
WSWPS = GAMS/GAMP*PTSDTP*GAMM/2.*POPTP*(1.-GAMM/GAM-1.)**(1.-1.)
WS3WP = GAMS/GAMS/GAMS/GAMS/GAMS*1.**(GAMM/GAM)
WS3WP = GAMS/GAMS/GAMS/GAMS/GAMS/GAMS*1.**(GAMM/GAM)
F(2)=
1WSWPI = WSDWPB/((1.-GAMMS/2.)*(POPTP**((1.-GAMS)/GAMS))**(-1.)
1.*POPTP**GAMM/GAMM/GAMMS/1.-POPTP**GAMMS/GAMM))
CALL (TRATE2,F,XMIN,XMAX,EPS,30,KONV)
IF(3NV - 2) = 1C1,1,485
PPDTP=POPTP
IF(X(1) LT.0. OR. X(2) LT.0.) GO TO 485
IF(APK*PTSDTP .GE. 1.) GO TO 40
WRITE(6,1020)
GO TO 490
19 KT = 0
PDPFP=PTSDLTP .25
PDPTS = POPTP/PTSDLTP
20 PDPFP=POPTP/PTSDLTP
WSWPI = ATJAP*SQR(2./GAMM*(GAMP/2.1***(GAMP/GAMM)) - (1./POPTP)**(1.EJECT 138
1./GAM) /SQR(1.-POPTP**GAMM/GAMM))
WSWPI = WSDWP1*sqrt(KP/RS*GAMS/GAM*GAMM/GAMMS*(1.-POPTS**GAMMS/GAMM))
GAMS)**PTSDLTP*POPTS**GAMM/GAM)
WSWPI = WSDWP2/((1.-GAMMS/2.)*(POPTP**((1.-GAMS)/GAMS))**(-1.)
1.*POPTP**GAMM/GAMM/GAMMS/1.-POPTP**GAMMS/GAMM))
FUNKY = WSDWP1 - WSDWP2
SPDTP = POPTP
CALL (ITRATE(POPTP, FUNKY, 0., KT)
IF(ABS(FUNKY) LT. 0.001) GO TO 40
IF(KT .GT. 251) GO TO 485
IF (SPDTP - POPTP .GT. 0.) POPTP =AMAX1(POPTP, 0.*SPDTP)
IF (SPDTP - POPTP .LT. 0.) POPTP =AMIN1(POPTP, 0.*SPDTP)
L PTSDTP)
IF(KT .EQ. 1) POPTP = 1.01* POPTP
GO TO 20
40 PPDPFP = PDPFP
WSWPI = .5*(WSWPI+WSWPI)
46 PTDPFP = PPDPFP
WSWPI = WSDWP1
AEDA = AEDAPS
PPDPFP = PPDPFP
XX = 1
BERN = 1
GO TO 200
47 PPDPFP = PDPFP
POPTS = POPTS
IF (POPTS .GE. 1./ANPR) GO TO 80

***CONTINING 92
ZZ = 1.
IF(ZZ.EQ.1.) GO TO 48
WSWP = WSWP*SQRT(RP/RGAMM/2.*GAMMS/2.*GAMM/2.*GAMM) - 1./1.*ANPR
EJECT 170
1)**(1./GAMM)/SQRT(1.-1./ANPR)**(GAMM/GAMM)
PPTS = PPTS*1./GAMS
1WSWP1 / WSWP*SQRT(RP/RGAMM/2.*GAMMS/2.*GAMM/2.*GAMM) - 1./1.*ANPR)**(GAMM/GAMM)
EJECT 171
IF(ANPR*PPTS .G.E. 1.) GO TO 49
WRITE(6,E1020)
EJECT 172
40 GO TO 490
EJECT 173
48 WSWP = WSWP1
EJECT 174
AEOAPS = AEOAPS*SQRT(2./GAMM*(GAMM/2.*GAMM)/(1./ANPR)**(GAMM/GAMM))
EJECT 175
IF(AMPP*PTS .GE. 1.) GO TO 49
EJECT 176
WRITE(6,E1020)
EJECT 177
GO TO 490
EJECT 178
50 PPTS = PPTS*1./GAMS
EJECT 179
IF(WSWP*GT.GE. WSWP1) GO TO 480
EJECT 180
WSWP1 = WSWP1
EJECT 181
AEOAPS = AEOAPS*SQRT(2./GAMM*(GAMM/2.*GAMM)/(1./ANPR)**(GAMM/GAMM))
EJECT 182
IF(AMPP*PTS .GE. 1.) GO TO 49
EJECT 183
WRITE(6,E1020)
EJECT 184
GO TO 490
EJECT 185
50 PPTS = PPTS*1./GAMS
EJECT 186
IF(ZZ .GE. 0.) CALL AREAS(1./PPOPTP,PPTS,ANPR,WSWP1)
EJECT 187
IF(ZZ .NE. 0.) CALL AREAS(1./PPOPTP,PPTS,ANPR,WSWP1)
EJECT 188
IF(PPOPTP .GT. 1./ANPR) GO TO 90
EJECT 189
CALL AREAS(ANPR,PPTS,ANPR,WSWP1)
EJECT 190
AEOAPS = AEOAPS*ANPR*ANPR*ATAPS
EJECT 191
AEOAPS = AEOAPS*ANPR*ANPR*ATAPS
EJECT 192
MP = MP
EJECT 193
MES = MS
EJECT 194
IFMODE1 .GE. 2., IC = IC - .007
EJECT 195
CT = IFMODE1*(FFF*FFFS)-ATAP*ATAP/ANPR/(IFCID+FIFS)
EJECT 196
FLAG = 1.
EJECT 197
XW3 = (PEPPT*ATAPS*GAM*MEP**2*PPOPTP*APAPS*(1.+GAMMS**2))/GAMS
EJECT 198
G3 TD 200
EJECT 199
90 PRCPT = .63 + .04*ALOG(WSWP1+.01)
EJECT 200
PRCTT = PRCPT/ANPR
EJECT 201
WSWP = WSWP1
EJECT 202
BERN = 3
EJECT 203
XX = 0.
EJECT 204
AEOAPS = AEOAPS
EJECT 205
PDPPTX = PPOPTP-.001
EJECT 206
G3 TD 200
EJECT 207
92 PEUNPT = PDPPTX
EJECT 208
PEUNPTS = PPOPTP
EJECT 209
***CONTINUING
IF (PRCPTT .LE. PEUPTP) GO TO 190
WRITE (6,1010)
GO TO 490

PTCST = PRCPTT/PTSPT
AIOAPS = WSDWP1/SQRT(1./PTSPTP/RS*GAMS/GAM*GAMM/GAMMS*(1.-PRCPTT)**(GAMMS/GAMS))
AIOAPS = AIOAPS + (1./PRCPTT)**(1./GAM)/SQRT(1.-PRCPTT)**(GAMM/GAM)

*** MACH SECTION ***
ME = 1.
KT = 0
150  FUN< = AEOAT - 1./ME*(2.*GAMM*ME**2)/(GAMP/2.)*((GAMP/(2.*GAM))
SVOL = ME
CALL ITRATE(ME,FUNX,0.,KT)
IF (ABS(FUNX) .LE. 1.E-4) GO TO 160
IF (KT .GT. .25) GO TO 475
IF (KT .EQ. 1) ME = 1.01

IF (SVQME-ME .GT. 0.) ME = AMAX1(ME, .5*(1.+SVQME))
IF (SVQME-ME .LT. 0.) ME = AMIN1(ME, 1.2*SVQME)
GO TO 150

160  CONTINUE
PTT*E = (1.4*GAMM/2.)*ME**2/(GAMP/GAM)
PTT*CP = PRTC*ST/PTSPT
IF (PTTPCP .GE. ANPR) GO TO 180
CALL AREASL(1./PRCPTT,PTSPT,0,WSDWP1)

AEPAPS = APOAT*AIOAPS
AESAPS = ASOAT*AIOAPS
MEP = MP
MES = MS
EXIT = APOAT*MEP + ASOAT*MES
FFS = PRCPTT*AEPAPS*(1.-GAMM*ME**2)
FFSS = PRCPTT*PTSPTP*AESAPS*(1.+GAMS*ME**2)
PDA = 1./ANPR*(16.*PRCPTT*ANPR/7.7)*(AEOAT*ATOAPS-AIOAPS)
FFID = GAM*SQRT(2./GAMP)/(GAMP/GAM)**(1.-1./ANPR)**(GAMM/GAM)
IM/GAM))

FFIDS = WSDW1/SQRT(12.*GAM/1.01/PPTS)**(GAMM/GAMS))

