A COMPUTER PROGRAM TO CALCULATE THE LONGITUDINAL AERODYNAMIC CHARACTERISTICS OF WING-FLAP CONFIGURATIONS WITH EXTERNALLY BLOWN FLAPS

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This document is a user's manual for the computer program developed to calculate the longitudinal aerodynamic characteristics of wing-flap combinations with externally blown flaps. A vortex-lattice lifting-surface method is used to model the wing and multiple flaps. Each lifting surface may be of arbitrary planform having camber and twist, and the multiple-slotted trailing-edge flap system may consist of up to ten flaps with different spans and deflection angles. The engine wake model consists of a series of closely spaced vortex rings with circular or elliptic cross sections. The rings are normal to a wake centerline which is free to move vertically and laterally to accommodate the local flow field beneath the wing and flaps. The two potential flow models are used in an iterative fashion to calculate the wing-flap loading distribution including the influence of the wakes from up to two turbofan engines on the semispan. The method is limited to the condition where the flow and geometry of the configurations are symmetric about the vertical plane containing the wing root chord.

The calculation procedure starts with arbitrarily positioned wake centerlines and the iterative calculation continues until the total configuration loading converges within a prescribed tolerance. The results available from the program include total configuration forces and moments, individual lifting-surface load distributions, including pressure distributions, individual flap hinge moments, and flow field calculation at arbitrary field points.

This program manual contains a description of the use of the program, instructions for preparation of input, a description of the output, program listings, and sample cases.
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>SUMMARY</td>
<td>1</td>
</tr>
<tr>
<td>INTRODUCTION</td>
<td>2</td>
</tr>
<tr>
<td>DESCRIPTION OF PROGRAM</td>
<td>3</td>
</tr>
<tr>
<td>Calculation Procedure</td>
<td>4</td>
</tr>
<tr>
<td>Program Operation</td>
<td>5</td>
</tr>
<tr>
<td>Program Usage</td>
<td>8</td>
</tr>
<tr>
<td>Limitations</td>
<td>8</td>
</tr>
<tr>
<td>Run time</td>
<td>9</td>
</tr>
<tr>
<td>DESCRIPTION OF INPUT</td>
<td>10</td>
</tr>
<tr>
<td>Vortex-Lattice Arrangement</td>
<td>10</td>
</tr>
<tr>
<td>Spanwise distribution</td>
<td>11</td>
</tr>
<tr>
<td>Chordwise distribution</td>
<td>12</td>
</tr>
<tr>
<td>Jet Wake Specification</td>
<td>13</td>
</tr>
<tr>
<td>Input Variables</td>
<td>18</td>
</tr>
<tr>
<td>Sample Cases</td>
<td>27</td>
</tr>
<tr>
<td>DESCRIPTION OF OUTPUT</td>
<td>29</td>
</tr>
<tr>
<td>Sample Case</td>
<td>29</td>
</tr>
<tr>
<td>Error Messages</td>
<td>32</td>
</tr>
<tr>
<td>PROGRAM LISTING</td>
<td>33</td>
</tr>
<tr>
<td>REFERENCES</td>
<td>59</td>
</tr>
<tr>
<td>TABLE I</td>
<td>60</td>
</tr>
<tr>
<td>FIGURES 1 THROUGH 9</td>
<td>61</td>
</tr>
</tbody>
</table>
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SUMMARY

This document is a user's manual for the computer program developed
to calculate the longitudinal aerodynamic characteristics of wing-flap
combinations with externally blown flaps. A vortex-lattice lifting-
surface method is used to model the wing and multiple flaps. Each
lifting surface may be of arbitrary planform having camber and twist,
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The calculation procedure starts with arbitrarily positioned wake
centerlines and the iterative calculation continues until the total
configuration loading converges within a prescribed tolerance. The
results available from the program include total configuration forces
and moments, individual lifting-surface load distributions, including
pressure distributions, individual flap hinge moments, and flow field
calculation at arbitrary field points.

This program manual contains a description of the use of the
program, instructions for preparation of input, a description of the
output, program listings, and sample cases.
INTRODUCTION

An engineering prediction method for calculating the static longitudinal aerodynamic characteristics of wing-flap combinations with externally blown flaps (EBF) is presented in reference 1. An externally blown flap is a STOL high lift device in which the jet efflux from turbofan engines mounted beneath the wing is allowed to impinge directly on the trailing-edge slotted flap system. A large amount of additional lift is produced through engine wake deflection and mutual interference effects. The purpose of the analysis in reference 1 is to provide a potential flow method, requiring little use of empirically determined information, to predict the detailed loading distribution on EBF configurations. The method involves the combination of two potential flow models, a vortex-lattice lifting-surface model of the wing and flaps and a vortex ring model of the jet wakes. The two flow models are combined by direct superposition such that a tangency boundary condition is satisfied on the wing and flap surfaces. An iteration between the jet wake position and the wing loading is carried out until the solution converges.

The computer program described in this report is an improved and extended version of the program of reference 2. Modifications include the following. An improved vortex-lattice lifting-surface method is used in which the trailing legs of the horseshoe vortices are allowed to bend around the flap surfaces so that all the trailing vorticity leaves the configuration tangent to the last flap. The geometry specification has been changed so that each flap surface can be modeled as a separate lifting surface with a maximum of ten flaps permitted. The iteration procedure has been automated so that the jet centerlines are positioned according to the local flow field direction beneath the wing and flaps, and the iteration procedure can be carried out a specified number of times or until convergence to a specified tolerance is achieved. The jet centerline calculation has been automated so that, after starting with an arbitrary jet location, the centerline is allowed to move so that it lies along local flow angles. The jet model of reference 2 was defined by a series of circular vortex rings. The improved jet model will now handle elliptic rings; therefore, the jet may start at the engine exit with an axisymmetric cross section and change to an elliptic cross section as it moves downstream and interacts with the
lifting surface. The jet cross-sectional area and shape must be specified by the user.

This document is a user's manual for the computer program developed to carry out the calculations in the EBF aerodynamic prediction method. Principal reliance is made herein to reference 1 for a description of the details of the method and the calculation procedure. Reference 1 also contains calculated results and comparisons with data for a variety of configurations. The following sections of this report will provide a description of the program, a description of the input, a description of the output, a program listing, and sample cases. The notation used is the same as that of reference 1.

DESCRIPTION OF PROGRAM

The purpose of this section is to describe the EBF aerodynamic prediction program in sufficient detail to permit a general understanding of the flow of the program and to make the user aware of the analytical models used to represent the jets and the lifting surfaces. Basically, the program models the lifting surfaces with horseshoe vortices whose circulation strengths are determined from a set of simultaneous equations provided by the flow tangency boundary condition applied at a finite set of control points distributed over the wing and flaps. The boundary conditions include interference velocities induced by some external source of disturbance such as the wake of a turbofan engine. The jet wake is modeled by a series of closely spaced ring vortices, circular or elliptical in shape, arranged on the boundary of the jet. The strength of the vortices is specified by the initial velocity in the wake which is determined from the momentum in the jet. The jet is allowed to interact with the wing and flaps through the jet induced velocity field on the lifting-surface control points. The wing and flaps are then allowed to interact with the jet by forcing the jet centerline to be aligned with the flow direction beneath the lifting surfaces. This process is repeated iteratively until convergence of both the lifting-surface loading and jet centerline position are attained.
Calculation Procedure

The general flow of the program, shown in the flow chart in figure 1, proceeds as follows. After run identification information and certain reference quantities are read in, the wing geometry is input and the wing lattice layout is set up and output. This is followed by similar calculations for the flap surfaces. This concludes the lifting-surface geometry specification; therefore, the influence coefficient matrix, which is the left-hand side of the equation set and a function of geometry only, can be calculated. The matrix is triangularized for use in the solution of the simultaneous equations. This concludes the first section of the program which need be considered only once in each calculation.

The next section of the main program is that part in which the solution is carried out and any iterations are performed. The first step is the input of the initial jet parameters and the set up of the jet centerlines in preparation for induced velocity calculations. The jet induced velocity field at each lifting-surface control point is computed at this time. The right-hand side of the equation set is now computed. Solution of the equation set produces the values for the circulation strengths of each horseshoe vortex describing the lifting surfaces. Given the circulation strengths and the induced velocity field, the load distributions on the lifting surfaces are calculated and resolved into total forces and moments. At this point in the solution, the total forces and moments correspond to those on a lifting surface in the presence of a jet or jets in some specified position relative to the wing and flaps. This may or may not be a converged solution. Using the just-computed circulation strengths on the wing and flaps, the induced velocity field at specified points on the jet centerlines is computed. The jet induced velocity field at these same points is also computed assuming each jet to be in its initially prescribed position. The total velocity field, including the free stream, is formed at the specified points on the centerline. The centerline at each of these points is assumed to have the computed flow direction, and its position is adjusted accordingly.

At this point in the solution, the first iteration is complete and the solution may or may not be converged. The jet centerlines have been moved; therefore, their new position does not correspond to the previously calculated induced velocity field on the wing and flaps; thus, the
interference loading on these lifting surfaces does not correspond to
the current jet positions unless the jets were moved only a small amount.
The option is available in the program to stop here or to continue on
for additional iterations.

If further iteration is indicated, the program returns to the
beginning of the iteration section and starts a second iteration by
computing the jet induced velocity field at the lifting-surface control
points. The solution continues as before. At the end of the current
iteration, two checks are made. The first test is on the local jet
centerline slopes. If these slopes have not changed an amount greater
than a prescribed convergence tolerance, convergence is assumed to be
attained, an appropriate message is printed, and the solution is
complete. If the centerline convergence test fails, the same tolerance
is applied to the current and previous values of total normal-force
coefficient. If this test indicates convergence, the program skips to
the final portion of the calculation procedure. If the convergence test
fails after the prescribed maximum number of iterations has been
completed, an appropriate message is printed and the program skips to
the final section.

In the final section of the program, the jet centerlines corre-
sponding to the last iteration are output. This jet configuration does
not correspond to the last set of loadings on the wing and flaps unless
convergence has been achieved, but it corresponds to the jet which should
be used for the next iteration. The purpose of printing these centerline
parameters is two-fold. First, it allows the user to compare the last
used centerlines with the new versions; and second, it provides a
centerline configuration with which to continue the iterations by
restarting the program.

The final calculation to be carried out, if requested, is the
computation of the induced velocity field at specified field points.
This option is provided so that the user may investigate the induced
flow field in the vicinity of a horizontal tail position or other
points of interest in the flow field.

Program Operation

The EBF prediction program is written in Fortran IV and has been
run on CDC 6600 and 7600 computers. The version described in this
The document was designed to be used under the FTN compiler with a level 2 optimization. Other compilers can be used with only minor modifications and lower optimization levels can be used with the only penalty being an increase in run time. No tapes other than standard input and output units are required for a typical run, although one option allows an externally induced velocity field to be brought in via tape unit 4.

The main program, WNGFLP, contains one item which is not a standard feature of all FTN compilers. Between cards WNG162 and WNG174 there are two calls to subroutine REQFL. This is a request for an adjustment in the core memory to make room for the influence coefficient matrix, FVN, which is stored in a one-dimensional array. The purpose of this adjustment is to minimize the core storage used until the large array is required. FVN is dimensioned for unit length on card WNG043. If subroutine REQFL or its equivalent is not available, the following changes are required. First, remove cards WNG162 through 174. Second, change the dimension of the FVN array on card WNG043 to a value which will cover the maximum number of elements in an influence coefficient matrix; that is, the square of the total number of vortex-lattice panels on the configuration of interest. Thus, the dimension of FVN can be made large enough to cover the largest array anticipated, or the minimum size array needed can be defined and the dimension changed as the number of vortex panels is increased.

There is an alternative solution which minimizes storage requirements for the FVN array when subroutine REQFL is not available. Program WNGFLP can be turned into a subroutine with cards WNG162-174 removed and the FVN dimension set at unity. A short main program can be written which consists of a blank common which sets the dimension of FVN to the required size and a call to subroutine WNGFLP. In this way, a short five-card main program is all that need be recompiled to change the size of the FVN array. This alternate set up for a main program is illustrated in figure 2 to accommodate a maximum vortex lattice of 165 elements. The changes to the current main program, WNGFLP, to make it a subroutine are also shown in this figure.

The following is a list of the components of the EBF program and a brief description of the function of each.

Main Program:

WNGFLP - controls the flow of the calculation and handles some input and output duties.
Subroutines:

WNGLAT - reads in wing input data, lays out the vortex lattice on the wing, and outputs wing geometric information.

FLPLAT - reads in flap input data, lays out vortex lattice on the flaps including wing trailing legs which lie on the flaps, and outputs flap geometric information.

INFMAT - calculates influence coefficient matrix.

FLVF - calculates influence function for a finite length vortex filament.

SIVF - calculates influence function for a semi-infinite length vortex filament.

RHSCLC - calculates the right-hand side of the simultaneous equations for the vortex strengths.

LINEQS - triangularizes the square influence coefficient matrix.

SOLVE - solves for the circulation strengths.

LOAD - calculates the forces on the bound and trailing vorticity associated with each area element.

FORCES - calculates and outputs the spanwise loading distributions and total forces and moments and pressure distribution on the complete configuration.

VELSUM - computes wing-flap induced velocity field at a specified point.

JET - reads in initial jet parameters, outputs total jet configurations, and calculates jet wake induced velocities at specified points.

JETCL - calculates the modified centerline position due to total velocity field induced on the centerline.

CORECT - corrects field point locations relative to vortex rings to avoid singularities.

VRING - computes velocity components induced by a single, circular vortex ring at an arbitrary field point relative to the ring.

ERING - computes velocity components induced by a single, elliptic vortex ring at an arbitrary field point relative to the ring.

JINTEG - solves for the J-integrals required in elliptic vortex ring equations.

ELI1 - computes the generalized elliptic integral of the first kind.
Subroutines (Cont'd):

ELI2  - computes the generalized elliptic integral of the second kind
ELLIPS - obtains complete elliptic integrals of the first and second
kinds from tables
QUART  - solves a quartic equation
CUBIC  - solves a cubic equation
QUAD   - solves a quadratic equation
SIMSON - does a Simpson's Rule integration

Program Usage

Limitations.- It should be remembered that the prediction method is
made up of potential flow models which presume the flow to be attached
to the lifting surfaces at all times. When applying the program to
configurations at very high angles of attack or to configurations with
very large flap deflections, the results will generally be too high as
separation may exist on portions of the real model.