CALL XTRP(AIOAT, CS, THETA, FIG11)
IF (2MODEL .GE. 2.) CS = CS-.007
TID = FFID + FFIDS
CT = (CS*(FFS+FFSS) - AEOAT*ATOAPS/PDA)/(FFID+FFIDS)
FLAG = 3
QUIT = (PRCPTT*AEPAPS*GAM*GAMM**2 + PRCPTT*PTSPTP*AESAPS*GAMS+MES***)
GO TO 500

180  CALL AREASL(1./PEOPTP,PTSPT,0,WSDWP1)
AEPAPS = APOAT*AEOAT*ATOAPS
AESAPS = ASOAT*AEOAT*ATOAPS
MEP = MP
MES = MS
EXIT = APOAT*MEP + ASOAT*MES
FFID = GAM*SQRT(2./GAM/2./GAMP)**(GAMP/GAM)**(1.-PEOPTP)**(GAMM/GAMS))
GO TO 210

*** CONTINUING ***
Continuing
CT = (CS*(FFS+FFSS) - AEOAT*ATCAPS/ANPR) / (FFID+FFIDS)
FLAG = 4.
IF(PEUPTP .GT. 1./ANPR) CTID = (1.*(FFS+FFSS) - AEOAT*ATCAPS/ANPR)
1./FFID*FFIDS)
X434 = (PEUPTP*AEPAPS*GAM*MEP**2 + PEUPTP*PTSPTP*AESAPS*GAMS*MES**2) EJECT 343
121*ANPR*ATFLOW
GO TO 500
EJECT 346
C*** BEAVST SECTION
EJECT 347
200 KT = 0
EJECT 348
IF(XX .EQ. 0.) POPTP=POPTP/2.
EJECT 349
210 POPTP=POPTP/PTSPTP
EJECT 350
SVPTS = POPTP
EJECT 351
WSWPT = AEA*A*SQR(2./GAM*((GAMP/2.)**(GAMP/GAM)) - (1./POPTP)**2(1./GAMS))
EJECT 352
1./GAMS)/SQR(1.-POPTP**(GAMP/GAM))
EJECT 353
WSWPT = WSWPT*SQRT(POPTP/GAM**2*GAMS/GAM**2-POPTP)**2(GAMS/1.GAMS)
EJECT 354
FUNKK = WSWP - WSWPT
EJECT 355
CALL ITRATE(POPTP,FUNKK,0.,KT)
EJECT 356
IF (ABS(FUNKK).LT. 1.E-6) GO TO 240
EJECT 357
IF (KT .GE. 25) GO TO 470
EJECT 358
IF (SVPTS - POPTP .GT. 0.) POPTP=AMAX1(POPTP,8.*SVPTS)
EJECT 359
IF (SVPTS - POPTP .LT. 0.) POPTP=AMIN1(POPTP,5.*(SVPTS+PTSPTP)
EJECT 360
IF(KT .EQ. 1.) POPTP = 1.01*POPTP
EJECT 361
GO TO 210
EJECT 362
240 PEPTPZ = POPTP
EJECT 363
IF (BERN .LT. 47) GO TO 470
EJECT 364
470 WRITE(6,1060)
EJECT 365
GO TO 490
EJECT 366
475 WRITE(6,1050)
EJECT 367
GO TO 490
EJECT 368
480 WRITE(6,1040)
EJECT 369
GO TO 490
EJECT 370
485 WRITE(6,1030)
EJECT 371
490 NOZERR = 1
EJECT 372
WRITE(6,9000)
EJECT 373
500 CONTINUE
EJECT 374
1010 FORMAT(1HO,RECOMP PRESS,GT. THROAT PRESS*)
EJECT 375
1020 FORMAT(100 SECONDARY FLOW TOTAL PRESSURE LESS THAN FREESTREAM STAT)
EJECT 376
IC* )
EJECT 377
1030 FORMAT(100 PUMPING CHARACTERISTICS ITERATION FAILED* )
EJECT 378
1040 FORMAT(100 UNCHOKED WSWP GREATER THAN CHOKED WSWP*)
EJECT 379
1050 FORMAT(100 MACH NUMBER ITERATION FAILED* )
EJECT 380
1060 FORMAT(100 EXIT PRESSURE ITERATION FAILED* )
EJECT 381
9000 FORMAT(1IH,ERROR IN EJECTOR NOZZLE ROUTINE*)
EJECT 382
RETJRN
EJECT 383
END
EJECT 384
***END
**BEGIN**

```
SUBROUTINE FLTSPD (IFSC, FSPD, AM, VOK, VOM, VOKI, VOMI, 
                   I PAH, TAN)
C
INPUT CODES
C
IFS = 1 MACH NUMBER
IFS = 2 TRUE AIRSPEED, KNOTS
IFS = 3 TRUE AIRSPEED, MPH
IFS = 4 EQUIVALENT AIRSPEED, KNOTS
IFS = 5 EQUIVALENT AIRSPEED, MPH
IFS = 6 CALIBRATED AIRSPEED, KNOTS
IFS = 7 CALIBRATED AIRSPEED, MPH

NOMENCLATURE
C
AM - MACH NUMBER       VCASKT - CALIBRATED AIRSPEED (KTS)
V3M - TRUE AIRSPEED (MPH) VCASMP - CALIBRATED AIRSPEED (MPH)
V3K - TRUE AIRSPEED (KTS) ALTER - GEOPOTENTIAL PRESSURE
V3MI - EQUIVALENT AIRSPEED (MPH) ALTITUDE (FT)
V3KI - EQUIVALENT AIRSPEED (KTS)
C3M4JN/FLTSP/ VCASKT, VCASMP
C3M4JN/GCALCC/ALTQ, ALTQ, ALTER, GEOPH
DIMENSION GAM (72)
DATA GAM / 72.0, 1.0, 0.0, 68.0, 
  101.0, 0.1, 402.0, 0150.0, 1.402, 0200.0, 1.402, 0250.0, 1.402, 0300.0, 1.402, 
  203.5, 0.1, 402.0, 0400.0, 1.402, 0450.0, 1.401, 0500.0, 1.401, 0550.0, 1.401, 
  306.0, 0.1, 399.0, 050.0, 1.398, 0700.0, 1.396, 0750.0, 1.394, 0800.0, 1.392, 
  409.0, 0.1, 387.1, 000.0, 1.381, 100.0, 1.374, 1200.0, 1.368, 1300.0, 1.362, 
  514.0, 0.1, 356.1, 150.0, 1.350, 1600.0, 1.345, 1700.0, 1.340, 1800.0, 1.336, 
  619.0, 0.1, 332.2, 200.0, 1.328, 2100.0, 1.325, 2200.0, 1.322, 2300.0, 1.319, 
  724.0, 0.1, 317.2, 260.0, 1.313, 2800.0, 1.309, 3000.0, 1.306, 
DIMENSION GAM (72)
DATA VCASV1 / 4.0, 1.0, 0.0, 3.0, 0.7, 0.0
DATA VCASV2 / 0.8, 0.0, 0.0, 250.0, 250.0, 500.0, 500.0
DATA VCASV3 / 750.0, 250.0, 200.0
DATA VCASV4 / 280.0, 500.0, 200.0
DATA VCASV5 / 200.0, 198.6, 250.0, 249.2, 300.0, 298.5, 350.0
DATA VCASV6 / 400.0, 396.8, 450.0, 445.6, 500.0, 494.2, 550.0
DATA VCASV7 / 600.0, 590.0, 650.0, 638.0, 700.0, 689.0
DATA VCASV8 / 0.0, 6.0, 1500.0, 200.0, 198.2, 250.0, 246.6, 300.0
DATA VCASV9 / 400.0, 386.4, 450.0, 434.0, 500.0, 479.1, 550.0
DATA VCASV10/ 600.0, 576.7, 650.0, 611.0, 200.0
DATA VCASV11/ 22.0, 250.0, 0.0, 0.0, 100.0, 99.8, 150.0
DATA VCASV12/ 200.0, 196.2, 250.0, 243.1, 300.0, 288.8, 350.0
DATA VCASV13/ 400.0, 376.1, 450.0, 418.1, 500.0, 469.0, 550.0
DATA VCASV14/ 600.0, 6*0.0
DATA VCASV15/ 18.0, 350.0, 0.0, 0.0, 100.0, 99.6, 150.0
DATA VCASV16/ 200.0, 193.4, 250.0, 237.9, 300.0, 283.3, 350.0
DATA VCASV17/ 400.0, 362.0, 450.0, 402.0, 10*0.0
```

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**DATA VQAS1**

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<tr>
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<td>638.</td>
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**DATA VQAS2**