The program is a model for the wing and flaps only; therefore, when
comparing predicted results with measured characteristics on a complete
configuration, the force and moment contributions due to such items as
the fuselage, nacelles, and leading-edge slat must be included as
additional items. This is illustrated in the data comparisons in
reference l.

There are certain limitations and requirements in laying out the
vortex-lattice arrangement on the lifting surfaces. These are discussed
in detail in the input section of this manual, but several of the more
important items are noted as follows. Since the current version of the
vortex-lattice method bends the trailing legs of the wing horseshoe
vortices around the flaps, in laying out the geometry care must be taken
that a flap surface not lie above the wing surface. For the same reason,
flap surfaces may not overlap.

The program has the capability of computing the induced velocity
field at any specified field point, but the modeling of the wing and
flaps with horseshoe vortex singularities can cause numerical problems
and unrealistic answers if a field point lies too near a singularity.
A general rule to follow when computing induced velocities is that the
field point should not be closer to a lifting surface than one half the width of the nearest horseshoe vortex. This also has an effect on the layout of the points defining the jet centerlines since wing and flap induced velocities are important in the centerline iterations. This detail is described when the preparation of jet input is discussed.

Run time.- Both the vortex-lattice lifting-surface and the vortex ring jet models can be time consuming in a typical calculation; consequently, their combination into the EBF program creates a calculation procedure which can be very costly in terms of computer time. When the program is used in the iterative mode, the required calculation time increases nearly linearly with the number of iterations. Estimating the computation time required for a calculation is difficult because of the variables involved. Size of the vortex lattice, number of flaps, number of jets, length of the jets, shape of the jets, spacing of the vortex rings, and iterations all help determine the total run time for a calculation. A list of typical execution times for different combinations of the above parameters is presented in Table I.

The long execution times for the elliptic jet cases are due entirely to the additional complexity involved in computing the induced velocities from elliptic vortex rings. The elliptic jet cases require so much execution time that multiple iterations have been avoided in the use of the program to date. There are some approximations to trim the run time for elliptic jets which have been used by the authors. An equivalent circular jet which has the same area distribution as the desired elliptic jet can be run through several iterations to get the approximate positions of the centerline. The elliptic jets can then be put along these centerlines, and the calculation continued for one or two additional iterations. In this way, the elliptic jet effect on the lifting surfaces can be obtained at some savings in total execution time.

Another method used to minimize execution time is to run the first several iterations with a minimum size lattice to determine the approximate position of the jet centerlines. Then, the full lattice can be input with the jets in their approximate positions and the solution carried out several more iterations to convergence.
DESCRIPTION OF INPUT

This section describes the preparation of input for the EBF computer program. In the following sections, some detailed information regarding the layout of the vortex lattice and the specification of the jet wake are presented. This is followed by a listing of all input variables and their format and positions in the input deck. The last topic in this section is a sample input deck illustrating a typical EBF calculation.

Vortex-Lattice Arrangement

The vortex-lattice method used in the EBF program is an extended and modified version of the wing-flap program presented in reference 2. For that reason, the wing-flap configuration considered herein is much more general than that previously handled, and the specification of the geometry for the input deck requires more detail than the input of reference 2. The characteristics of the configuration parameters are listed below.

Wing

- Mean camber surface may have camber and twist.
- Leading-edge sweep angle need not be constant across semispan.
- Trailing-edge sweep angle need not be constant across semispan.
- Taper need not be linear and there may be discontinuities in the local wing chords.
- Any dihedral angle is allowed but it must be constant over the semispan.
- Thickness effects are neglected.
- Tip chord must be parallel to root chord.

Flaps

- A maximum of ten flaps may be considered, but no more than three flaps may be behind any one wing chordwise row of panels.
- Each flap may have camber and twist.
- Leading and trailing edges must be straight and unbroken on each flap surface.
Flaps (cont'd)

- Flap chord must have linear taper.
- Thickness effects are neglected.
- There may be slots between the flaps, but the leading edge of each flap lies in the plane of the adjacent upstream lifting surface.

The vortex-lattice arrangement describing the wing and flaps is general enough to provide good flexibility in describing the lifting surfaces. A maximum of thirty (30) spanwise rows of vortices may be used, and each lifting-surface component can have a maximum of ten (10) chordwise vortices. The area elements on each lifting surface have a uniform chordwise length at each spanwise station. In the spanwise direction, the widths of the area elements may be varied to fit the loading situations; that is, in regions of large spanwise loading gradients, the element widths may be reduced to allow closer spacing and more detailed load predictions. The convergence of the predicted results as a function of lattice arrangement is described in Appendix A of reference 2. These results apply to the current program with the following exception. In reference 2, the spanwise distribution of the lattice elements on the flaps was chosen independent of the lattice on the wing. In the current program, the deflection of the wing trailing vortex legs requires that the spanwise lattice elements on the flaps be directly aligned with the lattice elements on the wing.

The maximum lattice size on the complete configuration is fixed at 250 in the program. The elements may be distributed in any proportion over the wing and flaps, and for the sake of economy, considerably less than this total number should be used for most calculations as illustrated by the run times in the table in the previous section of this document. The following comments, based on the recommendations of Appendix A of reference 2 and the authors' experience, are offered as an aid to selecting the proper vortex-lattice arrangement for a wing-flap configuration.

**Spanwise distribution.** Convergence of gross aerodynamic forces and moments to within 1 percent is obtained by using not less than fourteen equally spaced spanwise rows of vortices. If an unequal spanwise spacing is required to create a locally dense region of vorticity, the initial spacing should be laid out approximately equal, with additional rows
added in the regions of interest. The spanwise spacing can be adjusted
small amounts to meet some additional requirements without changing the
gross loading properties. For example, it is desirable that engine wake
centerlines be positioned directly beneath a row of lattice element
control points; therefore, small adjustments in the lattice can be made
to meet this requirement. It is also desirable that there be some sym-
metry in the widths of the vortex elements about the engine centerline
station. This can cause some unusual distributions of lattice widths
as illustrated in figure 3 where a typical lattice arrangement on the
four-engine EBF model of references 3 and 4 is illustrated. In this
case the number of spanwise vortices was limited to fifteen to minimize
the total number of elements in the lattice. In this particular case,
the only suggested modification in the spanwise layout would be to add
two additional narrow rows of vortices, one inboard of the inboard jet
and one outboard of the outboard jet and redistribute the outboard
vortices near the tip into slightly more narrow rows.

Chordwise distribution.- Results in Appendix A of reference 2 indi-
cate that four is the minimum number of chordwise vortices on the wing
for best results and more than six vortices do not change the predicted
loads appreciably. A larger number of chordwise vortices on the wing
can be used if a chordwise pressure distribution is the goal of the
predictions.

The number of chordwise vortices on the flaps is somewhat arbitrary.
A rule of thumb is that the chord of the vortex element on the flap
should not be greater than the chord of the wing elements. Generally,
the chord of the flap elements will be much smaller than the wing
elements. If gross forces are the objective of the prediction, one or
two chordwise vortices per flap are all that are needed. If pressure
distributions are desired, there should be three to four chordwise
vortices per flap. The gross force will change very little with
additional flap vortices.

A comment that was made in reference 2 is also pertinent here. Care
should be taken in laying out vortices in regions of wake impingement.
Since interference of the jet on the lifting surfaces is "felt" only at
the control points of the area elements, small vertical and/or lateral
changes in the wake centerline can cause unrealistic changes in the wake
induced loading if the area elements on the flap are too large. This
is caused by the covering and uncovering of area elements whose control points fall near the boundary of the jet. Results indicate that if a sufficient number of elements are used in the wake region of the wing and flap, the element sizes will be sufficiently small so that results will not be unduly influenced by changes in wake location.

The chordwise distribution of lattice elements on the EBF model in figure 1 should be considered a minimum lattice. Flap 1 has but one row of vortices, and flaps 2 and 3 have only two rows of vortices. This is adequate for force and moment calculations, but the pressure distribution results are not detailed enough for comparisons with data.

Jet Wake Specification

The vortex ring model used in the EBF program is an extended version of the jet wake program presented in reference 2. Whereas the original program considered only axisymmetric jets with the centerlines positioned a priori, the present program will handle elliptic cross-section jets and the centerlines are positioned by an iterative solution. This new method removes some of the tedious input preparation required by the previous program; however, the new method requires careful layout of the points describing the centerline and of the rings defining the jet boundary. The best way to illustrate the description of a jet model is to go through a sample case for a typical jet. A vortex ring model of the inboard jet in references 3 and 4 is developed as follows.

The first step is to locate the geometric position of the actual engine. From figure 2 of reference 4, the inlet of the inboard engine on the left wing panel is at \( X = 1.43 \text{ m}(4.68 \text{ ft}) \), \( Y = -1.48 \text{ m}(-4.85 \text{ ft}) \), and \( Z = 0.42 \text{ m}(1.38 \text{ ft}) \) in the wing coordinate system with origin at the wing leading edge at the airplane centerline. The engine exit is at \( X = -0.40 \text{ m}(-1.30 \text{ ft}) \), \( Y = -1.48 \text{ m}(-4.85 \text{ ft}) \), and \( Z = 0.42 \text{ m}(1.38 \text{ ft}) \). As noted in reference 2, the jet model should be extended upstream of the actual engine exit a distance of a minimum of two initial radii to give the model a chance to develop the exit velocity profile. Thus, the jet model could start at \( X = 1.43 \text{ m}(4.68 \text{ ft}) \) and go to \( X = -0.40 \text{ m}(-1.30 \text{ ft}) \) with a constant radius. This initial portion of the jet is longer than necessary; therefore, in the interest of conserving computation time, the jet is assumed to start at \( X = 0.14 \text{ m}(0.45 \text{ ft}) \), \( Y = -1.48 \text{ m}(-4.85 \text{ ft}) \), \( Z = 0.42 \text{ m}(1.38 \text{ ft}) \) and have an initial, constant radius section with length of 0.91 m(3.0 ft).

The initial cross-sectional area of the jet is assumed to equal the sum of the fan exit area and the core engine exit area. From figure 4
of reference 4, the fan and core engine exit areas are 0.159 and 0.050 sq m (1.71 and 0.54 sq ft), respectively. Thus, the initial jet area is 0.209 sq m (2.25 sq ft) which is assumed to be modeled by an equivalent circular cross section with radius of 0.258 meters (0.845 ft).

The next step is to determine the initial exit velocity in the jet model so that we may specify the vortex cylinder strength. If the average velocity in the exit is known from measurement, the vortex strength can be determined directly from equation (28) of reference 1; that is,

\[ \frac{\gamma}{V} = \frac{V_j}{V} - 1 \]  

(1)

where \( V_j/V \) is the ratio of the jet exit velocity to the free-stream velocity and \( \gamma/V \) is the strength of a constant radius, semi-infinite length vortex cylinder which represents a jet with the correct initial momentum and velocity. Since the necessary velocity is not usually available, an approximate value is calculated using equation (29) from the same reference.

\[ \frac{V_j}{V} = \frac{1}{2} \left[ 1 + \sqrt{1 + 2C_T \frac{S}{A_j} \frac{\rho}{\rho_j}} \right] \]  

(2)

To get \( V_j \) from this equation, the engine thrust coefficient, \( C_T \), and the density ratio, \( \rho/\rho_j \), in the jet are required. The density ratio, defined as the ratio of the ambient air density to the jet exhaust density, can be estimated from the exhaust temperature. In equation (2), \( S \) is the reference area used in defining \( C_T \), and \( A_j \) is the initial jet area which is calculated as the sum of the fan exit area and the core engine exit area. Assuming a density ratio of 2.6, which is reasonable for a tailpipe temperature of 538°C (1000°F), and choosing an engine thrust coefficient of 1.0, equation (2) produces \( V_j/V \approx 11.1 \). From equation (1), the vortex cylinder strength defining the jet model vorticity to be input into the program is \( \gamma/V \approx 10.1 \).

At this point the expansion rate and the shape of the jet must be chosen. If some empirical knowledge of the jet to be modeled or of a typical jet is available, it should be included in the specifications in order to get the best physical model possible. Before a jet is chosen, a decision must be made as to the cross-sectional shape of the
selected. Based on figure 10 of reference 1, which was obtained from flow field measurements, it is assumed that the jet cross section is a 2:1 ellipse at a point just aft of the last flap. These same measurements are not used to determine the expansion rate because the measured jet velocity ratio is much lower than we are considering. If we assume that an elliptic jet expands at about the same rate as an axisymmetric jet, the rate of expansion can be obtained from figure 8 of reference 1. At approximately 12 radii downstream of the jet exit, the local radius is approximately 2.2 times the initial radius; therefore, the jet cross-sectional area has increased to approximately 4.8 times its initial area. Using this value and the assumed 2:1 axis ratio, the jet is completely described at this one point aft of the flaps.

Assuming an axisymmetric jet with linear expansion between the engine exit and this point aft of the flap provides an area distribution for the jet. If we further assume that the jet remains axisymmetric until it reaches the flap surfaces and then, through linear variation of the length of the vortex ring axes, approaches the 2:1 ellipse, we obtain the solid curve for \( x_j \leq 12 \text{ ft.} \) shown in figure 4. The circular jet with the same area distribution is shown dashed in this figure. Both the circular and elliptic jets in figure 4 have nearly the same mass and momentum distributions along the jets. Beyond \( x_j = 12 \text{ ft.} \), the jet is downstream of the flaps, and its shape has less effect on the induced velocity field. Two options are open for this region of the jet. The elliptic shape can be maintained and simply extrapolated to the end of the jet, or the shape can be changed back to circular and extrapolated to the end. In the interest of saving computer time, the latter choice was made and the elliptic jet was returned to a circular shape in a short distance. This last region of the jet is assumed to have a lower rate of expansion as shown in figure 4. The following table illustrates the parameters of the jet in the jet coordinate system.
<table>
<thead>
<tr>
<th>( \frac{x}{m} ) (ft)</th>
<th>Equivalent Radius ( R_m ) (ft)</th>
<th>Area Ratio ( A/A_0 )</th>
<th>Elliptic Axes ( m ) ( a ) (ft)</th>
<th>Elliptic Axes ( m ) ( b ) (ft)</th>
<th>( a/b )</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 (0)</td>
<td>0.258 (0.845)</td>
<td>1.00</td>
<td>0.258 (0.845)</td>
<td>0.258 (0.845)</td>
<td>1.0</td>
</tr>
<tr>
<td>0.91 (3.0)</td>
<td>0.258 (0.845)</td>
<td>1.00</td>
<td>0.258 (0.845)</td>
<td>0.258 (0.845)</td>
<td>1.0</td>
</tr>
<tr>
<td>1.98 (6.6)</td>
<td>0.375 (1.23)</td>
<td>2.12</td>
<td>0.375 (1.23)</td>
<td>0.375 (1.23)</td>
<td>1.0</td>
</tr>
<tr>
<td>2.29 (7.5)</td>
<td>0.415 (1.36)</td>
<td>2.55</td>
<td>0.451 (1.48)</td>
<td>0.375 (1.23)</td>
<td>1.20</td>
</tr>
<tr>
<td>2.59 (8.5)</td>
<td>0.448 (1.47)</td>
<td>3.00</td>
<td>0.531 (1.74)</td>
<td>0.375 (1.23)</td>
<td>1.41</td>
</tr>
<tr>
<td>2.74 (9.0)</td>
<td>0.463 (1.52)</td>
<td>3.25</td>
<td>0.570 (1.87)</td>
<td>0.378 (1.24)</td>
<td>1.51</td>
</tr>
<tr>
<td>2.90 (9.5)</td>
<td>0.482 (1.58)</td>
<td>3.48</td>
<td>0.607 (1.99)</td>
<td>0.381 (1.25)</td>
<td>1.59</td>
</tr>
<tr>
<td>3.05 (10.0)</td>
<td>0.500 (1.64)</td>
<td>3.77</td>
<td>0.646 (2.12)</td>
<td>0.387 (1.27)</td>
<td>1.67</td>
</tr>
<tr>
<td>3.35 (11.0)</td>
<td>0.533 (1.75)</td>
<td>4.30</td>
<td>0.725 (2.38)</td>
<td>0.393 (1.29)</td>
<td>1.84</td>
</tr>
<tr>
<td>3.66 (12.0)</td>
<td>0.567 (1.86)</td>
<td>4.83</td>
<td>0.802 (2.63)</td>
<td>0.399 (1.31)</td>
<td>2.0</td>
</tr>
<tr>
<td>3.96 (13.0)</td>
<td>0.576 (1.89)</td>
<td>5.13</td>
<td>0.735 (2.41)</td>
<td>0.463 (1.52)</td>
<td>1.59</td>
</tr>
<tr>
<td>4.57 (15.0)</td>
<td>0.597 (1.96)</td>
<td>5.38</td>
<td>0.597 (1.96)</td>
<td>0.597 (1.96)</td>
<td>1.0</td>
</tr>
<tr>
<td>6.10 (20.0)</td>
<td>0.634 (2.08)</td>
<td>6.06</td>
<td>0.634 (2.08)</td>
<td>0.634 (2.08)</td>
<td>1.0</td>
</tr>
</tbody>
</table>

The above discussion includes the development of both an axisymmetric and an elliptic jet model. Either of the jets in figure 4 or the above table could be used to represent the momentum in the wake, and the only differences in the predicted interference effects would be caused by the different portions of the wing influenced by two jets. The elliptic jet would tend to spread the load out in a spanwise direction while the circular jet would concentrate the interference loading into narrow regions on the lifting surfaces.

A new rule of thumb has been developed to determine the total length of the jet. In reference 2, the length was specified on the basis of comparison with semi-infinite length vortex cylinder results. This method produced jets with lengths the order of \( 150 R_o \). The computer time required to calculate the induced velocity field from a jet of this length is excessive and not warranted on the basis of the small increase in accuracy achieved over shorter jets. In using the current program, it is suggested that the jet extend downstream a distance behind the last flap equal to the total chord of the wing and flaps combined. The user should investigate the effect of jet length on a particular configuration by running one case with an extended jet and comparing predicted results. Generally, jets longer than suggested above are not required unless velocity fields a long distance aft of the wing and flaps are required. If this is the case, the jet should be lengthened so that
it extends approximately one wing chord beyond the axial station at which field points are desired.

The next item to be considered once the jet length and shape are determined is the points on the centerline used to define the jet. Linear interpolation between specified points in the table of jet parameters is used for intermediate points along the jet. Thus, tabular points on the centerline are needed at the beginning, the end, and at any point at which there is a change in the expansion rate of the boundary. For example, in figure 4, the minimum required points in the jet table would be at \( x_j = 0, 3, 6.5, 12, 15, \text{ and } 20 \). This small number of points is adequate for a description of the jet if it did not move during the calculation; but since the program iterates on the centerline shape, additional points should be added to the table. The procedure for laying out the appropriate number and location of points on the centerline should be carried out in the following manner.

A sketch of the wing and flap surfaces at the spanwise station corresponding to an engine location is shown in figure 5. The jet centerline, assumed straight, is also shown in its correct position relative to the wing and flaps. Keeping in mind that more points on the centerline are required in the region of greatest movement, the points chosen to describe the centerline are shown as circles in the figure. The points should be dense along the portion of the centerline near the flaps except in the area immediately adjacent to the flap \( x_j \approx 10.7 \). Points are omitted from this area to avoid the numerical problems associated with being too near a horseshoe vortex. Points can be spread farther apart aft of the flaps since the induced velocities are reduced and the relative motion of these centerline points is less than other points upstream. In general, too many points are better than too few except in troublesome regions near the lifting surfaces.

The last critical parameter to be specified is the spacing between the vortex rings. Ideally, the closer the rings, the more accurate the results; but the closer the spacing, the more rings required to make up the jet model and the longer the computer time needed to compute an induced velocity field. A compromise number for the ring spacing is a distance equal to approximately 0.1 \( R_o \). This is not a firm number, but it is generally a good estimate. The program has an option built into it that allows the spacing to vary along the jet through use of the variable DSFACT. This is simply a multiplying factor used to scale up
the ring spacing to two or three times the initial value. This option should never be used in the vicinity of the wing and flaps as the accuracy of the induced velocity field at the control points will be reduced. It is permissible to increase the spacing downstream of the last flap. The use of this scaling factor is illustrated in the sample input decks.

Input Variables

The purpose of this section is to describe the variables required for input to the EBF program. An input form is presented in figure 6; and for each item of input data shown in the figure, the following information is given. The format for each card and the program variable names are shown first. The card column fields into which the data are to be punched are also shown. Within each block representing the card columns is the FORTRAN format type. Data punched in I format are right justified in the fields, and data punched in F format can be punched anywhere in the field and must contain a decimal point.

Note that all length parameters in the input list have dimensions; therefore, special care must be taken that all lengths and areas are input in a consistent set of units.

Item number 1 is an index NHEAD which indicates how many cards of information are to follow in item number 2. The value of NHEAD must be one or greater.

Item number 2 is a set of NHEAD cards containing hollerith information identifying the run and may start and end anywhere on the card. The cards are reproduced in the output just as they are read in.

Item number 3 consists of one card and contains the following information:

<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>SREF</td>
<td>reference area used in forming aerodynamic coefficients</td>
</tr>
<tr>
<td>REFL</td>
<td>reference length used in forming aerodynamic moment coefficients</td>
</tr>
<tr>
<td>XM,ZM</td>
<td>X and Z coordinates of point about which pitching moment is calculated; wing coordinate system and positive directions are shown in figure 3 and the following sketch</td>
</tr>
<tr>
<td>TOL</td>
<td>tolerance on ( C_N ) used for convergence criterion; a typical value is 0.05</td>
</tr>
</tbody>
</table>
limit, in degrees, on the maximum deflection angle of the jet centerline; this value is generally 70-85 percent of the maximum flap deflection angle and is always input as a negative number.

The variable DTH in Item 3 is used to model the turning effectiveness of the jet and flap system. Static jet turning efficiency results indicate that the efficiency decreases as the flap deflection angle increases. For example, in Figure 3 of reference 3, the 40° flap deflection configuration has an efficiency of approximately 0.75, and the 55° deflection configuration has a turning efficiency of 0.70. Thus, appropriate values of DTH for these two cases are -30.0° and -38.5°, respectively. If this limit is not used, the jet turning angle approaches the maximum flap angle and inaccurate results are predicted. The use of the limit can be bypassed by defining DTH to be -90.0 in Item 3.

The next eight items of input data describe the wing.

Item number 4 specifies the value of NWREG, the number of wing regions. The value of NWREG must be one or greater. The purpose of dividing the wing into regions is to handle discontinuities in local chord length. Region 1 must always extend from \( Y = 0 \) to the tip. The sequence and position of other regions is arbitrary. A wing with three regions is shown in the following sketch.
**Item number 5** contains three quantities which are also shown in the previous sketch. They are:

- **CRW** root chord of region 1, positive quantity
- **SSPAN** wing semispan, positive quantity
- **PHID** wing dihedral angle, degrees; positive dihedral is shown in the sketch

Items 6, 7, and 8 are data describing wing region number 1. Data input for this region determine the spanwise distribution of vortices for all wing regions and all flaps. The present program requires that the same spanwise distribution exist on all surfaces.

**Item number 6** contains five indices. They are:

- **NCW** number of chordwise vortices on wing region 1, $1 \leq NCW \leq 10$
- **MSW** number of spanwise vortices on left wing panel, $1 \leq MSW \leq 30$
- **NTCW** twist and/or camber? $NTCW = 0$, no $NTCW = 1$, yes
- **NUNI** if wing has no twist and the camber distribution is similar at all spanwise stations, $NUNI = 1$; for all other cases $NUNI = 0$ (omit if $NTCW = 0$)
- **NPRESW** is the wing pressure distribution to be calculated and printed? $NPRESW = 0$, no $NPRESW = 1$, yes

The minimum number of spanwise horseshoe vortices is determined by the wing-flap combination geometry. The program requires that vortex trailing legs lie at the following locations:

(a) the root chord and tip chord
(b) the side edges of all wing regions
(c) the side edges of all flaps
(d) points where there are breaks in leading-edge or trailing-edge sweep

**Item number 7** is a set of $MSW+1$ cards which specify the following:

- **Y(I)** $Y$ coordinate of the $I^{th}$ trailing leg on the left wing panel; $Y$ is a negative number on the left wing panel, but positive values may be input and program will correct the sign [$Y(1) = 0.0, Y(MSW + 1) = -SSPAN$]
- **PSIWLE(I)** leading-edge sweep of wing section to the right of the $I^{th}$ trailing leg, degrees; positive swept back (measured in wing planform plane)
PSIWTE(I)  trailing-edge sweep of wing section to the right of the \( I^{\text{th}} \) trailing leg, degrees; positive swept back (measured in wing planform plane)

NFSEG(I)  number of flaps behind wing section to the right of the \( I^{\text{th}} \) trailing leg

When \( I = 1 \), \( Y(I) = 0 \) and the other three quantities are omitted.

If NTCW = 1 in item number 6, item number 8 is included in the input data deck. These data specify the twist and/or camber distribution of wing region number 1 in terms of the tangent of the local angle of attack of the camberline for a root chord angle of attack of zero degrees. The input data are:

\[
\text{ALPHAL}(J) = \tan \alpha \text{ of the region 1 camberline at the vortex-lattice control points. If NUNI = 1, only data for the chordwise row adjacent to the root chord are input. The first value is for the control point nearest the leading edge. If NUNI = 0, data for all chordwise rows must be input starting nearest the root chord and working outboard. Data for each row start on a new card (omit if NTCW = 0).}
\]

The vortex-lattice control points are at the midspan of the three-quarter chordline of each elemental panel laid out by NCW, MSW, and the \( Y(I)'s \) of items 6 and 7.

Item numbers 9, 10, and 11 are input data for the other wing regions. If NWREG, item number 4, is one, items 9, 10, and 11 are omitted. If NWREG > 1, these items are repeated in sequence for regions 2 through NWREG.

Item number 9 contains two indices which locate this wing region spanwise relative to region 1. They specify the subscripts of the elements in the \( Y(I)'s \) array, input in item 7, associated with inboard and outboard side edges of this region.

\[
\text{IIN} \quad \text{inboard side edge is at } Y(\text{IIN})
\]

\[
\text{IOUT} \quad \text{outboard side edge is at } Y(\text{IOUT})
\]

Item number 10 contains five quantities. They are:

\[
\text{NCW} \quad \text{number of chordwise vortices in this region, } 1 \leq NCW \leq 10
\]

\[
\text{NTCW} \quad \text{twist and/or camber for this wing region?}
\]

\[
\text{NTCW} = 0, \text{ no}
\]

\[
\text{NTCW} = 1, \text{ yes}
\]
NUNI if this wing region has no twist and the camber distribution is similar at all spanwise stations, NUNI = 1; for all other cases NUNI = 0 (omit if NTCW = 0 for this region)

CIN inboard side-edge chord (see sketch), positive quantity

TESWP sweep angle of the trailing edge of this region, degrees

The vortices are laid out using the value of NCW for this region and the portion of the Y(I) array beginning with Y(IIN) and ending with Y(IOUT).

Item number 11 is included in the input data deck if NTCW = 1 in item 10. These data specify the twist and/or camber distribution for this wing region. These data are prepared in the same manner as described under item number 8, the similar information for wing region 1.

Item number 12 specifies the number of flap regions, NFREG. For a wing alone, NFREG = 0 and items 13 through 16 are not included in the input data deck. A flap region is a particular flap arrangement behind some spanwise region of the wing. The program will handle a total of ten flaps.

Item number 13 contains four items of input which are repeated in sequence NFREG times.

NINREG number of flaps in this region, $1 \leq \text{NINREG} \leq 3$

IIN inboard side edge lies at $Y(IIN)$ of item 7

IOUT outboard side edge lies at $Y(IOUT)$ of item 7

The next three items of input data are repeated in sequence NINREG times beginning with the flap nearest the wing trailing edge and moving rearward.