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</table>

**IF(ALTER.GT.0.0 .AND. ALTER.LT.55000.0) GO TO 9**

ALTER=0.0 FLTSP082

9 CALL XTRP(TAM, GAMO, 0.0, GAM)

S3TAM = SQRT(TAM)
S3GAM = SQRT(GAMO)
AJ = 41.427 * SQRT(TAM) * SQRT(GAMO)
S3SIG = SQRT(TAM / (TAM * .0793))
GJ TJ (10, 20, 30, 40, 50, 60, 70), IFSC

10 AM = FSPD

V3K = AM * AD +.5925

11 IF(IFSC .EQ. 4) GO TO 13

V3KI = VOK * SQSIG

IF(IFSC .EQ. 3) GO TO 14

V3M = VOK / 0.669

IF(IFSC .EQ. 5) GO TO 15

14 V3MI = VOKI / C.869

IF(IFSC .EQ. 6 .OR. IFSC .EQ. 7) GO TO 80

15 CALL XTRP(VOKI, VQASKT, ALTER, VQGAS)

VQASMP = VQASKT / 0.669

GJ TJ 80

20 V3K = FSPD

21 AM = VOK * 1.6678 / AD

GJ TJ 11

30 V3M = FSPD

V3K = VOKI * 0.669

GJ TJ 21

40 V3KI = FSPD

V3K = VOKI / SQSIG

---CONTINUING---

98
GJ TO 21
50 V3M1 = FSPD
    V3K = V3M1 * .869 / SQSIG
GJ TO 21
60 VCASKT = FSPD
    CALL XTRP(VCASKT, VOKI, ALTER, VCASEQ)
    V3K = VOKI / SQSIG
    VCASMP = VCASKT / 0.869
GJ TO 21
70 VCASMP = FSPD
    VCASKT = FSPD * 0.869
    CALL XTRP(VCASKT, VOKI, ALTEP, VCASEQ)
    V3K = VOKI / SQSIG
GJ TO 21
80 RETURN
END

***END
***BEGIN

SUBROUTINE ITERAT(G,V,X,N)
       X= 1.1
       Q= 1.0001
       W1=SQR(G)*ATAN(SQR(1.0/G*(X**2-1.0)))-ATAN(SQR(Q**2-1.0))
       I= 0
10  [I=I+1]
       IF(I. LE. 200) GO TO 20
       WRITE(6,9900)
       N=2
       RETURN
20  W= SQR(G)*ATAN(SQR(1.0/G*(X**2-1.0)))-ATAN(SQR(X**2-1.0))
       IF(ABS(V-W).LT. 0.0001) RETURN
       XI= 3*(V-W1)/(W-W1)*(X-Q)
       Q=X
       X= XI
       W1=W
       GO TO 10
9900 FORMAT(* FAILED TO CONVERGE IN ITERAT*)
END

***END
BEGIN

SUBROUTINE ITRATE(A3P,B3,B3P,LOOP)

IF (LOOP .EQ. 100) GO TO 100

A3=A3P
B3=B3P
IF (LOOP .EQ. 100) GO TO 100

A3P = A3P
B3P = B3P

IF (LOOP .EQ. 104) GO TO 104

A3P = (A3B3-A3B3)/DVISCR

END

***END
**BEGIN**

SUBROUTINE ITRATI(X, G, XMIN, XMAX, NUMIT, NSIGX, NSIGF, KONV)

F = G

IF(KONV .NE. 0) GO TO 20

C ... INITIAL ENTRY

XAVE = (XMAX + XMIN) / 2.E0

10 KONV = 1

LJOP = 0

FLEAST = 1.E6C

XS = X

FS = F

LIMITS = 0

NUMIT2 = NUMIT/2

X4NN = XMIN

X4XX = XMAX

20 DABSF = ABS(F)

IF(DABSF .GT. ABS(FLEAST)) GO TO 22

C ... SAVE BEST VALUE

SAVX = X

FLEAST = F

C ... TRY TO DECREASE INTERVAL OF APPROXIMATION

22 IF(LIMITS .EQ. 1) GO TO 25

IF(F*FS .GT. 0.E0) GO TO 28

LIMITS = 1

IF(X .GT. XS) GO TO 23

X4NN = X

X4XX = XS

F4NN = F

F4XX = FS

GJ TO 28

23 X4NN = XS

F4NN = F

GJ TO 28

25 IF(F*FMNN .LT. 0.E0) GO TO 26

X4NN = X

F4NN = F

GJ TO 28

26 X4XX = X

F4XX = F

28 C = ABS(XMNN)

IF(C .EQ. 0.E0) C = 1.E0

IF(ABS(XMNN - X4NN)/C .LT. 5.E-1*1.E**(-NSIGX) .AND. DABSF .LT. 5.E-1*1.E**(-NSIGF) .OR. DABSF .EQ. 0.E0) GO TO 80

IF(LJOP .GT. C) GO TO 30

C ... PERTURB INITIAL GUESS

X = X* SIGN(1.E-2*X, XAVE-X)

IF(X .EQ. XS) X = (XAVE*XMIN)/2.E0

***CONTINUING
C ... TEST FOR NONCONVERGENCE
30 IF (LJOP .EQ. NUMIT) GO TO 90
C ... REGULA FALSI
IF (LIMITS .NE. 1 .OR. LOOP .LE. NUMIT2) GO TO 50
X = (FMNN*XMXX - FMXX*XMNN) / (FMNN - FMXX)
IF (ABS(FMNN) .GT. 1.E1 .AND. ABS(FMXX) .GT. 1.E1 .AND.
1 ABS(FMNN-FMXX)/AMIN(ABS(FMNN),ABS(FMXX)) .GT. 1.E2)
2 X = (XMXX*XMNN) / 2.E0
GJ TJ 65
50 DIV = F-FS
IF(DIV .EQ. 0.E0) DIV = 1.E0
X1 = (FS-FS*X)/DIV
FS = F
X = X1
C ... TEST FOR OUT OF RANGE
60 IF (X .LE. XMNN) X = (XS+XMNN)/2.E0
IF (X .GE. XMXX) X = (XS+XMXX)/2.E0
C ... INCREASE ITERATION COUNTER
65 LOOP = LOOP+1
C ... RETURN
70 RETURN
C ... CONVERGENCE
80 K3NV = 2
GJ TJ 70
C ... NONCONVERGENCE
90 K3NV = 3
IF (LIMITS .EQ. 1) GO TO 70
X = SAVX
G = FLEAST
GJ TJ 70	
EVN

***FND
***BEGIN

SUBROUTINE ITRATA(N,X,F,XMIN,XMAX,EPB,NUMIT,KONV)
DIMENSION A(15,15),B(15,15),C(15,15),D(15),S(14),P(14),
1 X(N),F(N),DS(14),X(14),FS(14),TS(15),XMIN(N),XMAX(N),
2 EPS(N),G(15,15),E(15,15),O(15,15),R(15,15),
3 DF(14)
FJNC(A,B1,C1,M) = A(1)(B1-A1)(A1-C1)/M
IF(KONV .GE. 1) GO TO 25
C . INITIALIZATION
  KPT = 1
  L0CAL = 0
  KUT = 2
  DNV = -1.E60
  D0 6 J=1,N
  DNV = AMAX1(DNN, A3*ALOG10(EPS(J)))+1.F-2I
  DF(J) = 1.E1
  6  D(J) = 0.E0
  NN = N+DNN+5
  NNN = NUMIT/NN+1
  K0NV = 1
  ST = 1.E70
  N1 = 4+1
7  JJJ=0
     L = 0
  8  DJ 10  J=1,N1
10  AI(J,1) = 1.E0
  K0MPUT = 0
  K = 0
  PMIN = 1.E70
  DJ 15 J=1,N
  DS(J) = D(J)
     DJ(J) = X(J)
     S(J) = FUNC(X(J),XMAX(J),XMIN(J),KPT*(NN-N))
     P(J) = AMIN1(*EO*ABS(X(J)))+1.E-4, S(J)/(10*KPT))*
     1  SIGN1(E0, D(J)-DS(J))
       IF(ABS(P(J)) .GT. PMIN) GO TO 15
       PMIN = ABS(P(J))
15  CONTINUF
       DTMNIN = 1.F-9*AMIVII(1.E0,PMIN**N)
C . CONVERGENCE TEST
  25 DJ 35 J=1,N
     IF(ABS(F(J)) .GT. EPS(J)) GO TO 40
  35 CONTINUF
C . CONVERGENCE
  K0NV=2
  GJ TJ 440
C . COMPUTE CONVERGENCE FUNCTION
  40 T=0.E0
     DJ 42 J=1,N
  42 T=T+ABS(F(J))
C . SAVE BEST VALUE
     IF(T .GE. ST) GO TO 46
     IF(L .GT. 0) L=L-1
     IF(L<CAL .EQ. CI) L=0
     ST = T

***CONTINUING

104
DJ 44 J=1,N
XS(J) = X(J)
FS(J) = F(J)
IF(LOCAL .EQ. 1) GO TO 44
SJ(J) = FUNC(X(J),XMAX(J),XMIN(J),NN-JJJ)
44 CONTINUE
C * TEST FOR DISCONTINUITY
46 IF(KUT .EQ. 4) GO TO 49
DJ 48 J=1,N
IF(X(J) .EQ. XS(J)) GO TO 48
DFJ = 0.00
DJ 47 I = 1, N
47 DFJ = AMAX1(DFJ, ARS((F(I) - FS(I))/(X(J) - XS(J))))
IF(JMPUT .EQ. 0) F(J) = AMAX1(DFJ, DF(J))
IF(DFJ .LE. 1.02*DF(J)) GO TO 48
LOCAL = 1
KUT = 4
G0 T J 49
C * JJJ COUNTS THE NUMBER OF ITERATIONS
49 JJJ = JJJ+1
IF (JJJ-NN) 50, 94, 94
C * REPLACE WORST POINT
50 IF(JMPUT .EQ. 0) GO TO 100
DJ 65 J=1,N
65 IF(TS(J-TT) 65, 65, 60
60 TT = TS(J)
MAXROW= J
65 CONTINUE
A(MAXROW,1) = 1.00
DJ 85 J=1,N
A(MAXROW,J+1) = F(J)/EPS(J)
85 B(MAXROW,J) = X(J)
TS(MAXROW)= T
G0 T J 135
C * STORE BEST VALUE
94 DJ 95 JT=1,N
F(JT) = FS(JT)
95 X(JT) = XS(JT)
KPT = KPT+1
IF(KP .GT. NNN/2) LOCAL=1
IF(KP .GT. NNN) GO TO 98
G0 T J .7
C * NONCONVERGENCE
98 K3NV = 3
G0 T J 440
C * BUILD MATRIX OF POINTS
100 K=K+1
DJ 115 J=1,N
A(K,J+1) = F(J)/FPS(J)
115 B(K,J) = X(J)
120 IF (<-N) 120, 120, 130
120 X(K) = X(K)*P(K)
125 X(K-1) = D(K-1)
***CONTINUING
G3 T3 440

C. SOLVE LINEAR SYSTEM

130 X(I-1) = D(K-1)

KJMPUT = 1

135 DJ 140 I = 1,N1

G(I,J1) = A(I,J1)

Q(I,J1) = 1.E0

DJ 140 J = 1,N

Q(I,J) = B(I,J)

140 G(I,J) = A(I,J)

DJ 210 I1 = I,N1

DJ 200 J1 = J,N1

R(I1,J1) = 0.EC

200 E(I1,J1) = 0.EC

DJ 210 K1 = K1,N

210 G(I1,K1) = 0.EC

DJ 230 J2 = 2,N1

DJ 230 I2 = I,N1

RIJ2,J2-1) = R(J2,J2-1) + Q(12,J2) * R(J2,J2-1)

230 EIJ2,J2-1) = E(J2,J2-1) + S(12,J2) * E(J2,J2-1)

DJ 340 K3 = 1,N1

DJ 300 J3 = K3,N1

DJ 250 I3 = I,N1

RIK3,J3) = R(K3,J3) + Q(I3,K3) * Q(I3,J3)

250 EIK3,J3) = E(K3,J3) + G(I3,K3) * G(I3,J3)

IF(K3 - J3) 260, 260, 260

260 IF(K3 = 1) 300, 300, 300

270 IF(I.E-16*E(K3,K3-1)-1.E14*E(K3,K3)) 275, 340, 340

275 IF(1.E-14*R(K3,K3-1)-1.E14*R(K3,K3)) 300, 340, 340

280 IF(E(K3,K3) .LT. 1.E-60) GO TO 340

IF(R(K3,K3) .LT. 1.E-60) GO TO 340

E(K3,J3) = E(K3,J3) / E(K3,K3)

R(K3,J3) = R(K3,J3) / R(K3,K3)

DJ 240 I4 = 1,N1

Q(I4,J3) = Q(I4,J3) - Q(I4,K3) * R(K3,J3)

290 G(I4,J3) = G(I4,J3) - G(I4,K3) * E(K3,J3)

300 C@NTINUE.

DJ 340 J5 = 1,N

DJ 310 I5 = 1,N1

310 G(I5,J5) = C(I5,J5) + G(I5,K5) * B(I5,J5) / E(K5,K5)

340 C@NTINUE

DJ 350 I7 = 2,N1

IT = N1+1-I7

JT = IT + 1

DJ 350 J7 = 1,N

DJ 350 K7 = JT,N1

350 C(IT,J7) = C(IT,J7) - E(IT,K7) * C(K7,J7)

C. DETERMINE IF MATRIX IS SINGULAR

DET = 1.E0

DET1 = 1.E0

DJ 360 JMT = 1,N1

DET = DET*ABS(E(JMT,JMT))

360 DET1 = DET1*ABS(R(JMT,JMT))

IF(DET1 .GT. DTMIN**2 .AND. DET .GT. 1.E-20) GO TO 380

DJ 370 J = 1,N

X(IJ) = XS(IJ)

370 F(IJ) = FS(IJ)

***CONTINUING
G3 T3 8
C. TEST PREDICTIONS FROM MATRIX SOLUTION TO KEEP WITHIN BOUNDS
380   L = L + 1
   DO 430  J=1,N
   X(J) = C(L,J)
   IF(L'LOCAL .EQ. 0) GO TO 420
   STEP = S(J)/KUT**(L-1)
   IF(ABS(X(J)-XS(J)).GT. STEP) X(J) =XS(J) + SIGN(STEP,X(J)-XS(J))
   G3 T3 430
   420   IF(X(J) .LE. XMIN(J)) X(J) = XS(J) - L*S(J)
   IF(X(J) .GE. XMAX(J)) X(J) = XS(J) + L*S(J)
   430 CONTINUE
440 RETURN
END

***END
SUBROUTINE LSTOATI (NTAPE)
DIMENSION CARD(20)
INTEGER CARD, END1
DATA EN1/*END*/
DATA NEWP/*NEWP*/
J=NTAPE
REWIND J
5 LINE =0
WRITE (6,101)
101 FORMAT (11H1INPUT DATA/14H CARD COLUMNS ,
1 40H123456789C123456789012345678901234567890 ,
2 40H123456789C123456789012345678901234567890/14H)
READ (5,106) CARD
IF (CARD(1).EQ.END1) GO TO 20
IF (CARD(1).EQ.NEWP ) GO TO 5
WRITE (J,106) CARD
WRITE (6,103) CARD
LINE=LINE+1
IF (LINE=55) 1C,5,5
102 FORMAT (1H1)
106 FORMAT (20A4)
103 FORMAT (14X,2CA4)
20 WRITE(J,106)CARD
WRITE(6,103)CARD
WRITE (6,104)
REWIND J
104 FORMAT (9HOEND DATA)
RETURN
END

***END
SUBROUTINE NOZPLG (AT,AEAT,XE,THET,APB,GAMMA,PTNPP,CDN,CT,FLAG)

DATA KICDL3(/5,,1,,0,,22,,3,,/NOZPL000
DATA KIDCS3(/5,,1,,0,,22,,4,,/NOZPL005
DATA KICVL3(/5,,1,,0,,22,,3,,/NOZPL027
DATA KICVS3(/5,,1,,0,,22,,4,,/NOZPL028

A
 B
 C
 D
 E
 F
 G
 H
 I

A
 B
 C
 D
 E
 F
 G
 H
 I

A
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 I

NOZERR= 0
FLAG= 4.0
CTID = 1.