Item number 14 contains four indices. They are:

NCF number of chordwise vortices on this flap, $1 \leq \text{NCF} \leq 10$

NTCF twist and/or camber for this flap?
NTCF = 0, no
NTCF = 1, yes

NUNI if this flap has no twist and the camber distribution is similar at all spanwise stations, NUNI = 1; for all other cases NUNI = 0 (omit if NTCF = 0 for this flap)
NPRESF is a pressure distribution to be calculated and printed for this flap?
NPRESF = 0, no
NPRESF = 1, yes

The vortices are laid out using the value of NCF for this flap and the portion of the Y(I) array input as item 7 beginning with Y(IIN) and ending with Y(IOUT). IIN and IOUT were input in item 13.

**Item number 15** contains data which locate this flap with respect to the surface ahead of it, specify the inboard and outboard edge chords, and give the streamwise deflection angle.

- **GAPIN** the distance between the leading edge of this flap and the trailing edge of the preceding surface, measured in the plane of the preceding surface at the inboard side of the flap
- **CRFIN** inboard side-edge chord of this flap
- **GAPOUT** the gap distance at the outboard edge of the flap
- **CRFOUT** outboard side edge of this flap
- **DELXZ** the streamwise deflection angle measured relative to the wing root chord direction, degrees

A streamwise plane containing the inboard edge of a double-slotted flap configuration is shown in the following sketch. The leading edge of each flap lies in the plane of the preceding surface. All quantities in item 15 are input as positive values.

---

**Item number 16** is included in the input data deck if NTCF = 1 in item 14. These data specify the twist and/or camber distribution of this flap. They are prepared in the same manner as described under item number 8 for the wing except that the twist and/or camber angles
are measured relative to the angle of the flap inboard side-edge chord. These angles are all measured in a streamwise plane.

**Item number 17** contains one index.

NRHS the number of successive cases to be treated for this wing-flap combination, NRHS ≥ 1

The successive cases permitted by NRHS are those which affect only the right-hand side of the equation set for the circulation strengths (eqs. (14) and (15) in ref. 1). Thus, the wing-flap geometry must remain unchanged in successive cases. Changes are permitted in items 18 through 23; therefore, the successive cases may involve different angles of attack and/or different jet wakes.

The last six items of input data are repeated in sequence NRHS times.

**Item number 18** contains seven quantities which are:

ALFA wing root chord angle of attack relative to the free stream, degrees

KEI index indicating whether or not an externally induced velocity data set is to be input via tape 4
KEI = 0, no
KEI = 1, yes; data set is read from TAPE4 in a 3E13.6 format

NFPTS number of points in vicinity of wing-flap combination at which wing-flap induced velocities are to be calculated, NFPTS ≥ 0

KJET index indicating type of interference calculation
KJET = 0, no jet calculation, externally induced velocities may be read in if KEI = 1
KJET = 1, jet interference calculation made one time, no iteration
KJET > 2, iteration on jet centerline KJET times or until convergence is attained, which ever occurs first

MJETCL index used to restrict vertical motion of jet centerline during iteration
MJETCL = 0, no restriction of centerline motion
MJETCL = 1, centerline restrained from moving vertically upwards toward wing or flaps

NJETV index indicating whether or not jet induced velocities are to be included in external flow field calculation when NFPTS > 0
NJETV = 0, jet induced velocities not included
NJETV = 1, jet induced velocities included in flow field calculation
NJETCL index used to restrict horizontal motion of jet centerlines during iteration
NJETCL = 0, jet centerline is restricted from moving laterally out of original X-Z plane
NJETCL = 1, jet free to move laterally under influence of wing-flap induced velocity field

The indices KEI and MJETCL are included for diagnostic purposes; and for typical usage of the program, both indices should be zero. KEI is used to input an interference velocity field induced by some source of disturbance other than a jet wake. It cannot be used along with a jet wake; thus, if KEI = 1, KJET = 0. The index MJETCL = 1 is available to restrict the vertical motion of the jet centerlines in certain special cases. On occasion, large induced upwash velocities beneath the wing have forced the jets upward and caused unusually large jet interference effects on the wing. The index MJETCL is provided so that the effect of this upward jet motion can be investigated by the user.

The last index, NJETCL, is provided to restrict the lateral motion of the jet centerlines. Under a swept wing-flap configuration, large induced spanwise velocities can move the jet centerlines out of their original planes. This can cause difficulties in the interference calculation if the spanwise distribution of vortices is specified in a symmetric pattern about the initial centerline positions. Typical EBF measured span-load distributions (ref. 4) indicate very little lateral motion of the wake centerlines; therefore, the option to restrict this movement is provided. It is suggested that NJETCL = 0 be used for best results.

Items 19 through 22 identify the initial jet wakes, and they are omitted if KJET = 0.

Item number 19 is a single card containing six indices pertaining to the jet calculation. They are:

NHEAD number of heading cards to identify the jet model, NHEAD ≥ 1
NJET number of jet wakes; NJET = 1 for one jet wake, etc.
NCYL number of entries in table defining jet parameters, 2 ≤ NCYL ≤ 25
NNUM index controlling calculation of J-integrals required by elliptic vortex rings
NNUM = 0, integrals calculated analytically
NNUM = 1, integrals calculated numerically
**NPRINT**

index indicating whether or not optional output from the jet program is required

- NPRINT = -1, minimum output
- NPRINT = 0, induced velocities at wing control points output from subroutine JET
- NPRINT = 1, individual jet velocities at each control point output from subroutine JET

**NCRCT**

index indicating whether or not field point locations are corrected with respect to vortex ring locations

- NCRCT = 0, corrections made
- NCRCT = 1, corrections not made (to be used for diagnostic purposes only)

The last three indices in item 19 are provided for diagnostic purposes only. For general program usage, these indices should be NNUM = 0, NPRINT = -1, and NCRCT = 0. NNUM should be nonzero only if difficulties arise in the calculation of elliptic jets. This is discussed in a later section describing error messages. When the index NPRINT is equal to zero, jet induced velocities at the control points are output as they are computed. This is a duplication of output. If the user requires information regarding the contribution of each individual jet to the total induced velocity at a control point, NPRINT = 1 will cause this output to be printed. NCRCT is an index used during program development to investigate a situation in which a control point was located very near the edge of a vortex ring. Unrealistically large velocities were induced until the relative positions between the control point and the vortex rings were corrected. This correction places the vortex rings on either side of the control point equidistant from the point.

**Item number 20** is a set of NHEAD cards (from item 19) containing hollerith information identifying the jet. The information may start and end anywhere on the card and the information is reproduced in the output just as it is read in.

The following two items are repeated in sequence NJET times.

**Item number 21** consists of one card which contains the following jet specifications:

- **GAMVJ(J)**: the strength of the vortex cylinder representing the exit velocity of the J'th jet under the left wing panel
- **DS(J)**: the ring spacing of the vortex rings in the J'th jet; a typical value is 0.1R₀ where R₀ is the initial radius of a circular jet; if an elliptic jet is to be used, the appropriate spacing is 0.1 b₀
XQ,YQ,ZQ  the coordinates, in the wing system, of the origin of the jet model (YQ < 0)

**Item number 22** consists of NCYL cards containing the following information.

\[
\begin{align*}
XCLR(J,N) & \text{ the } N\text{'th set of coordinates specifying the centerline of the } J\text{'th jet in the jet coordinate system (fig.8(b))} \\
YCLR(J,N) & \text{ the semi-major axis of the vortex ring at the } N\text{'th point on the centerline of the } J\text{'th jet} \\
ZCLR(J,N) & \text{ the semi-minor axis at the same point} \\
AJET(J,N) & \text{ the slope of the centerline in degrees at the point being considered; THETA is negative when the centerline is bent down to pass beneath the flap} \\
BJET(J,N) & \text{ scale factor for the spacing between the vortex rings downstream of the } N\text{'th point; in region of wing and flaps, the values should be 1.0; aft of the last flap, the values can be greater than 1.0.} \\
DSFACT(J,N) & \text{ when a circular jet cross section is being described, } AJET = BJET; \text{ and when elliptic cross sections are being described, } AJET > BJET. \\
\end{align*}
\]

When a circular jet cross section is being described, AJET = BJET; and when elliptic cross sections are being described, AJET > BJET.

**Item number 23** is a set of NFPTS cards containing the X,Y,Z coordinates in the wing system, at which the wing-flap induced velocities are to be calculated. This term is omitted if NFPTS = 0.

Upon completion of the calculations specified by the above input deck, the program returns to the beginning. Additional input decks, starting with item 1, may be stacked one after another.

**Sample Cases**

In this section, two sample cases are described to illustrate the input preparation and the use of the program. The first sample case is a complete calculative example involving a four-engine EBF configuration with elliptic cross-section jets. The second sample case is an illustrative example of a wing with multiple regions and multiple flaps and a single engine. Its purpose is to provide a check run for the program.

The EBF configuration chosen for the first sample case is the four-engine model from references 3 and 4. The vortex-lattice layout on the wing and flaps is discussed in the Vortex Lattice Arrangement section and the actual lattice arrangement is shown in figure 3.
deflections chosen for this case correspond to the landing configuration, \(\delta f_1/\delta f_2/\delta f_3 = 15^\circ/35^\circ/55^\circ\). This particular configuration and lattice arrangement are used extensively for the comparisons with data in reference 1.

The jet wake model chosen for this sample case is the elliptic cross-section example discussed in the Jet Wake Specification section and shown in figure 4. The initial jet centerline is one which resulted from three iterations using the circular cross-section jet also shown in figure 4. The calculation is set up to run two iterations (KJET = 2) because of the large execution time required by elliptic jets. The total time required for two iterations, with the input deck set up as shown in figure 7(a), is approximately 600 seconds on the CDC 6600. If the circular jet radius distribution shown in figure 4 is substituted for the elliptic jet axes, the same run requires approximately 200 seconds.

A second sample input deck is illustrated in figure 7(b). This input deck, to be used as a check run for the program, describes the hypothetical EBF configuration shown in figure 8. The wing shown in figure 8(a), is modeled as two regions for illustrative purposes, but wing region 2 could just as easily be modeled as a flap surface with zero gap and zero deflection. Double-slotted flaps deflected 20° and 40° and a single, unslotted flap deflected 10° make up the two regions of the trailing-edge flap system. A minimum lattice is specified on the lifting surfaces to keep the calculation short. Wing region 1 is modeled by a 7 x 2 lattice and region 2 is modeled by a 2 x 1 lattice. Flaps 1 and 2 have three spanwise rows of vortices due to their position behind the wing. One chordwise row of vortices is placed on flap 1 and two chordwise rows on flap 2. Flap 3 is represented by a single vortex-lattice element.

A single circular jet wake with initial jet velocity five times free stream (\(C_\mu \approx 0.5\)) is placed at \(Y = -11\). Since this case is only a check run for the program, the jet is not extended downstream of the last flap as far as is normally recommended. The expansion rate is linear as the radius increases to two and one-half times its initial value between \(x_j = 3\) and 18. A sketch of the jet and its position relative to the wing and flap is presented in figure 8(b). The ring spacing is set at 0.1 and it is constant until \(x_j = 15\) where it is doubled for the remainder of the jet length. Assuming a turning efficiency of 75 percent, the limit on the turning angle of the jet centerline is set at \(-30^\circ\).
Some incidental features of this sample calculation are the following. Two iterations are specified ($K_{JET} = 2$), and after the last iteration, the induced velocity field, including the jet induced velocities ($N_{JETV} = 1$), is calculated at four field points ($NFPTS = 4$). The jet is free to move vertically ($M_{JETCL} = 0$) and laterally ($N_{JETCL} = 1$) under the influence of the velocity field beneath the wing and flaps. Pressure distributions are computed on the left wing panel, flap 2 in region 1, and flap 1 in region 2. The output corresponding to this input deck is presented in the next section.

**DESCRIPTION OF OUTPUT**

This section describes the output from the EBF program. The contents of a typical set of output from one of the previously described sample cases is discussed. This is followed by a description of some of the error messages which may be output during execution of the program.

Sample Case

The output generated during the execution of the sample case shown in figure 8(b) is presented in figure 9. Each page of output is described as follows.

The first page of output, shown as figure 9(a), is headed by the program title "EBF AERODYNAMIC PREDICTION PROGRAM," followed by the identification information on the several cards at the front of the input deck. This is followed by the reference quantities consisting of the reference area and length and the center of moment location. Next on the first page is the wing input data. All of the input describing the wing geometry and lattice arrangement is included in this section.

Output page 2 in figure 9(b) contains all the input data describing the flaps including the geometry and the lattice arrangement. Also printed on this page are the coordinates of the four corners of each flap in a coordinate system fixed in the flap with the origin at the leading edge of the inboard chord of the flap. The purpose of these coordinates is two-fold. First, they illustrate the slightly distorted shape of the flaps that occurs because the flaps are attached to swept trailing edges of the upstream surface. The flaps are required to span a certain length which is defined in planform; therefore, the actual
surface must be longer when it is deflected around a swept hinge line.
Second, the coordinates are useful in locating the flap loading center
of pressure defined in the flap coordinate system and printed on a later
page.

Output page 3 in figure 9(c) is headed with the title "HORSESHOE
VORTEX PROPERTIES." This table lists all the properties of the lattice
elements on each lifting surface. The quantities in the last column
on this page labeled "ALPHAL(J)" are the input values of combined twist and
camber. This table completes the configuration dependent information.
The first item following the table is a list of the variables pertaining
to the run to follow. The angle of attack, ALPHA, in degrees, the
indices from item 18 of the input deck, and the convergence tolerance
(5 percent) are printed here. The last line of output on this page is
a statement regarding the limit applied to the jet centerline deflection.
If a limit is not specified, no statement is printed.

The fourth page of output is a listing of the jet input as shown
in figure 9(d). The variables printed are the same values input via
the card deck with the addition of two columns of numbers. The variable
SCL is the curvilinear distance measured along the centerline in the same
units as the other centerline distance variables. For a straight jet
centerline with no inclination (THETA = 0), SCL is the same as XCL. The
last column, identified as P, is the perimeter of the jet at the partic-
cular station.