***BEGIN***
GAMMA = (GAMMA+1.0)/(GAMMA-1.0)
GAMMA = 1.0/GAMMA
GAMMA = GAMMA-1.0
GAMMA = GAMMA+1.0
PRCRIIT = (GAMMA/2.0)**(GAMMA/GAMMA)
IF(PNPP .GT. PRCRTIT) GO TO 10
NOZERR = 1
WRITE(6,9915)
10 THETAP = THEAAD*0.0174533
RCOS1 = COS(THETAP)
RCOS2 = COS(THETAP)**2
RE = SQRT(APB/2.141592)
R1 = RE + TAN(THETAP)*XE
AE = AEAT*RAT
RSR1 = RCOS1*(1.0-2*RSR2)+SQRT(R1**2+RSR2+AE/2.141592
1.0 = RCOS1*(2.0-RCOS2))/(RCOS1*(2.0-RCOS2))
RT = RS*RSR2*(RS-R1)
XT = (R1-RT)/SIN(THETAP)
S = (RS-R1)/RCOS1
CS = RCOS1
IF(2*MODEL .GE. 2.0)CS = CS-.007
THETAR = THETAP
AMF = 1.0001
AEASK = 1.0
IF(AEAT .GE. 1.0) GO TO 50
ABE = 0.9
AME = 1.0
ICOUNT = 0
AEAP = AEAT/CON
20 ICOUNT = ICOUNT+1
IF(ICOUNT .LE. 200) GO TO 30
WRITE(6,9900)
NOZERR = 1
RETURN
30 AEASK = 1.0/AME*((2.0/GAMMA*(1.0+GAMMA/2.0*AME**2)**(GAMMA/2.0*AME)**2))
IF(ABS(AEAP-AEASK) .LT. 0.001) GO TO 50
IF(AEAP-AEASK) .LT. 1.0 GO TO 35
IF(AME .LT. 1.0) GO TO 95
GJ = 20
40 ASSE = AEASK
ABE = AME
AME = AME+0.1
GJ = 20
50 PEPTN = (1.0+GAMMA/2.0*AME**2)**(-GAMMA/GAMMA)
FSAAS = PEPTN*AEASK*(1.0+GAMMA*AME)**2
PTPINV = 1.0/PTNPP
XQ4 = PEPTN*AEASK*GAMMA*AME**2*PTPINV*AT*CON
XEXIT = AME
FIPTA = GAMMA*SQRT(2.0/GAMMA*(2.0/GAMMA)**GAMMA/2.0-PTPINV**2)
1 (GAMMA/GAMMA))
TID = FIPTA
CTE = (CS*FSAAS-PTPINV*AEASK)/FIPTA
IF(AEASK .LE. 1.0) CTE = CTE + PTPINV*(1.0/CON-1.0)/FIPTA
IF(40 .LT. 1.0) GO TO 95
A = R1
B = -TAN(THETAP)
VE=SQRT(GAMBO)*ATAN(SQRT(1.0/GAMBO)*(AME**2-1.0)) - ATAN(SQRT(1.0))
AME**2-1.0)
AMEXP= SQRT(2.0/GAM1*(PTNPP**(GAM1/GAMMA)-1.0))
AMEXP= SQRT(GAMBO)*ATAN(SQRT(GAMBA*(AMEXP**2-1.0)))-ATAN(SQRT(1.0))
AMEXP**2-1.0)
AMEXP= ATAN(1.0/SQRT(AMEXP**2-1.0))
THEXP= THETAR-AMEXP-VE-AUE XP
THMAX= ATAN((RE-RS)/XE)
IF(THEXP LE THMAX) GO TO 60
THEXP= THMAX
RMAX= SQRT(GAMBO*SQRT(1.0/GAMBO)*(THEXP-THETAR+VE+1.570796)**2)
R + 1.0)
AMEXP= SQRT(GAMBO)*ATAN(SQRT(1.0/GAMBO)*(RMAX**2-1.0))-
AMEXP= SQRT(RMAX**2-1.0))
60 BB= TAN(THEXP)
AA= Rs
XI=-(A-AA)/(B-BB)
RI= A+B*Xl
PLTN= PEPTN
RS= RT
NUM=AMEXP-VE)/.01 74533
IF(NUM LT 5) NUM=5
RUM= NUM
CTD= 0.0
PSPTN= 0.0
DJ 80 J=1, NUM
Q= J
VL= VE+ Q/RUM *(AMEXP-VE)
CALL ITERAT(GAMBO,VL,AML,NOZERR)
IF(VDZERR.EQ.R1GO TO 65
WRITE(6,9905)
G3 T 90
65 AUL= ATAN(1.0/SQRT(AML**2-1.0))
THETL= THETAR+VL-VE-AUL
BB= TAN(THETL)
AA= RS
XL=-(A-AA)/(B-BB)
RL= A+B*XL
VC= 2.0*VL
CALL ITERAT(GAMBO,VC,XMC,NOZERR)
IF(VDZERR.EQ.R1GO TO 70
WRITE(6,9905)
G3 T 90
70 PCPTN= (1.0+GAM1/2.0*XMC**2) **(-GAMMA/GAM1)
CTD= CTD+1.0/FIPTA+(0.5*(PIPTN+PCPTN)-PTPINVI)*R1**2-RL**2)
1 *3.141592/(CONAT)
RS= RL
PIPTN= PCPTN
IF(XL.EQ. XE) PSPTN= PCPTN
80 CONTINUE
PBPTN= 4.312/PTNPP**1.975
PBPTN= 0.517*PTNPP+.0046
PB2PTN=PTPINV
IF(PBPTN GT PB2PTN) PBPTN= PB2PTN
IF(PB2PTN GT PBPTN) PBPTN= PB1PTN
CTD= (PBPTN-PTPINV)**APB/(CONAT*FIPTA)
IF(PBTN GT PTPINV) CTD= (FSA-A/PPINV*AEASK)/FIPTA+CTD+CTBD
NOZPL 111
NOZPL 112
NOZPL 113
NOZPL 114
NOZPL 115
NOZPL 116
NOZPL 117
NOZPL 118
NOZPL 119
NOZPL 120
NOZPL 121
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NOZPL 162
NOZPL 163
NOZPL 164
NOZPL 165
NOZPL 166
NOZPL 167

***CONTINUING
CT = CTE + CTD + CTBD

RETURN

CALL XTRP(1. - CT1D, DEDL, MO, K1CVL3)
CALL XTRP(1. - CT1D, DELS, MO, K1CVS3)
CALL XTRP(1. - CT1D, DCLL, MO, K1DCL3)
CALL XTRP(1. - CT1D, DELCS, MO, K1DCS3)

DELD = DELDS + (AT - ATMIN) * (DFDL - DELUS) / (ATMAX - ATMIN)
DELC = DELCS + (AT - ATMIN) * (DFCL - DELCS) / (ATMAX - ATMIN)

CT = DELD + DELC + CT1D
G3 TD 90

9900 FORMAT(* NOZZLE EXIT MACH NUMBER ITERATION FAILED*)
9905 FORMAT(* NOZPLG--MACH ITERATION FAILED AT LOCAL EXPANSION ANGLE*)
9915 FORMAT(* NOZPLG--PLUG NOZZLE MUST BE CHOKED*)

***END
| A  | 1.3, 0.997, 1.25, 0.996, 1.3, 0.995, 1.3, 0.995 | B  | 1.2, 0.997, 1.25, 0.996, 1.3, 0.995, 1.3, 0.995 |
|    |                                               | C  | 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0          |
| D  | 1.4, 2.0, 1.025, 0.997, 1.1, 0.997, 1.1, 0.997 |
| E  | 1.2, 0.997, 1.25, 0.996, 1.3, 0.995, 1.3, 0.995 |
| F  | 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0          |
| G  | 2.0, 4.0, 1.025, 0.997, 1.1, 0.997, 1.1, 0.997 |
| H  | 1.3, 0.997, 1.33, 0.997, 1.33, 0.997, 1.33, 0.997 |
| I  | 1.5, 0.996, 1.6, 0.9952, 1.63, 0.995, 0.0, 0.0 |
| J  | 2.2, 6.0, 1.025, 0.997, 1.1, 0.997, 1.1, 0.997 |
| K  | 1.4, 0.997, 1.5, 0.997, 1.56, 0.997, 1.56, 0.997 |
| L  | 1.6, 0.996, 1.7, 0.9945, 1.8, 0.993, 2.0, 0.9928 |
| M  | 2.2, 8.0, 1.025, 0.997, 1.06, 0.997, 1.06, 0.997 |
| N  | 1.1, 0.9955, 1.2, 0.9945, 1.3, 0.995, 1.4, 0.9955 |
| O  | 1.5, 0.996, 1.6, 0.9965, 1.8, 0.996, 2.0, 0.996 |
| P  | 2.2, 10.0, 1.025, 0.997, 1.045, 0.997, 1.045, 0.997 |
| Q  | 1.5, 0.993, 1.2, 0.991, 1.3, 0.991, 1.4, 0.9915 |
| R  | 1.5, 0.992, 1.6, 0.9925, 1.8, 0.9935, 2.0, 0.994 |
| S  | 2.2, 12.0, 1.025, 0.997, 1.032, 0.997, 1.032, 0.997 |