The next page of output shown in figure 9(e) is the first output from
the program after the circulation strengths are computed. This page,
labeled "HORSESHOE VORTEX STRENGTHS FOR ALPHA = xx.x DEGREES," contains
the computed circulation strength on each lattice element. The circula-
tion strengths (GAMMA/V) are printed in the last column on the page. Also
shown on this page are the externally induced jet velocities at each
control point. These velocities, UEI, VEI, and WEI are made dimension-
less by the free-stream velocity and their positive directions are defined
according to the wing coordinate system; that is, UEI is positive forward
and WEI is positive downward. If externally induced velocities are read
in via tape 4 (KEI ≠ 0), these velocities are printed on this page. Also
noted at the top of the page, directly beneath the angle of attack, is the
iteration number "NTIME" that corresponds to the printed results.

30
The output shown in figure 9(f) is headed at the top "AERODYNAMIC
LOADING RESULTS FOR ALPHA = xx.xx DEG." This is followed by a reiteration
of the reference quantities which are followed by the spanwise load
distributions. On each lifting surface at each spanwise lattice station
the span-load coefficient, the section normal-force coefficient, and the
section axial-force coefficient are presented. These results are normal
and axial to the plane of the particular lifting surface. Following the
section coefficients are the wing-alone force and moment coefficients.
These results are for both right and left wing panels. The axial force,
CAW, and the drag force, CDW, are both defined as positive aft. The
pitching moment is positive in the direction that tends to increase the
angle of attack of the wing.

The next section of output on this page is the individual flap
force and moment coefficients. These coefficients are for the flaps on
the left side of the configuration only. CNF is normal to the individual
flap surface and the center of pressure of the normal force on this flap
is at XF(CNF) and YF(CNF) where these coordinates are in the flap coordi-
nate system defined in figure 9(b). The axial-force coefficient, CAF,
and its spanwise center of pressure, YF(CAF), follow. The spanwise
force, CYF, and its center of pressure, XF(CYF), are the next items;
and finally, the hinge-moment coefficient, CHF, is the last item. The
sign convention of the flap hinge moments is such that a positive hinge
moment would tend to increase the flap deflection angle. The hinge
moments are taken about the flap leading edge. The last items on this
page are the complete configuration force and moment coefficients. These
are resolved into the wing coordinate system and the sign convention is
consistent with that described for the wing alone.

If pressure distributions are requested, they are output on the
next page shown in figure 9(g). The chordwise location, X/C, at which
the pressure coefficients are calculated corresponds to the location of
the bound leg in each lattice element. It should be remembered that
the pressure is constant over the entire lattice element. The last line
on the page is the number of the iteration just completed.

The velocity field induced by the wing-flap loading and the jet
models at specific points on the jet centerlines is printed at the top
of figure 9(h). The coordinates, in the wing system, correspond to the
points defining each jet centerline with the exception of the first two
points on each centerline. These points represent the physical engine
location and are assumed stationary and not allowed to move with the
remainder of the wake; therefore, induced velocities are not needed. The
perturbed jet position is shown on the lower portion of this page of output.
Notice that the jet deflection angle, THETA, is set equal to the prescribed
limit of $-30^\circ$ at two points on the centerline. Thus, the new centerline
has not been allowed to move as far as the induced velocity field wanted
to move it.

If a second iteration were not prescribed, the last page of output
containing the induced velocity field at specified field points would be
printed if requested (NFPTS > 0). If not requested, this would complete
the output.

However, additional iterations are requested; therefore, the jet
defined in figure 9(h) is allowed to interfere on the wing and flaps.
The results of the second iteration are shown in figures 9(i), (j), (k),
and (l) and these results are analogous to those just described in
figures 9(e), (f), (g), and (h), respectively. If convergence has not
been achieved or the maximum number of iterations completed, similar
groups of four pages will be printed until convergence or maximum number
of iteration is reached. At this point, a statement regarding the
convergence situation, number of iterations, and current level of con-
vergence (DEL) is printed as illustrated at the bottom of figure 9(l).
If convergence within the specified tolerance (TOL) is achieved, the
message "**** CONVERGENCE ATTAINED IN x ITERATIONS, DEL = x.xx****" is
printed.

The last page of output containing the induced velocity field at
specified field points is shown in figure 9(m). Note that both wing-flap
perturbation velocities and total velocities are printed on this page.
This concludes the discussion of the output from the EBF prediction
program.

**Error Messages**

The following error messages may be printed during program
execution.

"ERROR IN JET, B.GT.A"
is printed when an elliptic jet is input with the semi-minor axis longer
than the semi-major axis. This is a fatal error.

"EXECUTION TERMINATED, ERROR IN DS"
is printed when the vortex spacing is input as zero or less than zero. This is a fatal error.

"ANALYTICAL J(N) ERROR, XX POINTS"

is a warning message printed to alert the user that the analytical calculation of the J-integrals had numerical difficulties at the noted number of points. The program automatically switches to a numerical calculation technique for these points; therefore, the answers are correct. If the number of points is a large fraction of the total number of control points, there may be some error in the specifications of the jets or in the location of the jets with respect to the lifting surfaces. For example, this error message would be printed if one of the jets was located outboard of the wing tip by mistake or if the jet centerline was located in the plane of the wing. If the error message persists, consider switching to the numerical technique via the index NNUM in the input data. The penalty for using the numerical procedure is increased computer time and a slight decrease in the accuracy of the jet induced velocity calculations.

If the jet centerline deflection angle becomes $-90^\circ$ or less during iteration, the following message is printed.

"ERROR IN JETCL  j k -90.00"

where $j$ is the number of the jet and $k$ is the number of the point on the centerline causing difficulty. This is a fatal error. The error is caused by this particular point being too near one of the vortices on the wing or flap. To correct the situation, adjust the position of the point in question upstream or downstream a small amount and rerun or restart the calculation with the previous iteration.

PROGRAM LISTING

The EBF aerodynamic prediction program consists of a main program, WNGFLP, and twenty-four subroutines. Each deck is identified by a three-letter code in columns 74-76 and each deck is sequenced with a three-digit number in columns 78-80. The table below will act as a table of contents for the program listing on the following pages.
<table>
<thead>
<tr>
<th>PROGRAM</th>
<th>IDENTIFICATION</th>
<th>PAGE NO.</th>
</tr>
</thead>
<tbody>
<tr>
<td>WNGFLP</td>
<td>WNG</td>
<td>35</td>
</tr>
<tr>
<td>WNGLAT</td>
<td>WLT</td>
<td>37</td>
</tr>
<tr>
<td>FLPLAT</td>
<td>FLT</td>
<td>39</td>
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<td>INFMAT</td>
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<td>41</td>
</tr>
<tr>
<td>FLVF</td>
<td>FLV</td>
<td>43</td>
</tr>
<tr>
<td>SIVF</td>
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<td>43</td>
</tr>
<tr>
<td>RHSCLC</td>
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<td>44</td>
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<tr>
<td>LINEQS</td>
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<td>45</td>
</tr>
<tr>
<td>LOAD</td>
<td>LOD</td>
<td>45</td>
</tr>
<tr>
<td>FORCES</td>
<td>FOR</td>
<td>46</td>
</tr>
<tr>
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<tr>
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<td>57</td>
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<td>QUART</td>
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<td>58</td>
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<td>CBC</td>
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<td>QUAD</td>
<td>QAD</td>
<td>58</td>
</tr>
<tr>
<td>SIMSON</td>
<td>SIM</td>
<td>58</td>
</tr>
</tbody>
</table>
ADD CORR AREA FOR INFLUENCE COEFFICIENT MATRIX
IF PFOIL IS NOT AVAILABLE, REMOVE THIS SECTION AND INCREASE THE DImENSIONS OF PFOIL IN BLANK COMMON, ABOVE. TO NTOT+211.
WHERE NTOP = TOTAL NUMBER OF VORTEX PANELS ON WING AND FLAP.

CALL REFLC(IPLF)
IF (NJOB,E1) GO TO 85
DO 117, KPLF = 1, NPLF
117 CONTINUE

CALL REFLC(IPLF)
LFLW = LFLW + NTPW
CALL REFLC(IPLF)

CALL INFLC(IPLF)
CALL INFLC(IPLF)

CALL INFLC(IPLF)
CALL INFLC(IPLF)

CALL INFLC(IPLF)
CALL INFLC(IPLF)

READ(N,901) NWBH
DO 168, K = 1, NWBH
READ(N,932) ALFA, KE1, NPTS, N.jet, NJetcl, NJetv, Njetcl
IF (NJet,LE,0) GO TO 490

IF (NJet,GE,0) NO JET CALCULATION, INDUCED VELOCITIES MAY BE INPUT
1 N Jet calculation = NO iteration on centerline until convergence, OR JET TIME
2 JET CALCULATION = iteration on centerline until convergence, OR JET TIME

NJetcl = 1 ORJNAL JET CL CALCULATION METHOD
3 JETREWRESTRAINED FROM VERTICAL MOTION WAND HINGE MNT
4 NPTS = NUMBER OF FIELD POINTS AT WHICH HINGE FLAP INDUCED VELOCITIES ARE TO BE COMPUTED

NJetv = 0 ORHIT JET INDUCED VELOCITY FIELD
5 INCLUDE JET INDUCED AND FREE STREAM VELOCITIES
6 NJetcl = 1 JET CL FREE TO MOVE IN Y-DIRECTION

NJetv = 0 NO LATERAL MOTION OF JET CL ALLOWED

NJetcl = 1 JET CL FREE TO MOVE IN Y-DIRECTION

RETURN

IF (NJet,LE,0) GO TO 78
WRITE (6,783) ALFA, KE1, NPTS, N.jet, NJetcl, NJetv, Njetcl
IF (STIME,NE,0.0) WRITE (6,786) OTK
RETURN

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**Y**

CALCULATE VELOCITIES AT SPECIFIED FIELD POINTS

176 CONTINUE

HTIME = HTIME

CALCULATE FINAL POSITION OF JET CENTERLINE

178 HTIME = HTIME + 1

WRITE (4, 783) XP, YP, ZP, WP, MP, UEI(1), VEI(1), VEI(1)

GO TO 176

179 WRITE (4, 781) ISTEP, DEL

CALCULATE VELOCITIES AT SPECIFIED FIELD POINTS

78 IF (INPTB.EQ.0) GO TO 110

IF (INJETV.EQ.0) GO TO 193

WRITE (6, 783)

GO TO 188

103 WRITE (4, 738)

102 CONTINUE

HTIME = HTIME + 1

DO 105 215, INPTB

READ (5, 783) XP, PP, ZP, WP

CALL VELOM (XP, PP, ZP, WP, UEI(1), VEI(1), VEI(1), VEI(1))

IF (INJETV.EQ.0) GO TO 188

WRITE (6, 783)

GO TO 186

105 CONTINUE

END

SUBROUTINE NGLAT

THIS SUBROUTINE READS IN THE WING INPUT DATA AND LAYS OUT THE WING VORTEX LATTICE

COMMON STATEMENTS

COMMON /ST/ LGCN, MT

COMMON /PREF/ BSPAN, BREF, REF, LNX, LNY

COMMON /X80/ XP(20), YP(20), ZP(20), WP(20), MP(20)

1 CALPH(20), BALPH(20), CALV(20), BALV(20), CALW(20), BALW(20)

COMMON /XL/ LGCN, MT, LNX, LNY, YP(20), ZP(20), WP(20), MP(20), UEI(1), VEI(1), VEI(1)

CALL IINPT (XP, PP, ZP, WP, MP, UEI(1), VEI(1), VEI(1), VEI(1))

CONTINUE

WRITE (6, 783)

READ (5, 783)

RETURN

EXECUTION OF THE PROGRAM
Continuation of the program:

```
125 CONTINUE

C CALL OVER VORTICES IN THIS ROW

C CONTRIBUTION OF BOUND LEG

C 135 TOTAL

C THERE ARE FLAPS BEHIND THIS WIING FLAP = TRAILING LEGS IN WING PLANE

C 135 CALL 135

C 135 CALL 135

C 100 CONTRIBUTIONS FROM PANELS AFT OF WING

C 100 CONTRIBUTIONS FROM PANELS AFT OF WING

C 135 CALL 135
```

Notes:
- The code appears to be written in a computer language, possibly Fortran, which is used for scientific and engineering computations.
- The comments indicate steps in a computational process, likely related to fluid dynamics or aerodynamics.
- The variables and functions suggest calculations involving forces, velocities, or other aerodynamic parameters.
SUBROUTINE SOL4 (R,A,N)
DIMENSION R(I)
DIMENSION A(N,N)
COMMON F(I),B100(I),P(300)

1 IF(N,ER,EQ,135D0) GO TO 4
N=I
C
DO 7 K=1,N,N
K=I
H=1
I

7 B=I*(N+1)-K)
I=I+1
RETURN
END

SUBROUTINE LOAD(EVEL)
COMMON STATEMENTS
COMMON X,Y,1,'C',/C(250),/C250(),/C250(),/C250(0)

1 X=I*Z(1)-Z(1)
Y=I*Z(2)-Z(2)
Z=I*Z(3)-Z(3)

COMMON F/VA,1/VP,WF

DO 6 I=1,500,VP,WF

6 CONTINUE

COMMON FLOAT,INF,FLAF,Elf(10),MF(10),MF(10),MF(10)

CONTINUE

COMMON FLOAT,BOLE(10),BOLE(10),BOLE(10),BOLE(10)

CONTINUE

COMMON FLOAT,FLAIR,FLAIR,FLAIR,FLAIR

COMMON FLOAT(30),/C30()

LOGICAL EVEL
DIMENSION V(100),V(100),V(100),V(100),V(100),V(100)
COMMON F,SAFM(30),SAFM(30),SAFM(30)

CALCULATE FORCE COMPONENTS IN X, Y, AND Z DIRECTIONS AT BOUND LEG MIDPOINTS ON WING

SOL4 (EVEL)

SOL4 (EVEL)

SOL4 (EVEL)

SOL4 (EVEL)

SOL4 (EVEL)

SOL4 (EVEL)

SOL4 (EVEL)

SOL4 (EVEL)
CALCULATE FLAP FUNK AND MOMENTS

IF(NFLAP=EG0) GOTO 100

DO OVER FLAPS

WRITE (6,703)
WRITE(6,708)
WRITE (6,710) E=CA+CL+CO+CH
CL=CL
COT=CH
TAN=CC
C=TAN(CH)

CALCULATE COMPLETE CONFIGURATION FUNKS AND MOMENTS

100 WRITE (6,713)
WRITE (6,708)
WRITE (6,710)
COT=CC+CD
COT=CL+CD
COS=CC+CD
SIN=CL+CD
100 CONTINUE

LOOP OVER VORTEXES ON THIS FLAP

DO 80 N=1,ME
CRLFACN=CL
CYC=CYC
CRI=CRI

CONTINUE

18 IF(NFLAP=EG0) GOTO 100

C=183
C=184
C=185
C=186
C=187
C=188
C=189
C=190
C=191
C=192
C=193
C=194
C=195
C=196
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C=228
C=229
C=230
C=231
C=232
C=233
C=234
C=235
C=236
C=237
C=238
C=239
SUBROUTINE VELSUM(X,Y,Z,E)
  VEL 001
  VEL 002
  VEL 003
  VEL 004
  VEL 005
  VEL 006
  VEL 007

  CALCIULATED VELOCITIES DUE TO VORTICES AND THEIR MAKES AT
  A FIELDPOINT (X,Y,Z,E)
  COMMON STATEMENTS

  C

  210 CONTINUE
  WRITE (17,19) IGO,TMAG,CFL((X,Y,Z,E))
  WRITE (6,720) (PRES(I,J),J=1,N)
  WRITE (6,721)
  260 CONTINUE

  C

  300 IF (.NOT.LAPS,EQ,0) RETURN

  C

  LOOP OVER FLAPS
  DU 310
  IF (NFLAPS,EQ,0) GO TO 310
  IF (THEAD,EQ,1) GO TO 320
  WRITE (6,719)
  320 WRITE (6,722) IFLANP(1,1),IFLANP(1,2)
  WRITE (6,718) NCFP,NCFP
  PROC\NCFP
  DU 321
  321 X(J,J)=(PJ,2+75)/NCFP
  IF=MFNP(J,J)
  FBR=MFNP(J,J)/MFNP
  YEN=MFNP(J,J)/FPAN
  ERDF=MFNP(J,J)/FPAN
  GCHDF=MFNP(J,J)/FPAN
  JGDF=MFNP(J,J)
  SPP=MFNP(J,J)

  C

  LOOP OVER CHORDWISE ROWS
  DU 330
  IF=IN
  YMD(I,J)=(PJ,1+5)/200/FPAN
  YMD(I,J)=YMD(I,J)/IN
  CYRD(CFL(2,J),J)=CYRD(CFL(2,J),J)/200/FPAN
  CYRD(CFL(2,J),J)=CYRD(CFL(2,J),J)/IN
  WRITE (6,719) YMD(CFL(2,J),J,NCFP)
  WRITE (6,721)

  C

  350 CONTINUE
  360 CONTINUE
  RETURN
  END

  C

  FLAP PRESSURE DISTRIBUTION
  C

  C

  INFLUENCE OF KING VORTICES -- LUMP OVER CHORDWISE ROWS

  C

  C

  INFLUENCE OF INFINITE LENGTH MACH PIECES REMOVED THIS RUN
  C

  C

  C

  130 CONTINUE

  C

  INFLUENCE OF REMOVED THAILING LEGS IN LAST AV FLAP
CALL SIVF
ARFAFATUPFL
ARFAFATUPF
ARFAFATUPF
125 CONTINUE

C LOOP OVER VORTICES IN THIS CHORD-BASED ROW
RCHECKCH(I,B)=
C INFLUENCE OF MOUND LEG

C IMITASENC
XIMATLI(I)
YIMATLI(I)
ZIMATLI(I)
FRTATLI(I)
YFRATLI(I)
ZFRATLI(I)
CALL PFLY
CUMU
CVFV
CHNF
JFINAPT(1,M,0) GO TO 145
C NO FLAPS BEHIND THIS ROW, COMPUTE THE INFLUENCE OF INFINITE
TRAILING LEGS IN XING PLANE

C AXHJL
"OJ
CALL SIVF
CUNRFLU
CVCRFU
CHFUFU
FRTZ
YFRZ
ZFRZ
CALL SIVF
CUNRFLU
CVCRFU
CHFUFU
GO TO 146
C THERE ARE FLAPS BEHIND THIS ROW, COMPUTE INFLUENCE OF

C TRAILING LEGS BEHIND IN XING PLANE

C 145 XIMATLI(I)
YIMATLI(I)
ZIMATLI(I)
FRTATLI(I)
YFRATLI(I)
ZFRATLI(I)
CALL PFLY
CUNRFLU
CVCRFU
CHFUFU
XIMATLI(I)
YIMATLI(I)
ZIMATLI(I)
FRTATLI(I)
YFRATLI(I)
ZFRATLI(I)
CALL PFLY
CUNRFLU
CVCRFU
CHFUFU
CHFUFU
XIMATLI(I)
YIMATLI(I)
ZIMATLI(I)
FRTATLI(I)
YFRATLI(I)
ZFRATLI(I)
CALL PFLY
CUNRFLU
CVCRFU
CHFUFU
CHFUFU
147 YOMITR(I)
ONM2CUUVB
VNM2CUVBY
WHM2CUVB
150 CONTINUE
200 IMBASENC=NCHC

C INFLUENCE OF FLAP VORTEXES ON LOOP VNHP FLAPS

C JFMVAPS,PH,PL RETURN
DO 300 FLAT1,FPLA
300 CVFLATCF(IFL)
DO 300 CVFLATCF(IFL)
CDLAOFCLVX(IFL)
SUNKOFCLVX(IFL)
KAPRMEG(IFL)
VRABS=START

C LOOP OVER CHORD-BASED ROWS OF VORTICES ON THIS FLAP

C DU 250 ISMIF,ISFF

C INFLUENCE OF TRAILING LEGS IN FIRST FLAP BEHIND THIS ONE

C XIMANHP(IFL+1,IFL)
YIMANHP(IFL+1,IFL)
ZIMANHP(IFL+1,IFL)
2XMANHP(IFL+1,IFL)
2YMANHP(IFL+1,IFL)
2ZMANHP(IFL+1,IFL)
CALL PFLY
AFTUPATUPFL
AFTAFAVTUPF
AFTAFAAVTF
BFTUPATUPFL
AFTUPAFAVT
AFTUPAFAVT
GO TO 146

C CONTRIBUTION OF SEMI-INFINITE TRAILING LEGS IN SECOND FLAP

C XIMANHP(IFL+NAFL,IFL)
YIMANHP(IFL+NAFL,IFL)
ZIMANHP(IFL+NAFL,IFL)
2XMANHP(IFL+NAFL,IFL)
2YMANHP(IFL+NAFL,IFL)
2ZMANHP(IFL+NAFL,IFL)
CALL PFLY
AFTUPATUPFL
AFTUPAFAVT
AFTUPAFAVT
GO TO 146

C LOOP OVER VORTICES IN THIS CHORD-BASED ROW

C 212 CONTINUE
212 ISMIF+1=ISIF+1 CONFF=1
DO 220 TCMI,NCFF
C INFLUENCE OF MOUND LEG

C JFINLCH
XIMATLI(I)
YIMATLI(I)
ZIMATLI(I)
2XMATLI(I)
2YMATLI(I)
2ZMATLI(I)

C 220 IMBASENC=NCHC

C 220 IMBASENC=NCHC
CC THERE ARE FLAPS BEHIND THIS ONE. COMPUTE INFLUENCE OF
CC RIGID TRAILING EDGE IN THIS FLAP
CC 210 X1=XL1(T)
CC Y1=YL1(T)
CC Z1=T1(T)
CC X2=X1*F110+1,FL
CC Y2=Y1*F110+1,FL
CC Z2=Z1*F110+1,FL
CC CALL FLVF
CC CUNCWU
CC CY2CWF
CC CH2CHFW
CC GO TO 210
C
C SUBROUTINE JET(INP3,YP,UP,VP,V1,DAT10) JET 001
C COMPUTE VELOCITY INDUCED BY A SERIES OF ELLIPTIC VORTEX RINGS
C WITH VARIABLE LENGTH AXES FOLLOWING A PRESCRIBED PATH
C ALL FIELD POINT COORDINATES ARE INPUT IN THE WING SYSTEM AND
C TRANSFORMED TO ENGINE SYSTEM FOR CALCULATIONS
C ALL CENTERLINE COORDINATES ARE INPUT IN ENGINE SYSTFP
C ALL OUTPUT IS IN THE WING SYSTEM, OPTIONAL OUTPUT IN ENGINE SYSTEM
C
SUBROUTINE JETCL (INTIME,TOL)

CALL CALCULATE THE CHANGE IN JET CENTERLINE POSITION DUE TO THE
INDUCED VELOCITY FIELD OF THE TIP-SHARP JET.

COMMON /Xyclf/ UXCLF,YCLF,ZCLF,THETA,JET,MEJ;
1 COMMON /JCL/ JCL(25),JCL(25),JCL(25),JCL(25),JCL(25)
2 COMMON /XCLF/UXCLF,YCLF,ZCLF,THETA,JET,MEJ;
3 COMMON /JCL/ JCL(25),JCL(25),JCL(25),JCL(25),JCL(25)
C
NNP = 0
READ(10,NP)
DO 99 JCL = 1,NNP
99 CONTINUE
RETURN
90 WRITE (8,721)
STOP
990 WRITE (8,993)
STOP
END

SUBROUTINE JETCL (INTIME,TOL)

CALL CALCULATE THE CHANGE IN JET CENTERLINE POSITION DUE TO THE
INDUCED VELOCITY FIELD OF THE TIP-SHARP JET.

COMMON /Xyclf/ UXCLF,YCLF,ZCLF,THETA,JET,MEJ;
1 COMMON /JCL/ JCL(25),JCL(25),JCL(25),JCL(25),JCL(25)
2 COMMON /XCLF/UXCLF,YCLF,ZCLF,THETA,JET,MEJ;
3 COMMON /JCL/ JCL(25),JCL(25),JCL(25),JCL(25),JCL(25)
C
NNP = 0
READ(10,NP)
DO 99 JCL = 1,NNP
99 CONTINUE
RETURN
90 WRITE (8,721)
STOP
990 WRITE (8,993)
STOP
END

SUHRTINON JETCL (INTIME,TOL)

CALL CALCULATE THE CHANGE IN JET CENTERLINE POSITION DUE TO THE
INDUCED VELOCITY FIELD OF THE TIP-SHARP JET.

COMMON /Xyclf/ UXCLF,YCLF,ZCLF,THETA,JET,MEJ;
1 COMMON /JCL/ JCL(25),JCL(25),JCL(25),JCL(25),JCL(25)
2 COMMON /XCLF/UXCLF,YCLF,ZCLF,THETA,JET,MEJ;
3 COMMON /JCL/ JCL(25),JCL(25),JCL(25),JCL(25),JCL(25)
C
NNP = 0
READ(10,NP)
DO 99 JCL = 1,NNP
99 CONTINUE
RETURN
90 WRITE (8,721)
STOP
990 WRITE (8,993)
STOP
END
SUBROUTINE WING (NGAMMA, XFR, HFR, UFR, VFR, VFR)

NGAMMA = WING RADIUS/REFERENCE RADIUS
XFR = AXIAL DISTANCE TO FIELD PLATE/REFERENCE RADIUS
HFR = RADIAL DISTANCE TO FIELD PLATE/REFERENCE RADIUS
UFR = AXIAL VELOCITY/GAMMA
VFR = RADIAL VELOCITY/GAMMA

ENTRY

PFR, S, T, R

DIMENSION X(NGAMMA), Y(NGAMMA), Z(NGAMMA)

CALL ELLIP (X, Y, Z)

VAM = X(1, 1)

RETURN

END

SUBROUTINE ERG (GAMMA, X, Y, Z, VX, VY, VZ)

CUMULATE THE INDUCED VELOCITY COMPONENTS DUE TO AN ELLIPTICAL VORTEX RING

DIMENSION X(NGAMMA), Y(NGAMMA), Z(NGAMMA)

COMMON FMMX, FMMY, FMMZ

COMMON AE, AJ, AJM

ENTRY

PMMX, PMMY, PMMZ

JNMMX = JN

PMX1 = PMX0

PMX0 = PMX1

PMX2 = PMX1

PMX3 = PMX2

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PMX1 = PMX2
SUBROUTINE ELIRES,RES,X,CK)

PURPOSE
COMPUTES THE ELLIPTIC INTEGRAL OF FIRST KIND

USAGE
CALL ELIRES,RES,X,CK)

DESCRIPTION OF PARAMETERS

RES = RESULT VALUE
X = UPPER INTEGRATION LIMIT (ARGUMENT OF ELLIPTIC INTEGRAL OF FIRST KIND)
CK = COMPLEMENTARY MODULAR

METHOD
DEFINITION

REINTEGRAL{SUMMED OVER T FROM 0 TO TAN(CK)), SUMMED OVER T FROM 0 TO TAN(CK))}

EQUIVALENT IS THE DEFINITION

REINTEGRAL{SUMMED OVER T FROM 0 TO TAN(CK)), SUMMED OVER T FROM 0 TO TAN(CK))}

EQUIVALENT IS THE DEFINITION

ENVIRONMENT OF SPECIAL FUNCTIONS

REFERENCES

1. M. L. WEISZ, "NUMERICAL CALCULATION OF ELLIPTIC INTEGRALS AND
   ELLIPTIC FUNCTIONS,"
2. HANDBOOK SERIES OF SPECIAL FUNCTIONS
   NUMERISME MATHEMATISCH WIL, T1 1945, PP. 78-89.

******************************************************************************

1 IF(X2)<1
2 GOTO 18
3 RETURN
4 IF(CK)<4.3
5 GOTO 3
6 IF(X2)<1
7 GOTO 18
8 RETURN
9 SUBRATINE ELI2 centres,x,ck,ak)

PURPOSE
COMPUTES THE GENERALIZED ELLIPTIC INTEGRAL OF SECOND KIND

USAGE
CALL EL2,RES,X,CK,AK)

DESCRIPTION OF PARAMETERS

RES = RESULT VALUE
X = UPPER INTEGRATION LIMIT (ARGUMENT OF ELLIPTIC INTEGRAL OF SECOND KIND)
CK = COMPLEMENTARY MODULAR
AK = CONSTANT TERM IN NUMERATOR

METHOD
DEFINITION

REINTEGRAL{SUMMED OVER T FROM 0 TO AK(T)), SUMMED OVER T FROM 0 TO AK(T))}

EQUIVALENT IS THE DEFINITION

REINTEGRAL{SUMMED OVER T FROM 0 TO AK(T)), SUMMED OVER T FROM 0 TO AK(T))}

EQUIVALENT IS THE DEFINITION

ENVIRONMENT OF SPECIAL FUNCTIONS

REFERENCES

1. M. L. WEISZ, "NUMERICAL CALCULATION OF ELLIPTIC INTEGRALS AND
   ELLIPTIC FUNCTIONS,"
2. HANDBOOK SERIES OF SPECIAL FUNCTIONS
   NUMERISME MATHEMATISCH WIL, T1 1945, PP. 78-89.