### Fig. 11B

| A  | 1.1, 0.9915, 1.2, 0.9875, 1.3, 0.986, 1.4, 0.9862 | B  | 1.5, 0.9865, 1.6, 0.9875, 1.8, 0.989, 2.0, 0.990 |
| C  | 2.2, 14.0, 1.025, 0.997, 1.032, 0.997, 1.032, 0.997 |
| D  | 1.1, 0.990, 1.2, 0.9835, 1.3, 0.9815, 1.4, 0.981 |
| E  | 1.5, 0.981, 1.6, 0.9815, 1.8, 0.982, 2.0, 0.9835 |
| F  | 2.2, 16.0, 1.025, 0.997, 1.025, 0.997, 1.1, 0.988 |
| G  | 1.2, 0.9815, 1.3, 0.978, 1.4, 0.976, 1.5, 0.975 |
| H  | 1.6, 0.9753, 1.7, 0.9756, 1.8, 0.976, 2.0, 0.977 |
| I  | 2.2, 18.0, 1.025, 0.997, 1.1, 0.986, 1.2, 0.978 |
| J  | 1.3, 0.973, 1.4, 0.971, 1.5, 0.969, 1.6, 0.968 |
| K  | 1.7, 0.968, 1.8, 0.968, 1.9, 0.9685, 2.0, 0.969 |
| L  | 2.2, 20.0, 1.025, 0.997, 1.1, 0.9845, 1.2, 0.976 |
| M  | 1.3, 0.970, 1.4, 0.966, 1.5, 0.963, 1.6, 0.962 |
| N  | 1.7, 0.9618, 1.8, 0.9615, 1.9, 0.9612, 2.0, 0.9612 |

### Fig. 11C

| A  | 2.2, 0.0, 1.0, 0.0, 1.05, 0.01, 1.1, 0.02 | B  | 1.2, 0.004, 1.3, 0.008, 1.4, 0.011, 1.6, 0.019 |
| C  | 1.8, 0.026, 2.2, 0.04, 3.0, 0.062, 3.8, 0.076 |
| D  | 2.2, 3.0, 1.0, 0.0, 1.05, 0.001, 1.1, 0.002 | E  | 1.2, 0.004, 1.3, 0.008, 1.4, 0.011, 1.6, 0.019 |
| F  | 1.8, 0.026, 2.2, 0.04, 3.0, 0.062, 3.8, 0.076 |
| G  | 2.2, 5.0, 1.0, 0.0, 1.05, 0.02, 1.1, 0.04 | H  | 1.2, 0.007, 1.3, 0.011, 1.4, 0.015, 1.6, 0.026 |
| I  | 1.8, 0.037, 2.2, 0.057, 3.0, 0.09, 3.8, 0.11 |
| J  | 2.2, 7.5, 1.0, 0.0, 1.05, 0.025, 1.1, 0.005 |
| K  | 1.2, 0.01, 1.3, 0.016, 1.4, 0.024, 1.6, 0.041 |
| L  | 1.8, 0.057, 2.2, 0.086, 3.0, 0.136, 3.8, 0.164 |

***CONTINUING***
DATA FIGB1B / Nuzzle 054
A 1.2, .028, 1.3, .048, 1.4, .07, 1.6, .124, NOZZL061
B 1.8, .18, 2.2, .268, 3.0, .375, 3.25, .40, NOZZL062
C 22., 90., 1.0, 0., 1.05, .106, 1.1, .012, NOZZL063
D 1.2, .034, 1.3, .057, 1.4, .082, 1.5, .11, NOZZL064
E 1.6, .14, 1.8, .195, 2.2, .302, 2.77, .40 / NOZZL065

RAD = .0174533
G12GM1 = (GAMMA+1) / (2.*(GAMMA-1))
PI = 3.1415927
GAMAV = 32.174
R = 1716.5
FLG220 = 0.
NOZERR = 0
LDO0 = 0
CTID = 1.0
QMT = 1.
ATFLAT = CDN
PTPFS = PTPFS
PFSPSS = 1./PTPFS
FLAGAT=0.
IF(PTPFS .LT. ((GAMMA+1) / 2.)**(GAMMA/(GAMMA-1))) FLAGAT=1.
FLAGMT=0.
QMT=1.
FPTATS = GAMMA*SQRT((2./(GAMMA-1.))**(2./(GAMMA+1.))**(2.*G12GM1)
1.*(1.-PFSPSS**((GAMMA-1.)/GAMMA))))

AE = AEAT*AT
IF(VT .EQ. 1) GO TO 75
RT = SQRT(AT/PI)
RE = SQRT(AEAT/PI)
THET = ATAN(RE-RT)/SQRT(FL-(RE-RT)**2)

G0 TO 80

42 FSAATS = PERT*TPEAT**((1.*GAMMA*QME**2)
CALL XTRP(AEAT, CS, THETA, FIG11)
IF(Equality) GO TO 95
X4EXIT = QME
X4MN = PEPT*AEAT*GAMMA*QME**2*PTPFS*ATFLOW
IF (*P*PEPT *G, PFSPS) CTID = (FSAATS-PFSPSS*AEAT)/FPTATS
TID = FPTATS
CT = (CS*FSAATS-PFSPSS*AEAT)/FPTATS
FLAG=4.
G0 TO 500

75 IF(FLAGAT .EQ. 1) GO TO 162
C00 CONVENGENT NOZZLE -- CHOKED
CS = .997
IF(Equality) GO TO 107
ATFATS = 1.
AEAT = 1./ATFLAT
PEPT = ((GAMMA+1.) / 2.)**(-GAMMA/(GAMMA-1.))
PF4AX = ((GAMMA+1.) / 2.)**((GAMMA/(GAMMA-1.)))

***CONTINUING"
PEPFS = PEPTT*PTTPFS
FSAA5 = ATFATS*PEPTT*(1. + GAMMA)
PVARB = PEPTT
FLAG = 4.
IF (PTTPFS .GE. A1) GO TO 77
FLAG = 5.
PVARB = PFSPFT + (PEPTT - PFSPFT) * (PTTPFS - PMAX) / (A - PMAX)

77 XDN = GAMMA*PTPFS*PVARB*AE
TID = FPFTATS
XEXIT = 1.
CT = (CS*(FSAA5*PVARB*(AEATS-ATFATS) - PFSPFT*AEATS))/FPFTATS
IF (PTTPFS .GT. PVARB) CTID = (FSAA5 + PVARB*(AEATS-ATFATS) - PFSPTT)
1 * AEATS)/FPFTATS
GJ = 500
80 CALL XTRP(AEAT, DPTQT, THETA, FIG81)
QMT = 1.
90 IF (LOOP .GT. 5) GO TO 480
LOOP = LOOP + 1
PTITQT = 2.*(1.*.5*(GAMMA-1.1)*QMT**2)*(GAMMA/(GAMMA-1.1)) / (GAMMA*QMT**2)
PTEQT = PTITQT - DPTQT
PTFPTT = PTEQT/PTITQT
QMCALC = GRAV*SORT(GAMMA/RRR)*QMT*(1.15*(GAMMA-1.1)*QMT**2)*(-G12GNN)
G1M1)
QMFEXIT = SORT(2.*(PFSPFT**((1.-GAMMA1)/GAMMA-1.1)) / (GAMMA-1.1))
IF (FLAGAT.EQ.0.) QMFEXIT = 1.
QNID = GRAV*SORT(GAMMA/RRR)*QMFEXIT*(1.15*(GAMMA-1.1)*QMFEXIT**2)*(-G12GNN)
1-G12GNN)
CDN = QMCALC/QNID*ATFLAT
ATSAT =
1. ATFLAT*QMT*(12.*(GAMMA-1.1)*QMT**2) / (GAMMA*QMT**2) + (-G12GNN)
AEASA = ATSAT/PTEPTT
AEAES = AEAES/AEAT
AEAES = 1. / AEAES
If (AEAES .LT. 1.) GO TO 485
110 QMEE = .5
KT = 0
120 FUNC2 = AEAES - (12.*(GAMMA-1.1)*QMEE**2) / (GAMMA*QMT**2) + (-G12GNN)
SVQME = QMEE
CALL [TRATE(QMEE, FUNC2, 0., KT)]
IF (ABS(FUNC2) .LE. 1.E-4) GO TO 140
IF (KT .LE. 25) GO TO 145
IF (KT .EQ. 1) QMEE = .51
IF (SVQME - QMEE .GT. .0) QMEE = AMAX1(QMEE, .8*SVQME)
IF (SVQME - QMEE .LT. .0) QMEE = AMIN1(QMEE, .5*SVQME+1.1)
GJ = 120
140 PEPTE = (1.15*(GAMMA-1.1)*QMEE**2) / (GAMMA-1.1))
PEPTT = PEPTE * PTEPTT
PTFPTT = 1./PEPTE
IF (ABS(PFSPFT - PTPE) .LE. 5.E-3) GO TO 161
IF (PTTPFS .GE. PEPTT) GO TO 150
IF (FLAGMT.NE.1.) GO TO 145
DMT = DMT/2.
FLAGMT = 0.
145 QMT = QMT - DMT
GJ = 90
150 IF (QMT .GE. 1.) GO TO 163