******************************************************************************

SUBROUTINE T1L133,x,ka)

PURPOSE
COMPUTES THE TRIGONOMETRIC INTEGRAL OF THIRD KIND

USAGE
CALL T1L133,RES,X,KA)

DESCRIPTION OF PARAMETERS

RES = RESULT VALUE
X = LOWER INTEGRATION LIMIT (ARGUMENT OF TRIGONOMETRIC INTEGRAL OF THIRD KIND)
KA = CONSTANT TERM IN NUMERATOR

METHOD
DEFINITION

REINTEGRAL{SUMMED OVER T FROM 0 TO KA(T)), SUMMED OVER T FROM 0 TO KA(T))}

EQUIVALENT IS THE DEFINITION

REINTEGRAL{SUMMED OVER T FROM 0 TO KA(T)), SUMMED OVER T FROM 0 TO KA(T))}

EQUIVALENT IS THE DEFINITION

ENVIRONMENT OF SPECIAL FUNCTIONS

REFERENCES

1. M. L. WEISZ, "NUMERICAL CALCULATION OF ELLIPTIC INTEGRALS AND
   ELLIPTIC FUNCTIONS,"
2. HANDBOOK SERIES OF SPECIAL FUNCTIONS
   NUMERISME MATHEMATISCH WIL, T1 1945, PP. 78-89.

******************************************************************************

SUBROUTINE T1L123,x,ka)

PURPOSE
COMPUTES THE TRIGONOMETRIC INTEGRAL OF SECOND KIND

USAGE
CALL T1L123,RES,X,KA)

DESCRIPTION OF PARAMETERS

RES = RESULT VALUE
X = LOWER INTEGRATION LIMIT (ARGUMENT OF TRIGONOMETRIC INTEGRAL OF SECOND KIND)
KA = CONSTANT TERM IN NUMERATOR

METHOD
DEFINITION

REINTEGRAL{SUMMED OVER T FROM 0 TO KA(T)), SUMMED OVER T FROM 0 TO KA(T))}

EQUIVALENT IS THE DEFINITION

REINTEGRAL{SUMMED OVER T FROM 0 TO KA(T)), SUMMED OVER T FROM 0 TO KA(T))}

EQUIVALENT IS THE DEFINITION
SUBROUTINE QUMB (A, X, RX, XI)

C Solution of the quadratic equation

A(1) = X2 * A(2) + X1 * A(3) + A(4)
A(2) = X2 * A(3) + A(4)
A(3) = X2 * A(4)
A(4) = X2

DIMENSION A(4), RX(3), XI(3)

IF (A(4) eq 0) GO TO 100

100 X = X1 / A(4)

100 X2 = A(3) / X1

GOTO 100

END

SUBROUTINE QUMB (A, X, RX, XI)

C Solution of the quadratic equation

A(1) = X2 * A(2) + X1 * A(3) + A(4)
A(2) = X2 * A(3) + A(4)
A(3) = X2 * A(4)
A(4) = X2

DIMENSION A(4), RX(3), XI(3)

IF (A(4) eq 0) GO TO 100

100 X = X1 / A(4)

100 X2 = A(3) / X1

GOTO 100

END

SUBROUTINE QUMB (A, X, RX, XI)

C Solution of the quadratic equation

A(1) = X2 * A(2) + X1 * A(3) + A(4)
A(2) = X2 * A(3) + A(4)
A(3) = X2 * A(4)
A(4) = X2

DIMENSION A(4), RX(3), XI(3)

IF (A(4) eq 0) GO TO 100

100 X = X1 / A(4)

100 X2 = A(3) / X1

GOTO 100

END

SUBROUTINE QUMB (A, X, RX, XI)

C Solution of the quadratic equation

A(1) = X2 * A(2) + X1 * A(3) + A(4)
A(2) = X2 * A(3) + A(4)
A(3) = X2 * A(4)
A(4) = X2

DIMENSION A(4), RX(3), XI(3)

IF (A(4) eq 0) GO TO 100

100 X = X1 / A(4)

100 X2 = A(3) / X1

GOTO 100

END
REFERENCES


NIELSEN ENGINEERING & RESEARCH, INC.
Mountain View, California
November 1975
<table>
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<tr>
<th>Wing-Flaps</th>
<th>Jets</th>
<th>Iterations</th>
<th>Angles of Attack</th>
<th>Execution Time (sec.)</th>
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<td>2</td>
<td>Circular</td>
<td>20</td>
<td>0.1</td>
</tr>
</tbody>
</table>

Table I.- Typical execution times for EBF prediction program.
Figure 1. - General flow chart of program WNGFLP.
Figure 1.- Continued.
Compute final jet centerline parameters

Calculate velocities at specified field points

Figure 1.— Concluded.
Figure 2.- Alternate card decks defining program MAIN and Subroutine WNGFLP.
Figure 3.- Vortex-lattice arrangement for EBF configuration of references 3 and 4.

Note: All flaps shown undeflected.
Figure 4.- Jet wake model boundary specification.
Figure 5.- Jet centerline specification in region near lifting surfaces.
ITEM 1 FORMAT (I5), 1 card
  NHEAD
  1

ITEM 2 FORMAT (20A4), NHEAD cards
  TITLE
  A

ITEM 3 FORMAT (6F10.0), 1 card
  SREF 11 REF 21 XM 31 ZM 41 TOL 51 DTH
  F    F     F     F     F

ITEM 4 FORMAT (I5), 1 card
  NWREG
  1

ITEM 5 FORMAT (3F10.0), 1 card
  CRW 11 SSPAN 21 PHID 31
  F    F     F

ITEM 6 FORMAT (5I5), 1 card
  NCW 11 MSW 16 NTOW 21 NUNI 26 NPRESW
  I   I    I   I   I

(a) Page 1.

Figure 6.- Input forms for EBF prediction program.
ITEM 7 FORMAT (3F10.0,15), MSW + 1 cards
\[
\begin{array}{cccc}
| \text{Y(I)} & \text{PSIWLE(I)} & \text{PSIWE(I)} | \\
| F & F & I |
\end{array}
\]
Omit item 8 if NTCW = 0
MSW sets of cards if NTCW = 1 and NUNI = 1

ITEM 8 FORMAT (8F10.0), NCW values, eight per card. One set of cards if NTCW = 1 and NUNI = 1
\[
\begin{array}{cccc}
| \text{ALPHAL(1)} & \text{ALPHAL(2)} & \ldots & \text{ALPHAL(NCW)} | \\
| F & F & \ldots & I |
\end{array}
\]
Omit items 9, 10, and 11 if NWREG = 1. If NWREG > 1, repeat items 9, 10, and 11 in sequence.
NWREG - 1 times

ITEM 9 FORMAT (2I5)
\[
\begin{array}{cc}
| \text{IIN} & \text{IOUT} | \\
| I & I |
\end{array}
\]

ITEM 10 FORMAT (3I5, 2F10.0)
\[
\begin{array}{cccc}
| \text{NCW} & \text{NTCW} & \text{NUNI} & \text{CIN} & \text{TESWP} | \\
| I & I & I & F & F |
\end{array}
\]
Omit item 11 if NTCW = 0
IOUT - IIN sets of cards if NTCW = 1 and NUNI = 0

ITEM 11 FORMAT (8F10.0), NCW values, eight per card. One set of cards if NTCW = 1 and NUNI = 1.
\[
\begin{array}{cccc}
| \text{ALPHAL(1)} & \text{ALPHAL(2)} & \ldots & \text{ALPHAL(NCW)} | \\
| F & F & \ldots & I |
\end{array}
\]

(b) Page 2.

Figure 6.- Continued.
ITEM 12 FORMAT (I5), 1 card

```
NFREG
```

Omit items 13, 14, 15, and 16 if NFREG = 0.
If NFREG > 0, item 13, 14, 15, and 16 are repeated in sequence NFREG times.

ITEM 13 FORMAT (3I5), 1 card

```
 I6 11 16
NINREG IIN IOUT
```

ITEM 14 FORMAT (4I5), 1 card

```
 NCF NTCF NUNI NPRESF
```

NOTE: More than one set of items 14, 15, and 16 may be
required by NINREG on item 13.

ITEM 15 FORMAT (5F10.0), 1 card

```
1 11 21 31 41
GAPIN CRFIN GAPOUT CRFOUT DELXZ
```

Omit item 16 if NTCF = 0

ITEM 16 FORMAT (8F10.0), NCF values, eight to a card.

```
1 11 21 31 41 51
ALPHAL(1) ALPHAL(2) ... ALPHAL(NCF)
```

Omit item 16 if NTCF = 0

ITEM 17 FORMAT (I5), 1 card

```
NRHS
```

Items 18, 19, 20, 21, 22 and 23 are repeated in sequence NRHS time.

ITEM 18 FORMAT (F10.0, 6I5), 1 card

```
1 11 16 21 26 31 36 41
ALFA KEI NPPTS KJET MJETCI MJETV NJCETCI
```

(c) Page 3.
Omit items 19, 20, 21 and 22 if KJET = 0

ITEM 19 FORMAT (6I5), 1 card

ITEM 20 FORMAT (8A10), NHEAD cards

ITEM 21 FORMAT (5F10.5), 1 card

ITEM 22 FORMAT (7F10.5), NCYL cards

Omit item 23 if NFPTS = 0

ITEM 23 FORMAT (3F10.0), NFPTS cards

Figure 6.— Concluded.
### ENGINE EBF MODEL

<table>
<thead>
<tr>
<th>FLAP ANGLES (15/35/55)</th>
<th>GAP = 0.015C</th>
<th>CJ = 4.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>REF.</td>
<td>PERRY AND GREENE, NASA TN D-783</td>
<td>AYAGI, FALARSKI, AND ROEDIG, NASA TN X-62197</td>
</tr>
</tbody>
</table>

**SAMPLE CASE 1**

<table>
<thead>
<tr>
<th>FLAP ANGLES</th>
<th>18.5</th>
<th>ELLIPTIC JET, 2 ITERATIONS SPECIFIED</th>
</tr>
</thead>
<tbody>
<tr>
<td>JET CENTERLINE THETA LIMITED TO 36.5 DEGREES</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>200,34</th>
<th>5.56</th>
<th>1.56</th>
<th>0.05</th>
<th>18.9</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.19</td>
<td>19.08</td>
<td>0</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>27.71</td>
<td>18.29</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>27.71</td>
<td>18.29</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>3.62</td>
<td>27.71</td>
<td>18.29</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>4.3</td>
<td>27.71</td>
<td>18.29</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>5.6</td>
<td>27.71</td>
<td>18.29</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>6.08</td>
<td>27.71</td>
<td>18.29</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>6.77</td>
<td>27.71</td>
<td>18.29</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>7.45</td>
<td>27.71</td>
<td>18.29</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>8.55</td>
<td>27.71</td>
<td>18.29</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>9.23</td>
<td>27.71</td>
<td>18.29</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>10.5</td>
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<td>18.29</td>
<td>3</td>
<td></td>
</tr>
<tr>
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<td>18.29</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>13.7</td>
<td>27.71</td>
<td>18.29</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>15.5</td>
<td>27.71</td>
<td>18.29</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>17.3</td>
<td>27.71</td>
<td>18.29</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>19.08</td>
<td>27.71</td>
<td>18.29</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>3</td>
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<td></td>
</tr>
<tr>
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<td>0</td>
<td>1</td>
<td></td>
</tr>
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<td>1.425</td>
<td>0.045</td>
<td>0.05</td>
<td>19.0</td>
</tr>
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<td>1</td>
<td></td>
</tr>
<tr>
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<td>1.5</td>
<td>0.045</td>
<td>0.05</td>
<td>35.0</td>
</tr>
<tr>
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<td>0</td>
<td>0</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>0.11</td>
<td>1.668</td>
<td>0.045</td>
<td>0.05</td>
<td>95.0</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>0</td>
<td>12</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>2</td>
<td>13</td>
<td>0</td>
<td>-1</td>
</tr>
</tbody>
</table>

**JET MODEL**

<table>
<thead>
<tr>
<th>JT150-1</th>
<th>C(J) = 4.0</th>
<th>CJ = 1.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>ELLIPTIC CROSS SECTION NEAR FLAPS</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| 10.10 | 1.08 | -4.85 | 1.32 |
| 0 | 0 | 0.0000 | 0.045 | 0.00 | 1 |
| 3 | 0 | 0.0000 | 0.045 | 0.00 | 1 |
| 4.60 | 0.102 | 1.23 | 1.23 | 3.28 | 1 |
| 7.50 | 0 | 0.133 | 1.48 | 1.23 | 0.01 | 1 |
| 9.00 | 0 | 0.08 | 1 | 1.23 | -12.1 | 1 |
| 9.50 | 0 | 0 | 0.1 | 1.23 | -12.1 | 1 |
| 10.00 | 0 | 0 | 0 | 1 | 21.1 | 1 |
| 11.00 | 0 | 1.08 | 2.38 | 1.29 | -38.9 | 1 |
| 12.00 | 0 | 1.08 | 2.38 | 1.31 | -36.5 | 1 |
| 13.00 | 0 | 2.0 | 2.41 | 1.52 | -32.0 | 2 |
| 15.00 | 0 | 3.52 | 2.0 | 1.46 | -18.0 | 3 |
| 20.00 | 0 | 4.83 | 2.18 | 2.0 | -10.0 | 4 |
| 10.10 | 1 | 1.2 | 0.18 | 1.38 |
| 0 | 0 | 0.0 | 0.045 | 0.00 | 1 |
| 5 | 0 | 0.045 | 0.00 | 1 |
| 4.50 | 0 | 0.11 | 1.24 | 1.24 | 2.2 |
| 7.50 | 0 | 0.10 | 1.68 | 1.24 | -3.0 |
| 9.50 | 0 | 0.01 | 1.68 | 1.24 | -13.7 |
| 9.50 | 0 | 0.01 | 1.68 | 1.24 | -22.0 |
| 10.00 | 0 | 0.0 | 2.13 | 1.27 | -36.0 |
| 11.25 | 0 | 1.08 | 2.38 | 1.29 | -38.5 |
| 12.00 | 0 | 2.38 | 2.38 | 1.31 | -36.3 |
| 13.00 | 0 | 2.6 | 2.61 | 1.52 | -29.0 |
| 15.00 | 0 | 3.76 | 2.0 | 1.46 | -13.4 |
| 20.00 | 0 | 4.8 | 2.18 | 2.0 | -13.0 |

| -12 | -4.85 | 0 |
| -12 | -4.85 | 0.1 |
| -12 | -4.85 | 0.2 |
| -12 | -4.85 | 3 |
| -12 | -4.85 | 3.5 |
| -12 | -4.85 | 4 |
| -12 | -4.85 | 5 |
| -12 | -4.85 | 6 |
| -9.5 | -4.85 | 7 |
| -9.5 | -4.85 | 0 |
| -9.5 | -4.85 | 0.5 |
| -9.5 | -4.85 | 1 |
| -9.5 | -4.85 | 1.5 |

(a) Sample case 1.

**Figure 7.** Sample input decks for EBF prediction program.
SAMPLE EBF CONFIGURATION WITH 1 CIRCULAR JET WAKE, 2 WING REGIONS, 2 SLOTTED FLAPS, AND 1 AILERON TYPE FLAP

ENGINE CENTERLINE FREE TO MOVE IN Y AND Z DIRECTIONS, 2 ITERATIONS SPECIFIED

<p>| | | | | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>10.0</td>
<td>20.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>2 1</td>
<td>7 0</td>
<td>0 0</td>
<td>1 0</td>
<td>0 0</td>
<td>1 0</td>
<td>0 0</td>
<td>1 0</td>
</tr>
<tr>
<td>0.0</td>
<td>24.2</td>
<td>11.3</td>
<td>0 0</td>
<td>0 0</td>
<td>1 0</td>
<td>0 0</td>
<td>1 0</td>
</tr>
<tr>
<td>1 0</td>
<td>24.2</td>
<td>11.3</td>
<td>0 0</td>
<td>0 0</td>
<td>1 0</td>
<td>0 0</td>
<td>1 0</td>
</tr>
<tr>
<td>1.3</td>
<td>3 0</td>
<td>2.0</td>
<td>11.3</td>
<td>0 0</td>
<td>1 0</td>
<td>0 0</td>
<td>1 0</td>
</tr>
<tr>
<td>1 0</td>
<td>0 0</td>
<td>2.0</td>
<td>11.3</td>
<td>0 0</td>
<td>1 0</td>
<td>0 0</td>
<td>1 0</td>
</tr>
</tbody>
</table>

(b) Sample case 2.

Figure 7.—Concluded.
Figure 8. - EBF configuration for Sample Case 2.
Figure 8.- Concluded.

(b) Jet centerline detail.
**EBF AERODYNAMIC PREDICTION PROGRAM**

Sample EBF configuration with 1 circular jet wake, 2 wing regions, 2 slotted flaps, and 1 aileron type flap.

**Engine Centerline Free to Move in Y and Z Directions, 2 Iterations Specified**

Reference quantities used in force and moment calculation:

<table>
<thead>
<tr>
<th>Area</th>
<th>300,000000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length</td>
<td>10,000000</td>
</tr>
<tr>
<td>Moment Center</td>
<td></td>
</tr>
<tr>
<td>X_m</td>
<td>5,000000</td>
</tr>
<tr>
<td>Z_m</td>
<td>0,000000</td>
</tr>
</tbody>
</table>

**Wing Input Data**

Region Number 1

<table>
<thead>
<tr>
<th>Inboard Edge Chord</th>
<th>10,00000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Semispan</td>
<td>20,00000</td>
</tr>
<tr>
<td>Dihedral Angle</td>
<td>0,00000</td>
</tr>
</tbody>
</table>

14 vortices are to be laid out in this region. 7 spanwise by 2 chordwise.

Spanwise locations of trailing vortex legs, sweep angles of wing section to the right and number of flaps behind this section:

<table>
<thead>
<tr>
<th>Spanwise Location</th>
<th>LE Sweep</th>
<th>TE Sweep</th>
<th>Number of Flaps</th>
</tr>
</thead>
<tbody>
<tr>
<td>0,00000</td>
<td>24,20000</td>
<td>11,30000</td>
<td>0</td>
</tr>
<tr>
<td>2,50000</td>
<td>24,20000</td>
<td>11,30000</td>
<td>0</td>
</tr>
<tr>
<td>5,00000</td>
<td>24,20000</td>
<td>11,30000</td>
<td>2</td>
</tr>
<tr>
<td>9,00000</td>
<td>24,20000</td>
<td>11,30000</td>
<td>2</td>
</tr>
<tr>
<td>15,00000</td>
<td>24,20000</td>
<td>11,30000</td>
<td>2</td>
</tr>
<tr>
<td>15,50000</td>
<td>24,20000</td>
<td>11,30000</td>
<td>2</td>
</tr>
<tr>
<td>18,00000</td>
<td>24,20000</td>
<td>11,30000</td>
<td>0</td>
</tr>
<tr>
<td>20,00000</td>
<td>24,20000</td>
<td>11,30000</td>
<td>1</td>
</tr>
</tbody>
</table>

Region Number 2

This region extends from Y = 0,00000 to Y = 5,00000.

2 vortices are to be laid out in this region. 2 spanwise by 1 chordwise.

<table>
<thead>
<tr>
<th>Inboard Side-Edge Chord</th>
<th>2,00000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trailing Edge Sweep</td>
<td>11,30000</td>
</tr>
</tbody>
</table>

(a) Page 1.

Figure 9.- Sample output from EBF prediction program.
FLAP INPUT DATA

REGION NUMBER 1
There are 2 flaps in this region
They extend from y = 9.00000 to y = 15.00000

FLAP NUMBER 1
Inboard edge gap = 0.00000
Outboard edge gap = 0.00000
Inboard edge chord = 1.00000
Outboard edge chord = 1.00000
Deflection angle = 20.00000

3 vortices are to be laid out on this flap
3 spanwise by 1 chordwise

Spanwise locations of
trailing vortex legs
-5.00000
-5.00000
-13.00000
-15.00000

Xf, Yf coordinates of four corners of flap
(Flap lies in ZF=0 plane)
Xf
Yf
0.00000
0.00000
1.50000
0.00000
1.97598
10.52449
3.97598
10.52449

FLAP NUMBER 2
Inboard edge gap = 0.00000
Outboard edge gap = 0.00000
Inboard edge chord = 2.00000
Outboard edge chord = 2.00000
Deflection angle = 40.00000

6 vortices are to be laid out on this flap
3 spanwise by 2 chordwise

Spanwise locations of
trailing vortex legs
-5.00000
-7.00000
-13.00000
-15.00000

Xf, Yf coordinates of four corners of flap
(Flap lies in ZF=0 plane)
Xf
Yf
0.00000
0.00000
2.00000
0.00000
1.40728
10.58226
3.40728
10.58226

REGION NUMBER 2
There are 1 flap in this region
They extend from y = 18.00000 to y = 20.00000

FLAP NUMBER 1
Inboard edge gap = 0.00000
Outboard edge gap = 0.00000
Inboard edge chord = 1.00000
Outboard edge chord = 1.00000
Deflection angle = 10.00000

1 vortices are to be laid out on this flap
1 spanwise by 1 chordwise

Spanwise locations of
trailing vortex legs
-5.00000
-20.00000

Xf, Yf coordinates of four corners of flap
(Flap lies in ZF=0 plane)
Xf
Yf
0.00000
0.00000
1.20000
0.00000
-1.39357
2.00120
1.39357
-2.00120

(b) Page 2.

Figure 9.- Continued.
<table>
<thead>
<tr>
<th>VORTEX NUMBER</th>
<th>J</th>
<th>XBL(J)</th>
<th>YBL(J)</th>
<th>ZBL(J)</th>
<th>XCP(J)</th>
<th>YCP(J)</th>
<th>ZCP(J)</th>
<th>PSI(J)</th>
<th>SN(J)</th>
<th>ALPHAL(J)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>1.77277</td>
<td>-1.25000</td>
<td>0.00000</td>
<td>-4.9477</td>
<td>1.25000</td>
<td>0.00000</td>
<td>22.65556</td>
<td>1.25000</td>
<td>0.00000</td>
</tr>
<tr>
<td>2</td>
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<td>-1.25000</td>
<td>0.00000</td>
<td>-9.0277</td>
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<td>-5.01442</td>
<td>-3.75000</td>
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<td>1.25000</td>
<td>0.00000</td>
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<tr>
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<td>4</td>
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<td>-3.75000</td>
<td>0.00000</td>
<td>-8.81612</td>
<td>-3.75000</td>
<td>0.00000</td>
<td>16.35624</td>
<td>1.25000</td>
<td>0.00000</td>
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<td>5</td>
<td>9.12002</td>
<td>-3.75000</td>
<td>0.00000</td>
<td>-13.24073</td>
<td>-3.75000</td>
<td>0.00000</td>
<td>11.30000</td>
<td>1.25000</td>
<td>0.00000</td>
</tr>
<tr>
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<td>6</td>
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<td>-7.00000</td>
<td>0.00000</td>
<td>-7.82073</td>
<td>-7.00000</td>
<td>0.00000</td>
<td>22.65556</td>
<td>2.00000</td>
<td>0.00000</td>
</tr>
<tr>
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<td>7</td>
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<td>0.00000</td>
<td>-10.36714</td>
<td>-7.00000</td>
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<td>16.35624</td>
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<td>0.00000</td>
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<td>8</td>
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CIRCULAR JET WAKE MODEL FOR SAMPLE EBF CONFIGURATION, \( \nu J / \nu = 5 \)

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(c) Page 5.

Figure 9.- Continued.
# Aerodynamic Loading Results for Alpha = 10.00 Deg.

## Reference Quantities
- Wing Span: 80,000
- Area: 10,000
- Length: 500,000

## Spanwise Load Distributions

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(F) Page 6.

Figure 9.—Continued.
**** LEFT WING PANEL ****

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ITERATION 1

(g) Page 7.

Figure 9.- Continued.
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Figure 9.1 - Continued.
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<th>VEI(J)</th>
<th>WEI(J)</th>
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(i) Page 9.

Figure 9.—Continued.
AERODYNAMIC LOADING RESULTS FOR ALPHA = 10.00 DEG.

REFERENCE QUANTITIES
* WING SPAN, B AREA LENGTH
40,000000 300,000000 10,000000

SPANWISE LOAD DISTRIBUTIONS
********** LEFT WING PANEL **********

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WING ALONE FORCE AND MOMENT COEFFICIENTS
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INDIVIDUAL FLAP FORCE AND MOMENT COEFFICIENTS AND LOCATIONS AT WHICH FORCES ACT
(FLAP COORDINATE SYSTEMS = FLAP LIES IN XF, YF PLANE)

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<th>YF(CNF)</th>
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COMPLETE CONFIGURATION FORCE AND MOMENT COEFFICIENTS
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(j) Page 10.

Figure 9.- Continued.
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**ITERATION 2**
### Wing/Flap and Jet Induced Perturbation Velocities on the Jet Centerline

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<th>W/VINF</th>
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### (1) Jet Parameters

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</tr>
<tr>
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<td>.1039</td>
<td>.1926</td>
<td>15.034</td>
<td>30.000</td>
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<td>2.150</td>
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<tr>
<td>15.000</td>
<td>.145</td>
<td>.214</td>
<td>15.420</td>
<td>30.000</td>
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<tr>
<td>16.000</td>
<td>.1357</td>
<td>.2792</td>
<td>16.794</td>
<td>30.000</td>
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<td>2.300</td>
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</tr>
<tr>
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<td>.1564</td>
<td>.3946</td>
<td>19.113</td>
<td>30.000</td>
<td>2.500</td>
<td>2.500</td>
<td>2.500</td>
<td>2.500</td>
<td>2.500</td>
</tr>
</tbody>
</table>

**** No Convergence After 2 Iterations ****

TOL = .0500  DEL = .3605 ****
Figure 11 - Continued.

(m) Page 13.

| X     | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
|-------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
| Y     | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| Z     | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |

| U/VINP | 0.0194 | 0.0191 | 0.0196 | 0.0199 | 0.0201 | 0.0202 | 0.0202 | 0.0202 | 0.0202 | 0.0202 | 0.0202 | 0.0202 | 0.0202 | 0.0202 | 0.0202 |
| V/VINP | 0.0040 | 0.0040 | 0.0040 | 0.0040 | 0.0040 | 0.0040 | 0.0040 | 0.0040 | 0.0040 | 0.0040 | 0.0040 | 0.0040 | 0.0040 | 0.0040 | 0.0040 |
| W/VINP | 0.0063 | 0.0063 | 0.0063 | 0.0063 | 0.0063 | 0.0063 | 0.0063 | 0.0063 | 0.0063 | 0.0063 | 0.0063 | 0.0063 | 0.0063 | 0.0063 | 0.0063 |
| U/VINF | 0.0194 | 0.0191 | 0.0196 | 0.0199 | 0.0201 | 0.0202 | 0.0202 | 0.0202 | 0.0202 | 0.0202 | 0.0202 | 0.0202 | 0.0202 | 0.0202 | 0.0202 |
| V/VINF | 0.0040 | 0.0040 | 0.0040 | 0.0040 | 0.0040 | 0.0040 | 0.0040 | 0.0040 | 0.0040 | 0.0040 | 0.0040 | 0.0040 | 0.0040 | 0.0040 | 0.0040 |
| W/VINF | 0.0063 | 0.0063 | 0.0063 | 0.0063 | 0.0063 | 0.0063 | 0.0063 | 0.0063 | 0.0063 | 0.0063 | 0.0063 | 0.0063 | 0.0063 | 0.0063 | 0.0063 |

**INDUCED VELOCITIES AT SPECIFIED FIELD POINTS**