***CONTINUING
IF(FLAGMT.NE.0.) GO TO 155
DMT=DMT/2.
FLAGMT=1.

155 QMT = QMT+DMT
GO T0 90

161 CS = .995
IF(QMODEL .EQ. 2.) CS = CS-.007
AEATS = AEAT/ATSAT
QMXS=SQR T(2./((GAMMA-1.)*(1./PEPTT)++){(GAMMA-1.)/(GAMMA-1.)})
FSAA =PEP TT*AEATS *{(1.+GAMMA*QMX**2)}
QMXQ = PEPTT*AEATS*GAMMA*QMX**2*PTPFS*ATFLOW
TID = FPTATS
XMXIT = QMX
CT = (CS*FSAA - PEPTT*AEATS)/FPTATS
FLAG=1.
GO T0 500

162 CS = .997
IF(QMODEL .EQ. 2.) CS = CS-.007
QMT = SQR T(2.*PEPFS**2(1.-GAMMA)/GAMMA ) -1. )/ (GAMMA-1.)
ATFATS = ((1. + (GAMMA-1.)*QMT**2) )/ (GAMMA+1.)**G12GM1/QMT
PEPFS = 1.
FSAA = ATFATS*PFSPTT* (1.+GAMMA*QMT**2)
AEATS = ATFATS/ATFLAT
TID = FPTATS
PTPE = (1.+(GAMMA+1.)/2.)**(GAMMA/(GAMMA-1.))
XMQ4 = GAMMA*PTPFS/PTPE*AE*QMT**2
XMXIT = QMT
CT = (CS*(FSAA +PFSPTT*AEATS-ATFATS)) - PFSPTT*AEATS)/FPTATS
FLAG=1.
GO T0 500

163 AFATS=AEAT/ATSAT
QME = 1.
KT = 0.

165 FUNC1 = AFATS -((2.* (GAMMA-1.)*QME**2)/(GAMMA+1.))**G12GM1/QME
SVQME = QME
CALL ITRATE(QME, FUNC1, 0., KT)
IF (ABS(FUNC1 ) .LE. 1.E-4) GO T0 170
IF ( (KT .GT. 25) ) GO T0 475
IF ( (CT .EQ. 1. ) QME = 1.01
IF ( (SVQME - QME .GT. 0.1)*QME = AMAX1(QME , 0.5*(1.+SVQME))
IF ( (SVQME - QME .LT. 0.1)*QME = AMIN1(QME , 1.2*SVQME))
GO T0 165

170 PEPTT = (1. + .5* JME**2 *(GAMMA-1.))*(GAMMA/(GAMMA-1.))
WSW = 0.
PREPFS = .03 +.04*ALOG(WSW+1.)
PEPTT = PREPFS/PTPFS
IF(FLG220 .EQ. 1.) PREPTT=PECUPT*PREPFS
IF(PEPTT .LE. PEPTTGO TO 42
QMX = SQR T(2./(GAMMA-1.)*((1.*PRTT )||(1.-GAMMA)/GAMMA-1.))
QMX = QMX
AEATS = ((1.+(QMX**2*(GAMMA-1.))/(GAMMA+1.))**(G12GM1)/QMX

200 CALL XTRP(IAEAT,CS, THETA, FIG11)
IF(QMODEL .EQ. 2.) CS = CS-.007
PECUSP = .1*(IC**(.0332*THETA-3.7)) * (10.* (AEAT-1.))**(1.17)
PIPTT = PREPTT
PEPTT = PEPTT
P2PTT = PEPTT/PREPFS

***CONTINUING
PECUPT = PEPTT/PECUSP
IF (PECUPT .GT. PEPTT) GO TO 219
IF (PECUPT .GT. P2PTT) GO TO 218
PEPTT = PEPTT
AREATS = AREATS
QMI = QME
PECUPT = P2PTT
GJ T0 220

218 IF (PTTPFS .LE. 1./PECUPT) GO TO 220
219 FSAS = PIPTT* (1.+GAMMA*QMI**2)*AREATS
QI = PSPTT*(6.*PTTPFS*PFBPTT) *(AFATS-AREATS)/7.
XQM1 = PIPPTT*AREATS*GAMMA*QMI**2*PTTPFS*ATFLOW
TID = FPATTS
XEXIT = QMI
CT = (CS*FSAS - AEATS /PTTPFS + QI)/FPATTS
FLAG3 = 3.
GJ T0 500

220 PTPE = (1. + .5*(GAMMA-1.))*((GAMMA/(GAMMA-1.))
PTPEE = PTPETT - OPTETT
PTPE = PTPEE/PTPETT
QMEE = SQRT((2.5*PTTPET **((GAMMA-1.)/GAMMA)-1.)/(GAMMA-1.))
QME = SQRT((2.*PTPEE) **((GAMMA-1.)/GAMMA)-1.)/(GAMMA-1.))
AFATS = (2.*((GAMMA-1.)*QME)**2)/(GAMMA+1.1)**2*G12GMI/QMEE
FSAS = AEATS*(1.+GAMMA*QME**2)*PTTPET
FPATTS = GAMMA*SQRT((2./((GAMA-1.))*2./((GAMA+1.1))**2*(G12GMI)
XQM1 = PEPTT*AEATS*GAMMA*QME**2*PTTPFS*ATFLOW
FPATTS = FPATTS
CS = .995
IF (MODEL .EQ. 2.) CS = -.007
CSJUBP = (CS *FSAS -PTPETT*AEATS)/FPATTS
IF (FLG2 = 1) GO TO 225
FLG2 = 1.
GJ T0 175

225 QI = PECUPT*(((6.*PEPTT/PECUPT)/7.1)*(AREATS-AREATS)
FSAS2 = PREPTT*AREATS*(1.+GAMMA*QMI)**2
FPATTS = GAMMA*SQRT((2./((GAMA-1.))*2./((GAMA+1.1))**2*(G12GMI)
1 *((1.-PEPTT**((GAMMA-1.)/GAMMA)))
CALL XTRP(AREATS,CS, THETA, FIG11)
IF (MODEL .EQ. 2.) CS = -.007
XQM2 = PREPTT*AREATS*GAMMA*QMI**2*PTTPFS*ATFLOW
CTCUS = (CS*FSAS2-AEATS*PECUPT + QI)/FPATTS
XQM4 = XQM2*XNUM1*(PTTPS-PTEPE)/(1./PECUPT-PTEPE) + XNUM1
TID = (FPATTS - FPATTS) *( (PTTPS-PTEPE)/(1./PECUPT-PTEPE)+FPATTS
XEXIT = (QMI-QMEX)*((PTTPFS-PTEPE)/(1./PECUPT-PTEPE)+QMI
CT = (CTCUSP-CTSUBP)*(PTTPFS-PTEPE)/(1./PECUPT-PTEPE) + CTSUBP
FLAG = 2.
GJ T0 500

475 WRITE(6,630)
476 GJ T0 500
480 WRITE(6,620)
485 WRITE(6,610)
490 NOZERR = 1
WRITE(6,600)

***CONTINING
500 RETURN
600 FORMAT(1H1, '---ERROR IN NOZZLE---')
610 FORMAT(1H, 'COMPUTED NOZZLE DIVERGENCE AREA LESS THAN 1.')
620 FORMAT(1H, 'NOZZLE THROAT AREA ITERATION FAILED')
630 FORMAT(1H, 'NOZZLE EXIT MACH NUMBER ITERATION FAILED')

***END
BEGIN

SUBROUTINE XTRP(X,Y,Z,CV)
C     CURVE INTERPOLATION AND EXTRAPOLATION
C     SAME EXCEPT TRAP ADDED TO CALL EXIT WHEN A CURVE IS MISSING
C     QUADRATIC FIT ON BIVARIANT INTERPOLATION
C     MINIMUM STORAGE VERSION, X MUST INCREASE
DIMENSION CV(1C)
AX=X
AZ=Z
CV(1)=0.0
ICV=CV(1)+0.1
IF( ICV.EQ.5 ) ICV=4
IF( ICV.GT.0 .AND. ICV.LT.5 ) GO TO 901
WRITE(6,900) ICV
900 FORMAT(4SH CURVE MISSING OR WRONG IN A CALL TO XTRP, ID ,14)
RELLIM=-5.0
HTLIHP=SQRT(RELLIM)
FFOEG=CV(1000000)
CALL EXIT
901 CONTINUE
G3 T3 (1000,2000,3000,4000),ICV
C     UNIVARIATE LINEAR
1000 N= CV(4)+ 4.0
IF (AX-CV(5)) 1080,1050,1017
1017 D) 1025 I=7,N,2
IF (AX-CV(1)) 1040,1040,1025
1025 CONTINUE
G3 T3 1060
C     COMPUTE
1040 LRET= 3
G3 T3 3900
1050 A=CV(6)
1045 Y=A
G3 T3 9999
C     EXTRAPOLATION
1060 CV(3)=1.0
I=N-1
IF (CV(2)) 1040,9999,1040
1080 CV(3)=1.0
I=7
IF (CV(2)) 1040,9999,1040
C     UNIVARIATE QUADRATIC
2000 N=CV(4)+4.0
IF (CV(5)-AX) 2010,1050,2200
2010 D) 2015 I= 9,N,2
IF (CV(1)-AX) 2015,2020,2020
2020 CONTINUE
G3 T3 2225
2020 IF (CV(I-2)-CV(I-4)) 2025,2250,2250
2025 LRET=4
G3 T3 5000
C     EXTRAPOLATION
2200 CV(3)=1.0
I=9
IF (CV(2)) 2025,9999,2025
***CONTINUING
2225 CV(3)=1.0
*I=N-1
IF (CV(2)) 2025,9999,2025
2250 I=I+2
GJ TJ 2025
C BIVARIATE LINEAR
3000 K000FX=CV(4)
3035 IF (CV(7)-AZ) 3040,3040,3200
3040 NZ=CV(5)-1.0
D3 3045 J=1,NZ
LCZ=7+J*K000FX
IF (CV(LCZ)-AZ) 3045,3050,3050
3045 CONTINUE
GJ TJ 3400
3050 NX=CV(LCZ-1)
KXI=LCZ+1
JX=KXI+N-1
3100 IF (CV(KXI)-AX) 3105,3105,3352
3105 D3 3110 I=KXI,JX,?2
IF (CV(I)-AX) 3110,3115,3115
3110 CONTINUE
L3ET=1
GJ TJ 3375
3115 L3ET=2
GJ TJ 3900
3120 Y2=A
IF (AZ.NE.CV(LCZ)) GO TO 8801
Y = Y2
GJ TJ 9999
8801 LCZ=LCZ-K000FX
KXI=LCZ+1
IF (CV(KXI)-AX) 3125,3125,3353
3125 NX=CV(LCZ-1)
JX=KXI+N-1
3130 D3 3130 I=KXI,JX,?2
IF (CV(I)-AX) 3130,3135,3135
3130 CONTINUE
L3ET=2
GJ TJ 3375
3135 L3ET=1
GJ TJ 3900
3085 Y1=A
IF (AZ.NE.CV(LCZ)) GO TO 3950
Y = Y1
GJ TJ 9999
C EXTRAPOLATION
3200 CV(3)=1.0
LCZ=7*K000FX
IF (CV(21)) 9999,9999,3050
3352 L3ET=1
GJ TJ 3355
3353 L3ET=2
3355 CV(3)=1.0
IF (CV(21)) 3355,3360,3360
3360 I=KXI+2
GJ TJ (3115,3135),L3ET
3375 CV(3)=1.0
***CONTINUING
IF (CV(2)) 3380, 9999, 3380
3380  1=JX-1
GJ TJ (3115, 3135), LRET
3400 CV(3)=1.0
LZ=7*NZ*K000FX
IF (CV(2)) 9999, 9999, 3050
C CHECKS
3900 A = (AX-CV(1-2))*(CV(1+1)-CV(1-1))/(CV(1)+CV(1-1)+CV(1-1))
GJ TJ (305, 3125, 3045), LRET
3950 LZ= CV(3)*1.0
LZ=7*NZ*K000FX
3950 (CV(LZ1)+CV(LZ1)*Y2/Y1)/(CV(LZ1)-CV(LZ))+(Y1
GJ TJ 9999
C BIVARIATE QUADRATIC
4000 K000FX=CV(1)
4015 IF (CV(7)-AZ) 4020, 4020, 4100
4020 NZ=CV(5)-1.0
DJ 4025 J=2,NZ
LZ=7*NZ*K000FX
4025 CONTINUE
GJ TJ 4200
4030 LZ1=M = LZ - 1*K000FX
LZ2=M = LZ - 2*K000FX
IF (CV(LZ1)+CV(LZ2)) 4040, 4035, 4040
4035 LZ = LZ + K000FX
4040 NE = CV(LZ)-1)
4040 XX = LCZ+5
4040 JX = LCZ+NE-1
4040 Z3 = CV(LZ)
4300 IF (CV(XXX)-AX) 4310, 4310, 4450
4310 DJ 4320 I=K>3, JX, 2
IF (CV(1)-AX) 4325, 4325, 4325
4325 IF (CV(1)-CV(1)-1)) 4330, 4630, 4330
4330 LRET=2
GJ TJ 5000
4340 Y3=A
IF (Z3.NE.AZ) GO TO 8802
Y = Y3
GJ TJ 9999
8802 LZ=LZ-K000FX
4350 IF (CV(KX1)-AX) 4350, 4350, 4460
4350 JX=LZ+NE-1
4360 IF (CV(1)-AX) 4360, 4365, 4365
4360 LRET=2
GJ TJ 5000
4370 LRET=3
GJ TJ 5000

CONTINUING
4375 Y2=A
IF(Z2.NE.AZ) GO TO 8803
Y = Y2
GJ TO 9999
9803 LCZ=LCZ-K000FX
KX1=KX1-K000FX
KX3=KX3-K000FX
NE=CV(LCZ-1)
Z1=CV(LCZ)
IF(CV(KX1)-AX) 4380,4380,4470
4380 JX=LCZ+NE-1
DJ 4385 I=KX3,JX,2
IF(CV(I)-AX) 4385,4390,4390
4385 CONTINUE
LRET=3
GJ TO 4500
4390 IF(CV(I-2I)-CV(I-4)) 4395,4650,4395
4395 LRET=1
GJ TO 5000
4099 Y1=A
IF(Z1.NE.AZ) GO TO 5500
Y = Y1
GJ TO 9999
C EXTRAPOLATION
4100 CV(3)=1.0
LCZ=7*2*K000FX
IF(CV(2)) 9999,9999,4030
4200 CV(3)=1.0
LCZ=7*NZ*K000FX
IF(CV(2)) 9999,9999,4030
4450 LRET=1
GJ TO 4480
4460 LRET=2
GJ TO 4480
4470 LRET=3
GJ TO 4480
4480 CV(3)=1.0
I=KX3
IF(CV(2)) 4490,9999,4490
4490 GJ TO 1
4325,4365,4390,LRET
4500 CV(3)=1.0
I=JX
IF(CV(2)) 4510,9999,4510
4510 GJ TO 1
4325,4365,4390,LRET
4630 I=I+2
GJ TO 4330
4640 I=I+2
GJ TO 4370
4650 I=I+2
GJ TO 4395
C COMPUTE
5000 CONTINUE
A=CV(I-1)+AX-CV(I-4))(((CV(I-1)-CV(I-3))/CV(I-2)-CV(I-4))+AX-CVX
1((I-2)/CV(I)-CV(I-4))*((CV(I+1)-CV(I-1))/CV(I)-CV(I-2)-CV(I-4))
GJ TO 4099,4340,4375,1045,LRET
5500 IF(AZ.LT.Z2) GO TO 5502
IF(AZ.LT.Z2) GO TO 5501

***CONTINUING
122
Z1 = Z2
Z2 = Z3
Y1 = Y2
Y2 = Y3

5501 Y = (AZ-Z1) * (Y2-Y1)/(Z2-Z1) + Y1
RETJRN

5502 Y = Y1 + (AZ-Z1)*((Y2-Y1)/(Z2-Z1)+(AZ-Z2)/(Z3-Z1))*
1 ((Y3-Y2)/(Z3-Z2)-(Y2-Y1)/(Z2-Z1))

9999 RETURN
END

***END

Final Report 1 November 1969 to 31 July 1972


A computer program has been developed for predicting twin-nozzle/aftbody drag and internal nozzle performance for fighter type aircraft having twin buried engines and dual nozzles. The program is capable of generating the installed thrust-minus-drag data required for conducting mission analysis studies of aircraft of this type. The configuration variables which can be analyzed include (1) nozzle type (convergent flap and iris, convergent-divergent with and without secondary flow, and shrouded and unshrouded plug), (2) nozzle lateral spacing, (3) interfairing type (horizontal and vertical wedge), (4) interfairing length, and (5) vertical stabilizer type (single and twin).

The performance prediction methods incorporated in the program are based almost entirely on empirical correlations. Specifically, correlations used in conjunction with one-dimensional flow relationships are employed for the prediction of the nozzle thrust and discharge coefficients, and correlations of the test data obtained during the contracted effort are employed for prediction of the aft-end drag. The prediction methods account for the effects of nozzle pressure ratio and flow separation on both internal and external nozzle surfaces.

This manual describes the operation of the computer program in terms of program input requirements, performance prediction methods, and output format and includes a presentation of sample input/output cases and a complete computer listing of the program. The program has been developed for use on the CDC 6600 computer.
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